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ELEMENTS

OF

CHEMISTRY.

BY

J. MURRAY,

LECTURER ON CHEMISTRY, AND ON MATERIA MEDICA AND PHARMACY, EDINBURGH.

IN TWO VOLUMES.

VOLUME FIRST.

EDINBURGH:

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NOTICE.

I HAVE not announced this work as the second edition of the Elements of Chemistry, which I formerly published, as from the rapid progress of the Science, it has been necessary to write it nearly anew. Its object, however, is the same,—to give such a view of Chemistry as shall convey a just knowledge of its leading principles and more important facts, without including the discussion of controverted opinions, or the statement of those minute details which have with propriety a place in a Systematic Work.

EDINBURGH,
October 25. 1810.

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INTRODUCTION.

GENERAL VIEW OF THE NATURE, OBJECTS, AND APPLICATIONS OF CHEMISTRY. HISTORICAL SKETCH OF ITS ORIGIN AND PROGRESS. PRINCIPLES OF CHEMICAL ARRANGEMENT.

THE different departments of Physical Science have relations more or less intimate, whence it becomes difficult to establish their respective limits with perfect precision. Still there are certain leading characters by which the classes of phenomena, which it is their object to investigate, may be discriminated, and the sciences themselves sufficiently defined.

One extensive class includes the phenomena which arise from actions exerted between masses of matter at sensible, and often at immense distances, accompanied in general with no other change than that of place, and, in particular, not connected with any alteration in the properties of the bodies between which they have been exerted.

Actions of this kind, under different modifications, constitute the various branches of Mechanical Philosophy. Astronomy has for the objects of its inquiries, the movements of the heavenly bodies. Optics studies the phenomena which arise from the motion of the rays of light. To Pneumatics belongs the consideration of the impulse, pressure, and resistance of elastic fluids: and under Mechanics, in the extensive sense of the term, is placed the determination of the effects of the same forces on non-elastic fluids and solids. In all of these, the changes which are the objects of investigation are the results of sensible motions arising from the operation of powers which act at perceptible distances; they are therefore capable of being determined with precision; and hence a leading character of these sciences, that their principles can be established on mathematical evidence.

Another class of actions of a very different nature, comprises those which are exerted between the minute particles of matter. We are liable, in regarding any solid body, to consider it as a continuous mass, all the parts of which are in perfect contact. A little inquiry, however, is sufficient to convince us of the error of this conclusion, and to prove to us that every mass of matter, even in its densest state, is composed of minute particles, which are not in contact, but are only retained within certain distances by a peculiar force. We soon discover, too, that this force is liable to be variously modified, and that in consequence of this, these particles are capable of acting on each other, of changing their relative positions, and of entering even into intimate combinations. Hence arises an exten-

sive class of actions, more obscure and complicated than those which belong to the Mechanical Sciences. The investigation of these actions constitutes the Science of CHEMISTRY.

Chemical action is thus distinguished by characters sufficiently marked. It is exerted between the minute particles of matter: it brings them into new arrangements or combinations, whence changes are produced in the properties of the bodies subject to it; and being exerted at no sensible distances, it admits of no precise determination, as to its direction or intensity, but is discovered only from changes of constitution or of form. And Chemistry, in conformity to these views, may be defined, the Science which investigates the combinations of matter, and the agencies of those general forces whence these combinations are established and subverted.

The principal power productive of chemical phenomena, is that species of ATTRACTION, exerted between the particles of bodies, which brings them into intimate and permanent union. From its exertion between particles of a similar nature, arise the forms under which bodies exist, and many of the physical qualities of which they are possessed. And from its exertion between particles of different kinds, are derived the greater number of substances which compose our globe,—these consisting of certain elements retained by this power in a state of combination.

This attractive force is always modified in its action by certain repulsive powers. Of these the most general is the power of Heat. Its immediate operation is to separate the particles of bodies, and place them at greater distan-

ces; it thus changes their forms and qualities, and, when in a certain degree of intensity, subverts the combinations which attraction has produced. Galvanism is perhaps to be regarded as a force of a similar kind, or rather it communicates to the particles of matter both attractive and repulsive powers, whence similar changes of combination arise.

From actions so extensive and important, arise changes in the structure and constitution of bodies, connected with many of the established operations of nature, or capable of being adapted to purposes of utility, constituting various arts. Of these applications of Chemistry, a full development, even under a general point of view, would be incompatible with the limits of this preliminary discourse; but a few examples are required to convey a just idea of the extent of the science, and of the interest which its study is calculated to excite.

No view of adjustment in the economy of nature is more admirable than that which Chemistry traces with regard to the temperature of the globe, the sources of its variations, and the limits within which these are restrained. That degree of heat which is necessary to sustain the greater number of natural operations, is derived from the action of the solar rays on the surface of the earth; but from the mode in which this is communicated, it is necessarily unequal, or prevails in different degrees of intensity at different seasons, and at different regions of the earth; and did not certain arrangements exist, this inequality would continue progressive. These arrangements Chemis-

try unfolds, and by discovering that absorption of heat which attends the rarefaction of the atmosphere, the evaporation of water, and the melting of ice, and that evolution of heat which accompanies the reverse changes, it enables us to trace the causes by which the extremes of climate and the transitions of seasons are moderated, and the temperature over the surface of the globe is preserved within comparatively a limited range.

Chemistry has still to investigate another adjustment in the economy of nature, the necessity for which the researches of this science have alone discovered. That air is indispensable to living beings, is sufficiently demonstrated by familiar facts; but that this air, in being breathed by animals, is rapidly deteriorated, and rendered at length unfit to sustain life, is established by the experiments of the Chemist; and it is only by these experiments that the change of composition from which this arises is made known. It is of course only from the successful prosecution of these researches that we can discover the natural operations by which it is counteracted, and the due purity of the atmosphere preserved.

The spontaneous evaporation of water, its elevation in clouds, and its deposition in the form of dew, rain and snow, are dependent on chemical action. From the principles of this science, the laws which regulate these processes, so far as they are known, have been illustrated, and it is only from the extension and more strict application of these principles that their theory can be fully developed.

We trace the chemical agency of water in many other natural operations, in its action, for example, on the surface

of the earth, the disintegration it occasions, and the ultimate formation of soil; and in the processes of animated existence, particularly in sustaining the growth of plants, and affording the principles whence their products are formed.

By discovering to us, that the substances which belong to the Mineral Kingdom are compounds of certain elements, Chemistry demonstrates that their formation must have been the result of chemical combinations; and the application of its principles must afford the explanation of those arrangements, which the observations of the Geologist, skilfully generalized, have demonstrated to prevail in the structure of the solid parts of the globe. And it will also ultimately give the only sure basis on which the *species* of minerals are established and arranged.

We can trace the predominance of chemical action, not less in the processes of animated nature, though these, from their obscurity and complication, are more difficult of elucidation. In vegetation we discover a series of operations, in which the principles conveyed to the growing plant are brought into new combinations, so as to form its diversified products: some of the chemical agencies connected with it have been already successfully investigated; and in the progress of the science we may, without any undue confidence, predict its full development, as a result of chemical affinities, modified by the circumstances under which they are exerted. The chemical processes of the Animal System are still more complicated and more dependent on, or at least more intimately connected with, the peculiar laws of vitality; yet even in these, Chemistry has discovered a number

of important truths : the most perfect theory which we yet have of any function of life, that of respiration, and the production by that process of animal heat, is strictly chemical, and affords a proof of what may be attained in a more advanced state of chemical physiology.

With the processes of Art, Chemistry is not less strictly connected than with the operations of Nature ; nor would it be easy, in an Introductory Sketch, to do justice to its practical applications. The extraction of metals from their ores, the purifying, casting, and forging them, the production of metallic alloys, and of metallic pigments, the manufacture of glass, of pottery and porcelain, the processes of bleaching and of dyeing, of making starch, sugar, and vinegar, of fermenting and distilling, of tanning, of soap-making, and of preserving animal substances from putrefaction,—all of these, in their most minute details, are in the strictest sense of the term Chemical Operations. It is from the skilful application of the principles of this science, rather than from the uncertain suggestions of chance or of random experiment, that their improvement is to be derived. As Chemistry advances, its applications to purposes of utility will become more extensive, and more easily regulated ; and as it is unbounded in the objects of its researches, we can assign no limits to the extent of these relations, nor foresee how far it may yet add to the power of man.

This important department of Physical Science is altogether of modern origin. It had no place in the system of Ancient Philosophy; and though arts were practised from the most remote antiquity, the processes of which are dependent on chemical actions, the relations of these were never discovered, and their principles remained unknown.

Its origin is to be traced to a singular pursuit which commenced towards the decline of literature, and which continued for many ages to be followed with unabated ardour,—that of the art of transmutation, or of converting the baser metals into silver or gold. In the prosecution of these delusive researches, observations were necessarily made on the changes produced by the mutual chemical actions of bodies, and these formed the base on which the science of Chemistry has been gradually reared.

The date of the rise of Alchemy, as this pretended art of transmutation was named, is not exactly known. It has been traced to the fifth, the fourth, or even to the third century; but there is every reason to doubt of the authenticity of the authorities on which it has been referred to these early periods. Towards the close of the fifth century, some progress appears, however, to have been made in chemical, or rather alchemical investigations. Among the Arabians, who had received the science and literature of the Greek Empire, the study of alchemy was eagerly prosecuted; and transferred to Europe, it continued amid the darkness of the middle ages, and even to a later period, to delude and mislead those who endeavoured to penetrate the mysteries of nature. The ultimate failure of

these laborious researches led to the suspicion of the soundness of the views from which they originated; and the real, though slow progress of experimental inquiry, enlightened by the more philosophical spirit of investigation which marked the sixteenth century, banished at length the follies and deceptions of alchemy, and laid the foundation of chemical knowledge. At the conclusion of this period, a number of important facts had been established; some of the most powerful chemical agents had been discovered; the instruments of the principal operations of Chemistry were invented, and the methods of conducting its processes were improved.

It is not the object of this sketch to follow with any minuteness the progress of Chemistry through its successive stages. It is sufficient to give it a more rapid glance. Kunckel, Homberg, Lemery, and Geoffroy, were its first eminent cultivators free from alchemical bias. Van Helmont had called the attention of Chemists to the aërial fluids so frequently disengaged in their experiments, and had even pointed out some of their properties and distinctions,—a subject prosecuted by Boyle, especially in so far as related to the action of atmospheric air, and by Mayow, with still more extensive and accurate views. Bacon fixed the limits of Chemistry, and assigned it its due rank in the scale of natural knowledge; and Newton generalized its principal phenomena, by tracing more distinctly the combinations and decompositions, which are the chief objects of its investigations, to the operation of that species of attraction exerted at insensible distances between the particles of matter.

Beecher sought to anticipate what is the final object of chemical investigations, and what will only be attained when these have reached perfection,—the determination of the elements from the combination of which all the existing varieties of matter are formed: and Stahl, adopting in part his views, but limiting his speculations to the operation of one principle, that to which the property of communicating inflammability was ascribed, framed an hypothesis so extensive in its chemical relations, as to have been regarded at one time as a general system of the science, and so well constructed as to have commanded unlimited assent.

The process of Combustion is of primary importance in Chemistry, not only from the striking phenomena it displays, but from its affording in some measure a division of bodies founded on chemical relations, and from giving origin to some of the most important chemical agents. Changes analogous to those which occur in this process, are likewise produced by the operation of these agents; and thus, whatever theory is framed of combustion itself, is farther extended, and is indeed capable of being more or less remotely connected with nearly the greater number of chemical phenomena. Stahl supposed the existence of a common principle, Phlogiston, as he named it, in inflammable bodies: its disengagement, under the form of heat and light, constituted, he imagined, the process of burning: its escape gave rise to the change of properties, and particularly to the loss of inflammability, which the body suffering combustion always sustains: its communication again to the burnt body restores its original quali-

ties; and its transfer, in other cases of chemical action, gives rise to analogous effects.

This hypothesis connected a number of phenomena by a common principle, and apparently afforded a just explanation of them. Resting, however, on an imperfect knowledge of the facts which it generalized, the progress of the science discovered its imperfections, and established very different views.

Substances existing in the aërial form, are from their subtility apparently not easily subjected to the usual methods of chemical investigation; and hence, though some of the facts connected with their formation and disengagement had attracted the attention of Chemists, their chemical actions had never been clearly investigated, their distinctions established, nor the importance of their agency understood. Black, by his discovery of the properties and combinations of one of these aërial substances, Fixed Air, or Carbonic Acid Gas, demonstrated the importance of these researches, and the department of Pneumatic Chemistry was soon eagerly cultivated. By the discoveries of Cavendish, Priestley, and Scheele, the existence of other aërial fluids, their properties, and chemical relations, were established: and Lavoisier, entering the same path of experiment, and availing himself of these discoveries, advanced speculations distinguished by their novelty and ingenuity, and which soon assumed the place of the hypothesis of Stahl. The phenomena which had been ascribed to the evolution of phlogiston, Lavoisier proved to arise from the combination of the base of an aërial fluid, Oxygen, which forms the most active principle of atmospheric air.

He traced the chemical agencies of this principle, and framed a system seducing by its simplicity, resting apparently on a just induction, supported by experiments distinguished by precision, and which, after a short period of animated discussion, was universally received.

At the close of this period, Chemistry, it was imagined, had nearly attained perfection, or at least it was supposed that little more than insulated facts remained to be made known. A short time has been sufficient to demonstrate the narrowness of these views. The laws of chemical affinity, which had been regarded as established by Bergman, have been materially modified by the researches of Berthollet; views altogether novel have been presented, and the theory of chemical action rendered more precise in its minute details. And the acquisition of a new instrument of chemical analysis, in the power of Galvanism, has already, in the discoveries of Davy, subverted or rendered doubtful much of the established system, and opens a career of investigation, the limits of which no imagination can define. The science is probably only in its infancy: it is at least far distant from that maturity, if this shall ever be reached, when its ultimate object shall be attained, when the real elements of bodies shall have been detected, and all their modifications traced: we know nothing of its real extent; nor can we, from our present knowledge, form any just conception of the stages of discovery through which it has to pass.

THE last object in this introductory sketch is to state the principles on which the arrangements of Chemistry are formed.

The investigations of this science being directed to the actions which are exerted among the particles of matter, in consequence of which they pass into new arrangements and new states of combination, and these actions arising from the operation of certain general forces, it obviously divides itself into two great departments,—the first comprising the investigation of the general effects and laws of these forces; and the second considering their operation on individual substances. Under the former are placed the doctrines of Attraction, and of its antagonist force Repulsion, as produced by the operation of heat, light, and electricity; to the latter belongs the history of the chemical properties, and combinations of all known bodies.

The first of these divisions admits of little diversity of arrangement, nor is it of much importance in what order the subordinate parts belonging to it are placed. The second presents much greater difficulties, and hence the numerous systems of chemical classification that have been proposed.

Two general methods are suggested by the nature of the science itself. Its object is to discover the composition of bodies, or, by analytic operations, to resolve them into the principles of which they are composed. The necessary result of such investigations, is, that substances are arrived at beyond which the analysis cannot be carried. In the theory of Modern Chemistry these are regarded as

simple; they are characterized by their most striking properties, and their combinations are investigated.

Now it is obvious, that in forming a system of chemical classification, we may, following the synthetic mode, assume these simple substances as the basis of the arrangement, and place their compounds in a determinate order, according to their composition. Or we may follow the reverse method: we may arrange the substances, which are presented to us by nature, into orders founded on analogies in chemical properties; and from the history of such of them as are compounds, we may follow the results of analysis, and proceed to the history of their more simple principles.

Since the establishment of the system of Modern Chemistry, Chemists have in general given the preference to the first of these, the synthetic mode of classification. There is undoubtedly some advantage in placing the simple substances before the compounds which they form, and classifications on this principle have a more scientific form.

Had Chemistry attained maturity, a perfect synthetic arrangement might be constructed, which might also perhaps be best adapted to display the relations of the science. But while it continues progressive, this must be attended with such difficulties as to justify the adoption of the opposite method.

The radical imperfection of any arrangement in which certain substances assumed as simple form the basis of the system is, that the simplicity of these substances can never be demonstrated, and that the progress of the science ge-

nerally leads to the discovery that they are compounds. They are regarded as simple, only because we are unable to decompose them; but this may arise, not from their real simplicity, but from the imperfection of our knowledge, and of our instruments of analysis. Their composition is accordingly in general at length discovered, and whenever this happens, the basis of the classification is of course subverted, and a new class of substances, supposed to be simple, is again to be formed. But of the real simplicity of these, we have no better proof than of the former: the progress of discovery may, and probably will prove them to be compounds, and the whole system must be again changed. This fluctuation must continue until the ultimate principles of bodies are discovered,—a period from which Chemistry is at present far distant, and until then, no arrangement, founded on these principles, can be stable, but must perpetually fluctuate with the progress of discovery.

Another imperfection which attends synthetic chemical arrangements is, that the student, in entering on the study of the science, has presented to his attention substances with which he is not familiar, or rather which, generally speaking, are unknown to him. It is seldom that bodies occur in nature in their state of simplicity; natural substances are almost uniformly compounds; their elements, therefore, cannot be generally known, and the knowledge of them can only be arrived at by a long, and often a complicated train of investigation. This difficulty, too, must become greater as the science advances; for in proportion to the extent to which analysis

is carried, the ultimate principles which are discovered are more remote from the natural bodies at which the analysis has commenced. The present state of Chemistry, were it necessary to enlarge on this subject, affords ample proof of the justness of these observations; the composition of a number of substances, regarded as simple, having been very recently established, and their principles being substances before unknown, and which are capable of being discovered only by difficult and refined modes of investigation.

For the reasons now stated, it has appeared to me preferable to relinquish the strictly synthetic mode of arrangement, and to adopt one the reverse; to take substances as they are presented to us by nature, class them from analogies in their chemical properties, and thus form natural orders, the distinctions of which the progress of the science will not subvert. From these we may proceed, under each of them, to the history of their elements, so far as the analysis has been carried, and thus the beginner of the study is led, by the most natural method, from what is known to what is unknown, and can follow more distinctly all the steps of the investigation. In conformity to these views, the arrangement presented in the following table is formed.

TABLE OF CLASSIFICATION.

PART I.

OF THE GENERAL FORCES PRODUCTIVE OF CHEMICAL PHENOMENA.

OF ATTRACTION.

OF THE ATTRACTION OF AGGREGATION.

— CHEMICAL ATTRACTION OR AFFINITY.

OF REPULSION, AND THE POWERS BY WHICH IT IS PRODUCED.

OF CALORIC.

— LIGHT.

— ELECTRICITY AND GALVANISM.

PART II.

OF THE CHEMICAL PROPERTIES AND RELATIONS OF INDIVIDUAL SUBSTANCES.

OF ATMOSPHERIC AIR AND ITS PRINCIPLES.

OF THE CONSTITUTION OF THE ATMOSPHERE.

— OXYGEN.

— NITROGEN.

— ATMOSPHERIC AIR.

— THE CHEMICAL AGENCY OF OXYGEN IN ITS PURE FORM, AND AS IT EXISTS IN ATMOSPHERIC AIR.

OF WATER AND ITS BASE.

OF HYDROGEN.

— WATER.

OF ALKALIS AND THEIR BASES.

OF AMMONIA AND ITS BASE.

— POTASSA AND ITS BASE.

— SODA AND ITS BASE.

OF EARTHS AND THEIR BASES.

OF BARYTES AND ITS BASE.
— STRONTITES AND ITS BASE.
— LIME AND ITS BASE.
— ARGIL AND ITS BASE.
— MAGNESIA AND ITS BASE.
— SILEX AND ITS BASE.
— ZIRCON AND ITS BASE.
— GLUCINE AND ITS BASE.
— ITTRIA AND ITS BASE.

OF ACIDS AND THEIR BASES.

OF NITRIC ACID AND ITS BASE.

OF NITRIC ACID.
— NITROUS ACID.
— NITRIC OXIDE.
— NITROUS OXIDE.

OF SULPHURIC ACID AND ITS BASE.

OF SULPHUR.
— SULPHURIC ACID.
— SULPHUROUS ACID.
— SULPHURETTED HYDROGEN.
— SULPHURETTED AND HYDRO-SULPHURETTED ALKALIS AND EARTHS.

OF CARBONIC ACID AND ITS BASE.

OF CARBON.

— CARBONIC ACID.

— CARBONIC OXIDE.

— CARBURETTED, AND OXY-CARBURETTED HYDROGEN GASES.

— CARBURETTED SULPHUR.

OF PHOSPHORIC ACID AND ITS BASE.

OF PHOSPHORUS.

— PHOSPHORIC ACID.

— PHOSPHOROUS ACID.

— PHOSPHURETTED HYDROGEN.

— PHOSPHURETTED SULPHUR.

OF MURIATIC ACID AND ITS BASE.

OF MURIATIC ACID.

— OXYMURIATIC ACID.

— HYPER-OXYMURIATIC ACID.

OF FLUORIC ACID AND ITS BASE.

OF BORACIC ACID AND ITS BASE.

OF METALS.

OF GOLD.
— SILVER.
— PLATINA.
— IRIDIUM.
— OSMIUM.
— RHODIUM.
— PALLADIUM.
— QUICKSILVER.
— COPPER.
— IRON.
— LEAD.
— TIN.
— ZINC.
— NICKEL.
OF COBALT.
— MANGANESE.
— ARSENIC.
— BISMUTH.
— ANTIMONY.
— TELLURIUM.
— CHROME.
— MOLYBDENA.
— TUNGSTEN.
— TITANIUM,
— URANIUM.
— COLUMBIUM.
— TANTALIUM.
— CERIUM.

OF THE NATIVE COMBINATIONS OF ACIDS, EARTHS, METALS AND INFLAMMABLES. MINERAL COMPOUNDS.

OF SALINE MINERALS.
— EARTHY MINERALS.
— METALLIC MINERALS.
— INFLAMMABLE MINERALS.
— THE NATURAL POSITIONS AND RELATIONS OF MINERALS, AND OF THEIR FORMATION.
— MINERAL WATERS.

OF VEGETABLE COMPOUNDS.

OF THE FORMATION OF VEGETABLE COMPOUNDS.

— THE CHEMICAL PROPERTIES AND RELATIONS OF VEGETABLE COMPOUNDS.

— THE SPONTANEOUS CHEMICAL CHANGES AND DECOMPOSITIONS OF VEGETABLE COMPOUNDS.

OF ANIMAL COMPOUNDS.

OF THE FORMATION OF ANIMAL COMPOUNDS.

— THE CHEMICAL PROPERTIES AND RELATIONS OF ANIMAL COMPOUNDS.

— THE SPONTANEOUS CHEMICAL CHANGES AND DECOMPOSITIONS OF ANIMAL COMPOUNDS.

PART I.

OF THE GENERAL FORCES PRODUCTIVE OF CHEMICAL PHENOMENA.

THE powers which operate in producing chemical action, are that species of attraction which is exerted at insensible distances between the particles of matter, causing them to pass into new arrangements and new combinations, and certain forces of repulsion, by which this attraction is counteracted, and these arrangements and combinations are modified or subverted. In proceeding to the consideration of these general forces, the most natural method appears to be to place first the doctrines of attraction, and after these to consider the operation of its antagonist powers.

There is some difficulty, it must be admitted, in considering the general doctrines of Chemistry before its particular details; for as these doctrines are inferred by generalization from individual facts, the former cannot be thoroughly understood, or their evidence clearly perceived, while the latter are unknown. Hence some Chemists have proposed to reverse this method. But the dif-

ficulty is in reality one unavoidable in either mode of arrangement; for it is equally impossible to give the chemical history of a single substance, without supposing a previous knowledge of the general phenomena and laws of chemical combination. In balancing the advantages of these methods, the first, it appears to me, will still claim the preference. It is possible to illustrate the general laws of chemical action by examples from substances familiarly known, or which, though unknown, are equally adapted to convey illustrations of abstract truths; and these laws being established, they may be developed and explained more minutely from the mutual actions of individual substances, while the history of these substances is given with more advantage, and can be rendered more complete, when the general doctrines have been previously delivered. There can scarcely be a heavier task, or one more calculated to damp the ardour of study, than to have to acquire the insulated facts of a science, unenlightened by any knowledge of the principles which unfold their relations.

BOOK I.

OF ATTRACTION.

Attraction is a term employed in philosophical language to denote that power or force by which the masses or particles of matter have a tendency to approach to each other, and to enter into more or less intimate contact or union. Different species of attraction have been observed, which give rise to different phenomena, and operate, so far as can be traced, according to different laws.

The attraction of gravitation is exerted at sensible, and often at immense distances, and between masses of the greatest size: its force, according to the law demonstrated by Newton, being directly as the mass or quantity of matter, and inversely as the square of the distance. The magnetic and electric attractions, though they give rise to peculiar classes of phenomena, so far coincide with the attraction of gravity, as to operate at sensible distances, and on masses of matter, and even, as has been attempted to be demonstrated, according to the same law.

Besides these, a species of attraction is exerted between the particles of matter, and at distances generally insensible. This force, when exerted between particles of the same kind, is named the Attraction of Aggregation or Cohesion: when exerted between particles of different

kinds, it is denominated Chemical Attraction, or Chemical Affinity. Both are concerned in the production of chemical phenomena, and the latter is the force on which all the combinations of matter depend.

Both have been supposed to be ultimately the same power; the differences in the results of their operation being referred with much probability to the difference of the particles on which they operate; aggregation uniting particles of a similar kind, and therefore producing, in each case, an aggregate possessed of similar properties; while chemical attraction, combining particles of different kinds, must give rise to products in which some modifications of properties must be the result. It has even been contended, that both of these are only modifications of that more general force which is exerted at sensible distances between the masses of matter; and the apparent differences in the laws which regulate their action from those which gravitation observes, have been ascribed to circumstances, which, in the one case, operate powerfully, while in the other they can have little effect. In the operation of contiguous attractions, the figures of the particles of bodies must, it has been conceived, have an important influence; while the figures of masses of matter, operated on at great distances, can give rise to no appreciable result. "Considering the vast distance," says Bergman, "we may neglect the diameters, and look upon the heavenly bodies, in most cases, as gravitating points. But contiguous bodies are to be regarded in a very different light; for the figure and situation, not of the whole only, but of the parts, produce a great variation in the effects of attraction. Hence

quantities, which in distant attractions might be neglected, modify the laws of contiguous attraction in a considerable degree."

This question is one which we scarcely can determine, since we are unable to estimate the force of those modifying circumstances which may exist; and the laws by which these attractions act, instead of being deduced from any assumption of the law of gravitation, must in the present state of the science be inferred from observation and experiment.

CHAP. I.

OF THE ATTRACTION OF AGGREGATION OR COHESION.

AGGREGATION has been defined, that power which unites particles of a similar kind. We perceive its action exemplified in a solid mass of matter, the parts of which cohere with a certain force, which resists any mechanical action that would produce their separation, and which, in different bodies, is exerted with very different degrees of strength. In liquids it appears to be weaker, or the parts are disjoined with much more facility: and in substances existing in the aërial form it is entirely overcome, the particles, instead of attracting, repelling each other. Bodies exist therefore in the solid, the liquid, and the aëriform

state, according to the force with which the attraction of aggregation is exerted between their particles, and it is this attraction which unites these particles together.

Aggregation in bodies is weakened or overcome by two causes; by the repulsion communicated by heat, or by the attraction which may be exerted by the particles of one body to those of another.

Heat communicated to a solid body separates its particles to greater distances, as is evident from the enlargement of volume which it produces. By thus increasing the distances, the force with which the attraction of aggregation is exerted, is weakened: if the application of heat be carried to a sufficient extent, it is so far weakened that the body passes into the liquid form; and if carried still farther, the attractive force is entirely overcome, repulsion is established between the particles, and the body passes into the aëriform state.

The same effects are produced by the exertion of that attraction which unites the particles of one body with those of another. If a liquid, for example, is poured on a solid substance, it often happens that the attraction exerted by the liquid to the solid is sufficiently powerful to subvert the cohesion of the solid; its particles are disunited to combine with those of the liquid, the solid diminishes in size, and at length entirely disappears. This forms the chemical process of Solution. A similar effect is sometimes produced by the chemical action of an aëriform fluid; and in some cases the mutual attraction, even of two solids, is such as to diminish the power of cohesion so far as to admit of their union, and their transition to a liquid state.

When these powers, whether of heat or of chemical attraction, are withdrawn, cohesion resumes its force; but with results which are different, according to the circumstances under which this happens.

When the attraction of aggregation is suddenly exerted, and with considerable force, the particles are united in general indiscriminately, and according to no regular law. If a body which has been melted is suddenly cooled to a sufficient extent, it becomes solid, without its particles being united in such a manner as to produce any regular structure or form. Or if its cohesion had been suspended by the chemical attraction exerted by another body towards it, and if this attraction suddenly cease to operate, the force of cohesion is resumed, and the solid substance appears usually in the form of a powder. This latter case forms the chemical operation of Precipitation. A similar result is obtained, when, in consequence of chemical combination, a substance is rapidly formed, between the particles of which the attraction of aggregation is exerted with considerable force.

But if the attraction of aggregation is exerted more slowly, the particles on which it operates are united not indiscriminately, but usually with regularity, so as to form masses of regular structure and figure, bounded by plane surfaces and determinate angles. This forms the operation of crystallization, and such masses are denominated Crystals.

Crystallization may take place either from a state of fluidity produced by heat, or from a similar state produced by the exertion of a chemical attraction. Of the first

we have examples in ice, which shoots in long slender crystals, when water is cooled to a sufficient extent, and also in a number of the metals which have been melted, and then subjected to slow cooling. Of the second we have examples in many saline substances, which, when they have been dissolved in water, concrete in crystals, when part of that water has been withdrawn by evaporation, or when its solvent power is diminished by a reduction of its temperature. In any of these cases, if the operation is conducted slowly, so as to admit of the particles uniting by those sides most disposed to union, crystals are formed, and these are in general larger, more transparent, and more regular in their form, the slower the crystallization has been allowed to proceed.

The production of these regular forms is favoured by affording a nucleus, from which the crystallization may commence; and still more so, if this nucleus is of the same matter as the substance to be crystallized, and is of a regular figure: and on this is founded a method of producing crystals of great regularity, and of large size.

The access of the air has likewise an influence on crystallization; a solution of a salt, for example, which has been inclosed while hot in a vessel, from which the air has been in a great measure expelled, not crystallizing when cold, but shooting into a congeries of crystals, the moment the air is admitted. The sudden admission of the air appears to operate by the pressure it exerts on the surface of the liquor, causing the approximation of the particles of the dissolved solid, whence the exertion of the attraction of cohesion is favoured; and hence any equiva-

lent pressure applied in a similar manner has the same effect.

In this sudden crystallization, is very well displayed a phenomenon, which always attends this process, the evolution of heat.

An enlargement of volume is often produced by crystallization, as in the example of ice, of several metals, and of a number of salts; while, in other cases, the reverse is the case, the volume of the crystallized substance being less than while it existed in the liquid state.

Crystals formed from a watery solution, generally retain a portion of water in a combined state. This is named their water of crystallization: when deprived of it, they lose their transparency and density. Some part with it from mere exposure to the air, and suffer these changes: they are then said to effloresce: if they attract water and become humid, they are said to deliquesce; but these properties of efflorescence and deliquescence are relative, and depend much on the state of the atmosphere with regard to humidity.

By the process of crystallization, substances may often be obtained separate which exist in the same solution. If one is less soluble than the other, it will after a certain extent of evaporation crystallize, while the other remains dissolved, and may be obtained by a subsequent evaporation: Or, if one is more soluble in hot than in cold water, while the other is nearly equally soluble in either state, the one will be obtained by crystallization when the liquor has cooled, while the other, when the necessary degree of evaporation has taken place, may separate while the solu-

tion is hot. The mutual attraction of substances dissolved together, sometimes, however, counteracts their crystallization, or causes each to crystallize with some intermixture of the other; and this, too, alters the crystalline forms which either is disposed to assume.

Crystallization sometimes takes place in the transition from the aërial form, as is well exemplified in the arrangement of a flake of snow.

Every substance in crystallizing is disposed to assume a certain regular figure; sea salt, for example, assumes the form of a cube; nitre, that of a prism. This figure, however, is not invariable, but is liable to be modified by circumstances, and the same substance is therefore found nnder different crystalline forms.

The theory of crystallization is still obscure. The particles of bodies may be of certain regular figures, and in uniting, these particles may be disposed to approach by certain sides in preference to others, probably by those which admit of the most extensive contact. Hence a regular structure and figure, uniform with regard to each substance, may be produced.

The mechanical structure of crystals has been investigated with much labour by Hauy. He has shewn that in every crystallized substance, whatever may be its actual form, there is a nucleus of a determinate figure, and which, by mechanical analysis, that is, by splitting the actual crystal according to its natural joinings, may be extracted. This nucleus or primitive form, he has shewn, is constant with regard to each substance, however various the actual forms of its crystals may be; and he has farther explain-

ed, how, by additions of particles to this nucleus, according to certain laws, these secondary forms may be produced. The development of this theory, however, requiring extensive details, and being not strictly elementary, I may refer for the statement of it to my System of Chemistry.

CHAP. II.

OF CHEMICAL ATTRACTION OR AFFINITY.

CHEMICAL attraction is that force by which the particles of different bodies are united intimately, forming not a mere aggregate or mixture, but a substance in which new qualities are acquired, the properties of the bodies combined being more or less changed. The term affinity has been used to denote the same power, from an opinion, that some peculiar relation or resemblance exists between those bodies, which are most disposed to exert this mutual attractive force; and the term, though derived from a groundless hypothesis, may, without any reference to its origin, be conveniently used as synonymous with chemical attraction.

The immediate result of the exertion of chemical attraction between two bodies, is the intimate union or assimilation of their particles, so as to form a homogeneous

mass. This result is in chemical language named *Combination*. It is to be distinguished from *Mixture*, in which the particles, however intimately they may be blended, still exist apart, so that they are capable of being recognised, and of being separated by mechanical operations, and retain their properties unimpaired. It is also to be distinguished from *Aggregation*, which is only the union of particles of a similar kind, forming an aggregate which has the general properties of the particles of which it is composed, whatever may be its mechanical structure or form.

The substance formed by chemical combination is named a *Compound:* the substances of which it is composed are its *Component* or *Constituent Parts* or *Principles*. When these are separated from their state of combination, the process is named *Decomposition*. If decomposition has been performed more peculiarly with the view of discovering the composition of a body, it is named *Chemical Analysis*. If the decomposed substance is reproduced by the union of its constituent parts, the operation is denominated *Chemical Synthesis*. The *Integrant particles* of a body are understood to be the most minute parts into which it can be resolved without decomposition; they are of course similar to each other, and to the substance which they form. The *Constituent particles*, again, are those into which it is resolved by decomposition, which are therefore of a different nature, both with regard to the substance itself, and with regard to each other. It is between these that chemical attraction is exerted, while

aggregation is conceived to be exerted between the integrant particles of bodies.

The theory of chemical attraction is still far from having attained perfection, though it has been the subject of much investigation. Newton, as has been already stated, suggested the idea, that the phenomena of chemical combination and decomposition might be owing to an attraction exerted between the particles of bodies, and varying in its force. This view was soon adopted by chemists. The elder Geoffroy endeavoured to ascertain the relative degrees of strength with which attraction is exerted among bodies, and gave the results under the form of a table. The subject continued to be prosecuted, until a number of observations more or less exact were accumulated, which Bergman reviewed, and placed in a clearer light. And more recently Berthollet has by his researches extended the theory of affinities, and presented views with regard to it extremely important, and very different from those which had been considered as established.

From these preliminary observations and definitions, we may proceed to the more full statement of the doctrines of chemical attraction, generalizing these as far as the present state of our knowledge admits.

Sect. I.—*Of the Phenomena which arise from the exertion of Chemical Attraction.*

The immediate result of the exertion of chemical attraction between bodies, is their intimate union or combination, and the most general phenomenon attending this combination is a change in the properties of the bodies combined. The secondary qualities of bodies, depending on the peculiar arrangements of their particles, it is easy to conceive that when these arrangements are subverted, the properties must be altered, and that in the formation of a new substance new qualities must be acquired.

Chemical combination is accordingly, in general, attended with very striking changes of properties; so striking, indeed, that we can seldom infer with certainty, from our knowledge of the properties of any body, what will be the properties of the compound it forms when united with another.

Still the entire change of properties from combination, is not an invariable result. There are many cases in which they are only modified; and in some cases, as for example in the combinations of salts with water, so slightly so, that there is scarcely any evident change, but change of form.

V. p. 53. Berthollet has proposed a view of this subject, which in some measure reconciles these apparently opposite results.

The properties of bodies, he supposes, would always remain in their combination, but for certain causes foreign to the combination itself, by which they are modified, and in some cases entirely disguised. Thus, there are properties which are incompatible, different tastes or colours, for example, which cannot exist together, and which must therefore neutralize or modify each other. From the approximation of the particles, which is the effect of combination, changes must be produced too in the secondary qualities depending on their arrangement. The same cause must give rise to modifications of chemical properties; for if in consequence of this approximation, much cohesion is acquired, this must counteract the affinities of the principles of the compound, and of course render its action less energetic: and, on the other hand, if, by the condensation attending chemical union, the bodies uniting have passed from the aëriform state to the liquid form, this, by removing the obstacle which elasticity opposes to their chemical action, may facilitate that action, and render it more extensive and powerful. Lastly, the diminution which is produced by the reciprocal force itself that unites two bodies, in the affinities which either of them exert to others, must cause the chemical action of compounds to be in general weaker than that of their constituent principles, though this may in certain cases be modified by the other causes which operate. Thus we perceive, that notwithstanding the changes that attend combination, the theory may be just, that the properties of bodies combining, enter with them into the combination, and would always be discoverable in the compound, were it not for the opera-

tion of modifying circumstances. And we derive the rule, which in general will be found to hold true, that where energetic affinities are exerted, or where substances having opposing properties are combined, the properties will be materially changed; but where the affinity is not powerful, and therefore the combination not very intimate, or where the substances combined are such as agree in the general assemblage of their qualities, the properties of the compound will not be very remote from those of its more active ingredient, or from the mean of those of its constituent parts. Even in very intimate combinations, we can often trace the properties of compounds from those of their component parts; as, for example, the high refractive power of water, from its inflammable ingredient,—a property which led Newton to his singularly acute conjecture, that it contains an ingredient of that nature. The comparative volatility of compound salts, which are formed of principles disposed to assume the elastic form, affords a similar example.

In those combinations in which the changes of properties are least considerable, there is generally one change to be discovered to a greater or less extent, and which may even be regarded as a test of chemical union,—a change of density, the density of the compound never being the mean of the densities of its component parts. In the greater number of cases the density is augmented, and sometimes to a great extent. In other cases, however, it is diminished, or the volume is enlarged.

As in chemical combination the particles of two bodies are made to approximate, we might expect that conden-

sation would be always the result; and it is not very obvious how enlargement of volume should sometimes be produced. Berthollet has very well explained this. The immediate effect of combination is in every case condensation; but if the consequence of the combination is, that one of the bodies changes its form from the solid to the liquid, the enlargement of volume which attends this change of form may more than counterbalance the condensation from the combination; and hence, on the whole, diminution of density will be the result. It is accordingly in cases of solution, or where a solid body is acted on by a liquid, so as to be brought into the liquid state, that the exceptions to the more general law are observed. It must be added, however, that they are not altogether confined to these, but that sometimes there is enlargement of volume, even when the compound exists in the solid state, as in the combinations of some of the metals. When this happens, it is probably from a crystalline arrangement, which the particles of the solid assume in becoming solid, and is similar therefore to the increase of volume which attends the congelation of various substances.

A change of temperature, in other words the production either of heat or cold, is, next to the change of properties, the most important phenomenon attending chemical combination. The production of heat is the more frequent change: it is often intense, and the great source of heat in the operations of art is chemical combination. Cold is also, however, not unfrequently produced. It very generally is the consequence of the solution of saline substances in water, or in other more active liquids, and is

still more intense in the mutual action of salts, and snow or ice.

Wherever a production of heat is observable in chemical combination, we can trace an increased density accompanying it; and the evolution of heat may be ascribed to this, since we know, that the mechanical condensation of a compressible body produces heat. On the other hand, where cold is produced in chemical action, there is always an enlargement of volume, to which, therefore, the cold may be ascribed. But we do not find that the production either of heat or cold, from chemical action, is proportional to the increase or diminution of density. Allowing the latter, therefore, to be the cause of the change of temperature, there must be some other circumstance by which it is modified. This is the change of form. It is sufficient, at present, to state, that when a body passes from the aëriform to the liquid state, or from the liquid to the solid state, it gives out heat, and in the opposite changes absorbs it, in quantities not proportional to the degree in which the density is altered by the form; and hence such transitions of form, when they accompany chemical action, which they frequently do, modify the production of heat or cold which arise from the condensation attending the combination itself. By taking into consideration these two circumstances, the production of heat or cold from chemical action is explained with more precision than if one of them only were admitted in the theory; and there can be no doubt, that both, when they occur, have a share in producing the change of temperature.

Sect. II.—*Of the Circumstances by which the exertion of Chemical Attraction is influenced.*

Chemical attraction is not an invariable force, which, as exerted by any body, operates in all cases with the same strength. Its exertion is powerfully modified by circumstances foreign to it. Of these we can distinctly trace the influence of quantity of matter, cohesion, insolubility, specific gravity, efflorescence, elasticity, and temperature.

1. Quantity of matter. The discovery of the influence of this circumstance we owe to Berthollet. Some of the facts from which it has been inferred had been known to chemists, and in the explanations given of these some approximations made to the principle itself. By Berthollet, however, it has been more fully developed, more clearly demonstrated, and more extensively applied.

The most direct proof of the law is derived from the fact, that a compound may be decomposed if a large quantity of a substance exerting an attraction to one of its principles be made to act upon it, while from the action of a smaller quantity of the same substance no decomposition ensues. Of this there are many examples in chemistry, particularly in the decompositions of compound salts.

Another proof of it is, that a substance having an affinity to one of the principles of a compound, comparatively weaker than the affinity which they exert to each other, can still produce at least a partial decomposition of the

compound, if it be brought to act on it in large quantity; the increase in its quantity in some measure compensating for the weakness of its affinity.

Lastly, what is in strict conformity to the same law, if a compound is submitted to the action of a substance, exerting an attraction to one of its principles, even much stronger than the attraction which unites them, still the decomposition is only partial, or a portion of the principle abstracted by the decomposing substance remains combined with the ingredient with which the entire quantity of it was combined in the compound; for, in proportion as the decomposition goes on, the increase in the relative quantity of that ingredient adds so much to the force of the attraction it exerts to the principle abstracting from it, as to be able to counterbalance the attraction producing the decomposition, and therefore to suspend its action. Hence there is a partition of the substance attracted, between the two bodies exerting attractions towards it; and the proportions of this partition are determined as much by the differences in the quantities of these, as by the difference of energy in their affinities.

From these general facts, which are supported by numerous individual experiments, Berthollet has established the law, that affinity is modified by quantity of matter, or, more precisely, that the chemical action of any body is exerted in the ratio of its affinity and quantity. It is one of much importance in its applications, enabling us to explain with more precision many cases of chemical combination and decomposition; and illustrating the operation

of some of the other circumstances which influence chemical attraction.

2. Cohesion. Cohesion is that force by which the integrant particles of a body are held in union: it must therefore counteract the action of any power, the tendency of which is to separate these particles, in order to bring them into new arrangements or combinations. Hence it powerfully modifies the exertion of chemical attraction; and from the opposition of these two forces, in different degrees of energy, arise numerous shades of combination, more or less intimate, as the one predominates over the other, from the mere adhesion of the surfaces of bodies, or the absorption of a liquid into the interstices of a solid, to the most perfect chemical union. If cohesion be powerful, a strong affinity may be effectually resisted, and no combination take place, though the bodies have a strong reciprocal attraction, of which we have many examples in chemistry. If cohesion be inconsiderable, a weak affinity may be predominant, and a combination be effected. And whatever diminishes the force of aggregation, favours the exertion of chemical attraction.

From the influence of this circumstance in counteracting combination, bodies in the solid state seldom act chemically on each other, whence the axiom was established in Chemistry, *Corpora non agunt nisi sint soluta.* To this there are exceptions, as in the action of various compound salts on each other, producing mutual decomposition, though both are solid, or in the action of some of these salts on ice or snow, even at very low temperatures. Yet still, in general, fluidity is necessary to chemical action; and

if not possessed by either of the bodies which are designed to act on each other, it is necessary that it should be communicated, either by the application of heat, or by the previous operation of a solvent. Hence fusion and solution are the common *media* of chemical action.

Cohesion, existing in liquids to a certain extent, may counteract their mutual attraction where this is weak, though in general the resistance it opposes is so inconsiderable, that liquids combine readily, and in all proportions.

To these views, with regard to the effect of cohesion on combination, Berthollet has added some others, more novel, and equally important. He regards it not merely as a quality of bodies actually solid (or remaining in a slight degree in liquids) resisting the exertion of affinity, and ceasing to act when solidity is destroyed; but as a force which continues to operate when it has been apparently overcome, or when its effects are not sensible, and which, by a progression in its action, may at length influence combination. It may be suspended by a superior affinity, or by the agency of heat; and its energy may be so far subdued as to appear negative; but still it continues so far active, that if the forces by which it was weakened are diminished, its action will be exerted even before solidity takes place, and will counteract affinity. Or if, in consequence of new affinities, combinations are produced, it may determine the proportions in which the elements are combined; for being exerted between the integrant particles resulting from the combination, whenever its intensity is sufficiently powerful to counterbalance the affini-

ty of the liquid in which these are formed, it will give rise to precipitation or crystallization, will of course withdraw the substance formed from the sphere of action, will oppose an obstacle to any further exertion of chemical power, and by such operation may determine the proportions of the combination. This effect, resulting from cohesion, will require to be stated more fully in considering the limits to the exertion of attraction.

3. Insolubility. This property is merely the effect of cohesion in a solid, considered in relation to the liquid in which it is exerted, and of course its operation is similar. It opposes a resistance to the exertion of any attraction towards the body possessed of it, and it is an obstacle to the progress of combination, beyond that stage at which the insolubility withdraws the substance formed from the sphere of attraction. It equally favours decomposition, when, in consequence of it, a substance, separated from a combination, is separated, and ceases to counteract the action of the decomposing substance.

4. Specific gravity. Much difference of specific gravity in two bodies is an obstacle to their mutual union, since it is a cause favouring their separation, and of course a more powerful affinity is required to produce their union, than if such a difference did not exist.

5. Efflorescence. The operation of this circumstance, in influencing chemical action, is comparatively trivial, yet it sometimes can be traced. In mixtures of saline substances, a substance evolved or formed by their mutual decomposition sometimes rises on the surface in a loosely aggregated mass or congeries of minute crystals, forming

what is named an Efflorescence. It is thus withdrawn from the action of the other substances, and this may contribute to the progress of the decomposition, or allow it to become more complete. Its influence has accordingly been observed in some important cases, particularly in the decomposition of sea-salt by calcareous matter, and the production, both natural and artificial, of carbonate of soda.

6. Elasticity. The property of elasticity is possessed, in such a degree, as to influence chemical action only by substances in the aërial form. In that form, the particles of a body are mutually repellent; and they are thus placed at great distances from each other. When two aëriform bodies, therefore, are presented to each other, their particles are at distances too great to admit of the exertion of chemical attraction, so as to bring them into intimate union. Hence elasticity is generally an obstacle to chemical combination. In some cases where the mutual attraction is strong, it is overcome, and two aëriform bodies combine together; but more generally the reverse is the case, or the attraction does not operate.

In conformity to this view, those circumstances which repress elasticity favour the combination of elastic fluids. Mechanical pressure, strongly and suddenly applied, causes different aëriform bodies to combine. The application of cold, especially when aided by pressure, has a similar effect. What appears singular, heat often gives rise to the same result; its operation, however, which is afterwards to be considered, may be reconciled perhaps to this principle.

In the combination of an elastic fluid with a body not possessed of elasticity, as a liquid, as the obstacle to their union is in part removed, it generally takes place more readily, at least to a certain extent. Still, however, the elasticity operates, and places limits to the quantity of the aëriform body which the liquid absorbs. Hence this quantity is increased by whatever counteracts this force, as by the application of pressure. Cold has a similar effect, though the operation of this is in some measure counteracted by the cohesion it communicates to the liquid; and if this is carried so far as to produce solidity, the absorption of the aëriform body is not only counteracted, but the quantity which had been absorbed is often, at the moment of congelation, disengaged. In this way we can account for the fact, which otherwise appears anomalous, that the application of heat, especially if sudden and intense, often favours the combinations of aëriform with solid substances; the diminution which the heat occasions in the cohesion of the solid, more than counterbalancing the augmentation of elasticity in the other.

Since elasticity in general counteracts combination, it may easily be understood that it will favour decomposition. If a compound consist of a solid ingredient, and of another, which, when uncombined, exists in the aërial form, it will be less difficult of decomposition, either by the application of heat, or by the action of another substance upon it, than if it were composed of two non-elastic bodies. If exposed to heat, the elastic ingredient, being disposed to acquire the state of elasticity, its affinity to the other is weakened, and it is at length expelled. Or, if the

compound be submitted to the action of a substance which exerts an affinity to its non-elastic ingredient, this, in conformity to the usual law, weakens the affinity exerted between this and the other ingredient, and allows a portion of the latter to assume the elastic form. This again being thus withdrawn from the sphere of action, opposes no resistance to the action of the substance by which it was displaced, and therefore does not counteract the progress of the decomposition. Hence the decomposition of such compounds is in general more complete than that of those composed of inelastic substances, the substance excluded in the latter still continuing to act in opposition to the one by which it has been displaced, and the substance to which both exert an affinity remaining in combination with portions of each of them.

7. Temperature. Much of the effect of temperature, or the state of bodies with regard to heat and cold, on chemical action, is to be ascribed to the operation of some of the preceding causes, and particularly to the changes which these states occasion in cohesion and elasticity. Being in general complicated, however, and giving rise to peculiar results, it requires to be considered apart.

The application of heat usually favours chemical combination, there being numerous examples where two bodies do not combine at a low temperature, but enter into combination when their temperature is raised.

When the combination of solid substances is favoured by heat, the result is obviously to be ascribed to the diminution which the heat produces in the state of cohesion, this removing an obstacle to the exertion of their mutual

affinity. Where it favours the combination of a solid with a fluid, or even with an aëriform body, as it frequently does, its operation is still similar, the cohesion of the solid being weakened, and the resistance which that cohesion opposes to the combination of its particles with those of the other substance being so far removed.

In this case, however, the result is rendered more complicated by the circumstance, that while the heat diminishes the cohesion of the one ingredient, it increases the elasticity of the other. This sometimes counteracts the combination, especially where the mutual affinity is not strong.

A very peculiar fact, and which appears at the first glance not to accord with these views, is, that heat favours the combination of elastic fluids with each other. If two bodies in the aëriform state are mingled together, it often, indeed, generally happens, that no combination takes place. But if heat be suddenly applied, as, for example, if a burning body or an ignited spark be introduced into the mixture, they instantly combine. Here the result appears altogether anomalous: the obstacle to the combination of substances in the aërial form is their elasticity, and the distances at which, in consequence of this, their particles are placed. By applying heat, this is increased, and the combination, instead of being facilitated, it might be supposed would be counteracted.

Is the following hypothesis adequate to the solution of this difficulty? When an ignited spark is introduced into the mixture, the space on which it falls has heat communicated to it, whence an expansion, proceeding from that

space, is produced; and this expansion, by the pressure it must occasion on the surrounding particles, will cause them to approximate, and thus to unite. The whole effect is instantaneous, and it is on this that it depends. Were the heat to be slowly applied, and gradually raised, it would be diffused through the whole mixture, and the particles would be merely separated to greater distances. But a single point being heated to a high degree, while the surrounding particles remain at their usual temperature, the expansion from the former must press on the latter suddenly, and more quickly than the heat can be communicated. These, therefore, instantly approximate within the space at which chemical attraction is exerted, and their union is effected. The result of the combination is a farther evolution of heat, successively but rapidly taking place, which produces a similar effect on the contiguous particles, until the combination is complete. There are some cases, however, in which so little heat is extricated, that the introduction of a single spark is insufficient, and therefore a succession of sparks must be applied.

The application of heat, in particular cases, favours decomposition as well as combination. Where, of the substances combined, one is more disposed than the other to pass into the elastic form, this tendency is favoured by a high temperature, and frequently so much so, that their mutual affinity is overcome, and decomposition ensues. By a similar operation, heat aids the decomposition of such compounds, by the affinity exerted by a third substance to the more fixed ingredient, and it often promotes the mutual decomposition of two compounds, favouring

the union of the two more volatile ingredients, and thus allowing the attraction between the ingredients, which are comparatively fixed, to operate with effect.

In all cases, then, in which heat favours chemical action, it does so by the changes it occasions in the cohesion, or in the elasticity of the bodies concerned; but these often modify each other, and hence it often gives rise to apparently opposite results; it is therefore only by considering it in relation to both, that we obtain a just theory of its operation.

The same view is to be taken of the operation of cold. By diminishing elasticity, it sometimes favours combination; and in other cases, by increasing cohesion, it may counteract this, and give rise to decomposition. Or the one of these effects may modify the other, and thus give rise to results, which, were the joint action not attended to, would appear anomalous.

From the influence of the circumstances by which chemical attraction is counteracted, the corollary follows, that it cannot be affirmed in any case that bodies have no attraction to each other. There are many examples in which bodies do not combine, as in the familiar one of oil and water; but it is obvious, that since combination is in no case the simple result of the exertion of attraction, but always of attraction prevailing over cohesion, elasticity, or specific gravity, we cannot affirm, from combination not taking place, that no mutual attraction exists. All that can be inferred is, that the attraction is not sufficiently strong to overcome the opposing forces. It is difficult to conceive

of attraction otherwise, than as a force with which every particle of matter is endowed, and which is exerted to every other; and the theory is evidently superior, which supposes this power, in particular cases, to be prevented from being efficacious, by the interference of extraneous forces, to that which supposes, that between certain substances it is altogether wanting, especially since in all cases the action of such forces can be demonstrated, at least to a certain extent, which may be sufficient to account for the result.

From the influence, too, of these circumstances, combined with the admission that all bodies have mutual attractions, it follows, as a probable conclusion, that the affinities exerted by compounds are merely the affinities of their constituent principles, modified by the circumstances under which they are exerted. It is no doubt true, that the affinities exerted by the compound are often extremely different from those of its elements: it combines with substances to which they appear to have no attraction, and it refuses to unite with others with which they form intimate combinations. But this may be expected from the very different conditions under which they operate, and it is perhaps possible to point out how they may be diversified by circumstances, the influence of which is undoubted.

Thus, from the affinity which one of the elements of a compound exerts to the other, the affinities of either to other substances must be so far counteracted, and hence the cause of what is generally the case, the attractions ex-

erted by a compound being less powerful than those of its constituent parts.

This, however, may be modified by other circumstances attending the combination, which may either concur with it, and still farther weaken the affinities of the compound, or which may counteract it, and render them even more energetic. Thus, if a substance, by combination, pass from the solid to the liquid state, it acquires the advantages derived from fluidity, and its affinities, formerly counteracted by its cohesion, may now, notwithstanding some diminution which they suffer from the combination, be exerted with more effect. Or, if elastic substances by combination form a liquid, the advantage gained from this condensation and removal of elasticity may more than counterbalance the diminution of force from combination, and may render their affinities more extensive and more powerful. Or the reverse of these modifications may happen. If the result of a combination be the transition of a substance from the liquid to the solid state, the cohesion acquired will add to the diminution of its affinity from the combination itself; or if an aëriform compound be produced, the elasticity of this may concur with the effect of the combination in weakening the energy of its action.

With these views, many facts in the details of Chemistry strictly correspond, and they afford some happy explanations of chemical phenomena. Affinities thus modified, Berthollet has named Resulting, to distinguish them from the affinities of the immediate principles of a compound, which, in contradistinction, he names Elementary. The anomalous cases of chemical attraction, which have been

placed together under the name of Disposing Affinity, appear to belong to the same class, and principally to arise from the modifications produced in elementary affinities by combination.

Sect. III.—*Of the Limits to the Exertion of Chemical Attraction.*

Chemical attraction obeys certain limits; *first*, with regard to the relative quantities in which it causes bodies to combine, and, *secondly*, with regard to the number of substances between which it may be exerted, so as to bring them into simultaneous combination.

First, In the greater number of combinations, there are limits to the attraction exerted, with regard to relative quantity; or the bodies are not always combined in indefinite quantities, but often only in determinate proportions. Under this general proposition, several classes of facts may be arranged.

1*st*, There are cases in which two bodies can be combined together only in one proportion, and if an excess of either ingredient of the compound be present, it remains uncombined, with its properties unchanged. The constituent principles of water afford an example of this.

2*dly*, Attraction is frequently exerted between two bodies, as to combine them in two, in three, or even in four proportions; but these are always determinate, so that in

the intermediate proportions no combination is established. These combinations give rise to compounds which differ entirely in their properties from each other, the differences being frequently as great as if they were formed of principles altogether different. From this cause principally arise the diversities in the properties of the substances belonging either to the animal or vegetable kingdom, these consisting in general of the same principles, united only in different proportions.

3dly, Combination is sometimes unlimited to a certain extent, but when this is reached it is arrested. Water, for example, will dissolve any quantity of a salt up to a certain proportion; but when this has been combined with it, the mutual attraction ceases to operate with effect, and no larger quantity can be dissolved. The limitation of combination in this case is named Saturation; and when the water has dissolved the largest quantity of the salt which it can dissolve, it is said to be saturated with it.

Lastly, There are cases of combination absolutely unlimited, or in which bodies unite in every proportion. This is observed to happen principally in the combination of liquids with each other, where the compound retains the liquid form.

When combination takes places in determinate proportions, it generally happens that there is one proportion in which the properties of the bodies combining are mutually lost or neutralized; the distinctive properties of neither ingredient appearing in the compound; while in the proportions different from this, the properties of the ingredient which is in excess may be recognised, weakened on-

ly to a certain extent. The stage of the combination at which this happens is named the point of Neutralization, and sometimes the point of Saturation. The latter, however, is more properly employed in the sense already pointed out, as denoting the extreme of combination; and the term Neutralization is preferable, as signifying that state in which the properties of the bodies are mutually lost or neutralized.

It is a question of some interest and importance, to what causes these varieties of combination are to be ascribed; and it would be satisfactory to reduce them to one general principle. This has been attempted by Berthollet, and though, from the difficulty of the subject, some obscurity is attached to it, his views are probably just.

The principle of his theory is, that affinity is a force always disposed to operate on bodies, and to unite them in all proportions; that any limits opposed to its exertion arise from external forces, cohesion, elasticity and others, by which it is influenced, and that it is only by the operation of these that determinate proportions are established.

We find the preceding general facts in a great measure to accord with this principle. Thus, where these external forces do not operate, as in the mutual action of two liquids, the compound remaining liquid, the combination is unlimited with regard to proportion. When cohesion or elasticity is present in the subjects of the combination, as in the action of a liquid on a solid, or in the absorption of an aëriform substance by a liquid, these forces limit the quantity of the solid that can be dissolved,

or of the air that is absorbed, in the manner already explained,—the affinity producing the combination becoming weaker as the combination proceeds, while the cohesion of the remaining solid, or the elasticity of the unabsorbed air, continues as at first, and therefore an equilibrium must be arrived at, when the combination will cease. Up to that period it may take place in indeterminate proportions; but when it is reached, a limit is placed, beyond which it cannot proceed. Lastly, When, in the progress of combination, the result in any part of it is great condensation, this, by the obstacle it may oppose to the exertion of affinity, or even from the greatness of the condensation, by withdrawing the product from the sphere of action, may limit the combination to that point, or to the proportion at which this effect is greatest; or if, by particular circumstances, this is overcome, in the further progress of the combination it may again happen; and, in this way, compounds, in two or three determinate proportions, may be formed.

Precisely an opposite view has sometimes been maintained of chemical combination, that it is an attribute of the power of affinity itself to unite bodies in determinate proportions. And this principle has lately been applied with some novelty by Mr Dalton and Dr Wollaston. They proceed on the assumption, that when bodies combine chemically, they are disposed to unite in determinate proportions; and the combination is either a binary one, that is, consists of one atom or particle of the one body, combined with one of the other, or where the two bodies combine in different proportions, the combination in one

proportion is probably binary, and in the others in certain arithmetical relations, as that of two atoms with one, three with one, &c. With this principle Mr Dalton has connected a system, relating to the weights of the atoms of bodies, and has applied it to the explanation of the constitution of a number of chemical compounds.

Much of this system is hypothetical, and, with regard to the principle itself, it appears irreconcilable with the law of chemical affinity so well established, that bodies act chemically in the ratio of their affinity and quantity; for, if combination take place in determinate proportions, if one atom of *a* is disposed to combine with one atom only of *b*, what farther force can be gained from the presence of a number of particles of *b*? While, if bodies act in the ratio of their affinity and quantity, their power of combination, unless arrested by external circumstances, must be unlimited; for the action of a number of particles of the one body is, by the very supposition, held capable of being extended to one particle of the other, and there is no point at which it ceases to operate.

The question, therefore, rests on the evidence with regard to these principles. And from the numerous facts which support the conclusion, that quantity of matter influences affinity, there can remain little doubt of the truth of the principle itself, and of the superiority of the system which rests upon it. This system, too, accords better with the general train of chemical facts, than the opposite one, that chemical attraction has a tendency to unite the particles of bodies in determinate proportions.

Secondly, Chemical attraction observes certain limits, with regard to the number of substances which it combines together. It not only unites two substances; it frequently brings three or more into combination.

When three substances are placed within the sphere of chemical action, it often happens, either that two of them combine, to the exclusion of the third, or that one is combined with each of the others, being divided between them in proportions determined by their affinities and quantities. In some cases, however, instead of either of these varieties of combination, the three substances have their affinities balanced, in such a manner that they enter into simultaneous combination, and form only one compound. Even four, five, or perhaps more substances, may be thus combined together. Such combinations are named Ternary, Quaternary, &c. according to the number of their constituent parts.

There are numerous examples of such combinations among the metals. If three or four metals be fused together, they often unite, and form one uniform compound. There are also frequent examples of ternary combinations among the salts, one acid being saturated by the joint action of two bases. Nature, too, presents us with a number of such combinations. Nearly all the substances belonging to the vegetable kingdom are compounds of at least three principles; and the composition of the animal products is still more complicated, four or five principles being combined in their formation.

These combinations appear to take place principally where the mutual attractions, under given circumstances,

are nearly of the same force, and where the external forces of cohesion, &c. do not much interfere. Did the attraction of one ingredient to any of the others much exceed their mutual affinities, it would probably give rise to an insulated binary compound; or did the compound resulting from the union of any two of the ingredients differ much in its constitution from those formed by the others, this circumstance would determine the chemical action, and cause the separation of such a compound. But where neither of these circumstances is present, the affinities may be balanced, and give rise to one combination. Hence, probably, their formation more peculiarly in the vessels of vegetables and animals, where, from the motion and agitation to which they are subjected, the compression under which they are placed, and the smallness of the mass in which the affinities operate, the circumstances of cohesion and elasticity are in a great measure prevented from operating, and giving rise, as they otherwise would do, to binary combinations.

Sect. IV.—*Of the Forces with which Chemical Attraction is exerted.*

Bodies exerting attractions to others, exert them with very different degrees of force; and from this arises a series of important chemical changes.

From the attraction exerted by one substance to another, their combination takes place. But this attraction

may be inferior in force to the attraction which either of these substances exerts to a third body. In this case, if this body be brought to act on the compound which the others have formed, it will decompose it; the two which exert to each other the strongest attraction will combine, and the third will be separated. Hence arise an extensive series of decompositions; and hence, too, is derived the power of the Chemist to recover, in an insulated state, substances which have been combined together, as well as to obtain the principles of which natural compounds are formed.

The case now explained has been named Single Elective Attraction,—a substance combining with another apparently in preference to a third. It was usually supposed that this combination is exclusive, and that the substance which is displaced is obtained pure and insulated. In many cases, however, it has been discovered, that in conformity to the law of chemical attraction, that bodies act in the ratio of their affinity and quantity, the excluded substance retains a portion of the one with which it was originally combined; and in other cases it attracts a portion of the decomposing substance. It is only where the external circumstances, especially cohesion and elasticity, which influence chemical affinity, operate powerfully, that complete decomposition is produced.

When this difference in the relative forces of attraction was observed, it was a very obvious idea to construct tables in which they might be represented, as far as they were ascertained by experiment. This was first done by Geoffroy, a French chemist, in 1718, and since his time

the labours of many chemists have been directed towards correcting and extending these tables. Their construction is extremely simple. The substance whose attractions are to be enumerated, is placed at the head of a column, and the substances to which it has attractions are placed beneath it, in the order of their relative forces, the substance to which it has the strongest attraction being immediately under it, the others following in that order, and the one to which it has the weakest attraction of course closing the column. Thus the attractions of lime and of muriatic acid are represented in the following tables :

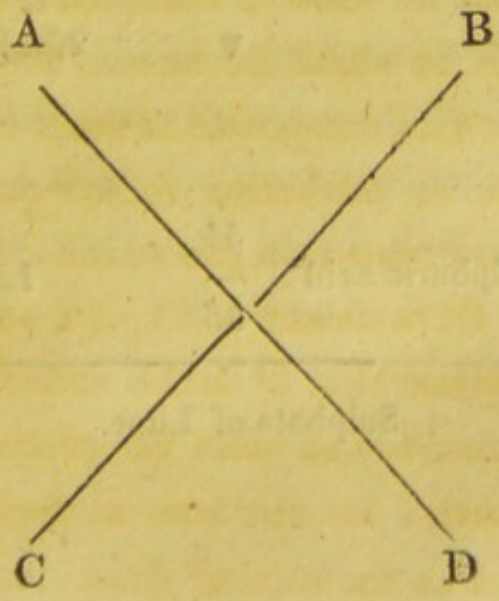
Lime.	Muriatic Acid.
Oxalic acid.	Barytes.
Sulphuric acid.	Potash.
Tartaric acid.	Soda.
Phosphoric acid.	Lime.
Nitric acid.	Ammonia.
Muriatic acid.	Magnesia.

There is another case of elective attraction, more complicated. Suppose we have a compound formed by the union of A and B, in which the force of attraction is equal to 20, and that to this compound another substance, C, is added, which has an attraction to A, equal to 16; it is evident that no decomposition can ensue. But suppose a fourth substance, D, is united to C, with an attraction equal to 7, and suppose that D has an attraction to B equal to 12, then a decomposition must be effected on mixing these two compounds; for the sum of their existing attractions is inferior to the sum of those tending to sepa-

rate them; the former, the affinity of A to B and the affinity of C to D, being equal only to 27; the latter, the affinity of C to A and of D to B, being equal to 28. A B, C, D therefore, are decomposed, and two new compounds, C A, B D, are formed.

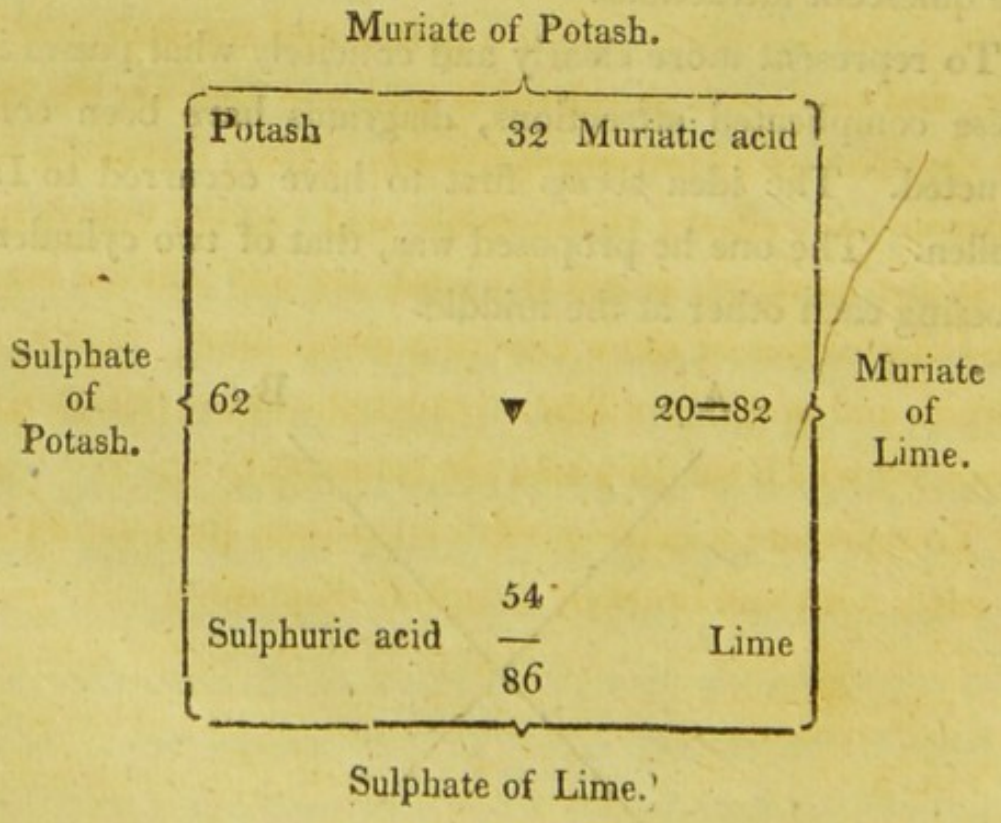
This is what is named, in the language of Chemistry, Double Elective Attraction; two elective attractions being exerted, and two new compounds formed. Of the two attractions which are exerted, the tendency of the one is to preserve the original compounds undecomposed, that of the other is to separate their principles. The former have been named by Mr Kirwan the Quiescent, the latter, the Divellent Attractions,—terms which are generally used. It is evident, that a double decomposition can only be effected, where the sum of the divellent is superior to that of the quiescent attractions.

To represent more clearly and concisely what passes in these complicated attractions, diagrams have been constructed. The idea seems first to have occurred to Dr Cullen. The one he proposed was, that of two cylinders crossing each other at the middle.



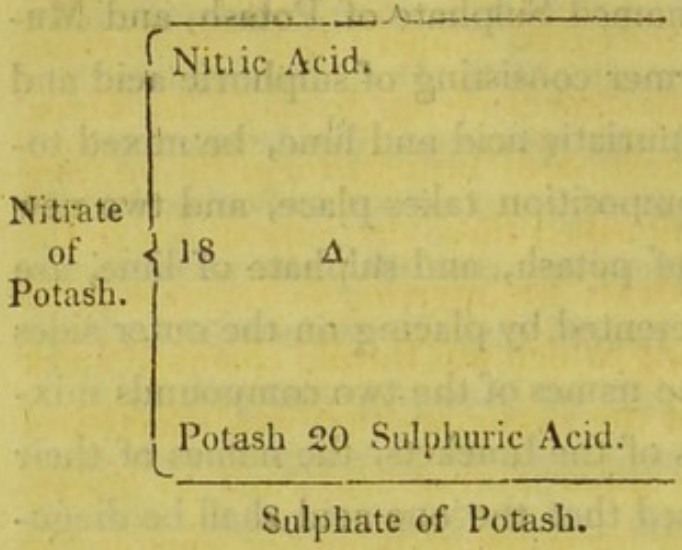
If on mixing the compounds denoted by A C, B D, the attractions of A to B, and of C to D, overcome the quiescent attractions, A C, B D; the resulting decomposition is represented, by supposing the extremities A B, C D, of the cylinders to be brought together; by which also the production of the two new compounds will be denoted by the conjunction of these letters.

The diagram proposed by Bergman, consists of two brackets connected by straight lines, forming a square, at the sides and corners of which, the names of the existing compounds, and of their ingredients, are placed; and though not conveying a more clear idea of the operation itself, is better calculated to represent all the circumstances connected with it.



Thus in the scheme which Bergman himself gives, if the two compounds, named Sulphate of Potash, and Muriate of Lime, the former consisting of sulphuric acid and potash, the latter of muriatic acid and lime, be mixed together, a double decomposition takes place, and two new compounds, muriate of potash, and sulphate of lime, are formed. This is represented by placing on the outer sides of the two brackets the names of the two compounds mixed, and at the corners of the brackets, the names of their ingredients, so disposed that the one acid shall be diagonally opposite to the other. If the numbers expressing the relative force of attractions of the principles of these compounds be also added, it will be obvious that a decomposition will ensue. If the attraction between potash and sulphuric acid equal 62, and that between lime and muriatic acid 20, the sum of the quiescent attractions will be 82. But if the attraction between potash and muriatic acid be 32, and that between sulphuric acid and lime 54, the sum of the divellent attractions will be 86. These, therefore, will operate with effect; the muriatic acid and the potash will combine together, as will the sulphuric acid and the lime; and the names of these resulting compounds, muriate of potash and sulphate of lime, are placed without the straight lines, by which the brackets are connected.

To represent a single elective attraction, the same figure is used, with one bracket, as in this diagram.



Where the quiescent attractions are superior to the divellent, and where of course no decomposition takes place, the scheme consists of two unconnected brackets, with the names of the compounds at each side, and of their ingredients at each corner; the numbers, denoting the forces of attraction, being interposed.

In these decompositions it frequently happens, that one or both of the new compounds prove insoluble, and consequently fall down. This is denoted by bending downwards in the middle, the line placed between the substance and the square, as in diagram 2, where the undermost line is bent down to shew that the Sulphate of Lime is precipitated. If one of the substances be volatilized or sublimed, the line is bent upwards in the middle, as in diagram 3, where the upper line is drawn in this manner, to shew that the Nitric Acid is volatilized. If they are neither precipitated nor volatilized, the brackets are merely connected by straight lines.

Lastly, the circumstances under which the decomposition takes place, require to be pointed out. Sometimes it is effected by the substances being dissolved by water, sometimes by the application of heat to them in the solid state. Bergman distinguished these decompositions in the humid and in the dry way, by inserting in the middle of the diagram a triangle, △, which was the old chemical mark for fire, to denote that the decomposition was effected in the dry way, or by the application of heat; and an inverted triangle, ▽, the mark for water, to point out when it was done in a watery solution. The same method is still used, the signs only having been changed, a perpendicular line | being the mark for heat, and the compound figure, ⏚, for water. To facilitate the construction of such diagrams, all the chemical agents have likewise been distinguished by particular symbols.

Such are the doctrines of single and double elective attraction, as they were delivered by Bergman, and until lately received by chemists. A different view has been given by Berthollet of these changes, which it is necessary to explain.

In Bergman's theory, affinity is regarded as an invariable force; and the decompositions ascribed to elective attraction are considered as depending on the various degrees of intensity with which this force is exerted by each body towards others. In the theory of Berthollet, the changes are referred to the operation of those circumstances by which attraction is influenced. If the substances which in any case of complex affinity act on each other be

liquid, or be soluble in the fluid, which is the medium of action, and if the compounds they form in any stage of combination have no great cohesion or insolubility, no evident change appears when they are mixed together; there is a mutual saturation, and the opposing substances remain united, forming a combination, in which the forces are balanced. But if, on any of the parts of such a combination, the force of cohesion or insolubility, or the power of elasticity operate with energy, these external forces subvert the balance, give rise to separations, and are hence the cause of the results which were ascribed to the predominance of divellent over quiescent affinities.

Thus, if four substances are presented to each other, two of which have a greater tendency to cohesion than the others, or which form a compound of sparing solubility, instead of the whole forming one combination, the two which form the insoluble compound will, from the influence of cohesion, combine together, and be separated by precipitation or crystallization, the other two remaining in combination and in solution. And if even these four substances were previously in the reverse binary combinations, the same extraneous force will cause an exchange of principles, or the phenomena which have been ascribed to elective affinities will be produced. The case is the same where three substances are presented to each other. If the combination of two of them give rise to a substance, of sparing solubility, or having a strong tendency to cohesion, this circumstance will determine their union, and the separation of the insoluble compound, instead of the ba-

lance of affinities which would otherwise have been the result.

In other cases, the power of elasticity interferes and gives rise to similar effects, especially where heat is applied. An elastic ingredient, in what has been named Single Elective Attraction, will, from this cause, be more easily displaced; and, in double elective attractions, it will determine the combination of the two opposing substances which are most disposed to assume the elastic form.

In this theory of complex affinity, as Berthollet denominates what used to be termed Elective Attraction, there is probably much that is just; and it accords well with many facts relating to these decompositions. There is still, however, some degree of doubt with regard to the principle on which it rests; and the subject would require a discussion too abstruse to be admitted into this elementary view.

There is no problem in chemistry, the solution of which would be more important, than that with regard to the absolute forces of attractions which bodies exert. That they differ in force, as exerted by each body to a series of others, is sufficiently evident; the difficulty is to discover their degrees of strength. Were these accurately known, many of the deductions of the science would rest on calculation; but the solution has hitherto been very imperfectly obtained.

Several of the methods on which the solution has been attempted, rest on false principles. Guyton, observing that different metals adhere to the surface of quicksilver with

different degrees of force, supposed that these might indicate their respective affinities to that metal,—a method not only limited as to the possibility of its execution, but inaccurate, inasmuch as the adhesion denotes merely the facility of combination, which depends as much on the cohesion of the metals as on their attractive powers. Wenzel had supposed that the quantity of a body dissolved in a given time by another, affords a measure of the force of the affinity exerted,—a principle equally defective, since the rapidity of combination depends not merely on the affinity, but on this modified by the other circumstances which influence chemical action. Neither can any results connected with the facility of decomposition of compounds afford any certain indications, since these are equally dependent on the same circumstances.

Mr Kirwan observed a connection between the affinities of bodies and the quantities of them required to neutralize the properties of other substances with which they combine; and Berthollet, correcting and extending his views, has advanced the principle, that the power possessed by a body, of neutralizing the properties of another, is the result of the strength of its affinity to that body, and may therefore be regarded as a measure of it; the affinity of any substance to another being more powerful, as a given weight of it can neutralize a greater quantity of that other. To discover, therefore, the forces of affinity, as exerted by different bodies, it is only necessary to determine the quantities required to produce neutralization in those with which they combine.

On this principle, Berthollet has indicated the order of the affinities of the principal acids, and of the bases which they neutralize; and this order is very different from that inferred from the known series of decompositions. This, indeed, is no just objection against the theory; for these decompositions arising from the operation of other forces besides that of affinity, there are no grounds to infer that they shall correspond with the real scale of the forces of attraction. There is some reason to doubt, however, whether the principle is altogether just; and, even if it were, the investigation is, in the present state of our knowledge, attended with such difficulties, that the results are far from being certain. At the end of this chapter will be found tables representing the quantities of the principal acids and bases necessary to produce reciprocal saturation.

From the observations that have been made under this and some of the other sections, it must be apparent that the relative forces of affinity, as represented in the common tables of elective attraction, are altogether inaccurate. They represent only a series of decompositions, which arise from the operation of circumstances which influence attraction, as much as from differences in the strength of attraction itself. Nor do they even express the order of these decompositions with accuracy; since the influence of quantity, which so materially modifies the results, has been neglected. They are therefore of less utility than has been believed. As they may be condensed, however, in a short space, and may sometimes be consulted, they may be added in concluding the statement of the doctrines of chemical attraction.

TABLE OF AFFINITIES.

I. OXYGEN.	Uranium
Carbon	Molybdena
Zinc	Tungster
Iron	Cobalt
Hydrogen	Antimouy
Manganese	Nickel
Cobalt	Arsenic
Nickel	Chrome
Lead	Bismuth
Tin	Lead
Phosphorus	Copper
Copper	Tellurium
Bismuth	Platina
Antimony	Mercury
Quicksilver	Silver
Arsenic	Gold
Sulphur	
Gold	III. NITROGEN.
Silver	Oxygen
Platina	Hydrogen
Muriatic Acid	
II*. OXYGEN.	IV. HYDROGEN.
Titanium	Oxygen
Manganese	Sulphur
Zinc	Carbon
Iron	Phosphorus
Tin	Nitrogen

V. CARBON.	Potash
Oxygen	Soda
Iron	Lime
Hydrogen	Ammonia
	Magnesia
VI. SULPHUR.	Zircon
Oxygen	VIII. AMMONIA, POTASH, AND SODA.
Potash	Acids
Soda	Sulphuric
Iron	Nitric
Copper	Muriatic
Tin	Fluoric
Lead	Phosphoric
Silver	Oxalic
Bismuth	Tartaric
Antimony	Arsénic
Quicksilver	Succinic
Arsenic	Citric
Molybdena	Benzoic
Tellurium	Acetic
VII. SULPHURETTED HYDROGEN.	Saccho-lactic
	Boracic
Barytes	Sulphurous
	Nitrous
	Carbonic
	Prussic

* This is Vauquelin's table of the affinities of oxygen for metals, founded on the difficulty with which their oxides are decomposed by heat.

Water
Oil
Sulphur

IX.
BARYTES.

Acids
Sulphuric
Oxalic
Succinic
Fluoric
Phosphoric
Saccho-lactic
Nitric
Muriatic
Citric
Tartaric
Arsénic
Benzoic
Acetic
Boracic
Sulphurous
Nitrous
Carbonic
Prussic
Sulphur

X.
STRONTITES.

Acids
Sulphuric
Oxalic
Tartaric
Fluoric
Nitric
Muriatic
Succinic
Phosphoric
Acetic
Arsénic
Boracic
Carbonic
Sulphur

XI.
LIME.

Acids
Oxalic
Sulphuric
Tartaric
Succinic
Phosphoric
Saccho-lactic
Nitric
Muriatic
Fluoric
Arsénic
Citric
Benzoic
Acetic
Boracic
Sulphurous
Nitrous
Carbonic
Prussic
Sulphur

XII.
MAGNESIA.

Acids
Oxalic
Phosphoric
Sulphuric
Fluoric
Arsénic
Saccho-lactic
Succinic
Nitric
Muriatic
Tartaric
Citric
Benzoic
Acetic
Boracic
Sulphurous
Carbonic
Prussic
Sulphur

XIII.
ARGIL.

Acids
Sulphuric
Nitric
Muriatic
Fluoric
Arsénic
Oxalic
Tartaric
Phosphoric
Acetic

XIV.
SILEX.

Fluoric Acid
Potash

XV.
ACIDS NITRIC & NITROUS.

Potash
Soda
Barytes
Strontites
Lime
Magnesia
Ammonia
Argil
Metallic Oxides

XVI.
ACIDS MURIATIC & OXY-MURIATIC.

The same as in No. 15.

XVII.
SULPHURIC ACID.

Barytes
Strontites
Potash
Soda
Lime
Magnesia
Ammonia
Argil
Metallic Oxides

XVIII.
SULPHUROUS ACID.

Barytes
Strontites
Lime
Potash
Soda
Magnesia
Ammonia
Argil
Metallic Oxides

XIX.
PHOSPHORIC ACID.

Lime
Barytes
Strontites
Magnesia
Potash
Soda
Ammonia
Argil
Metallic Oxides

XX.
CARBONIC ACID.

Barytes
Strontites
Lime
Fixed Alkalies
Magnesia
Ammonia
Argil
MetallicOxides

XXI.
FLUORIC ACID.

The same as in No. 19.

XXII.
BORACIC ACID.

The same as in No. 19.

XXIII.
ARSENIC ACID.

Lime
Barytes
Strontites
Magnesia
Potash
Soda
Ammonia
Argil
MetallicOxides

XXIV.
OXALIC ACID.

The same as in No. 19.

XXV.
TARTARIC ACID.

The same as in No. 19.

XXVI.
CITRIC ACID.

Lime
Barytes
Magnesia
Potash
Soda
Ammonia
Argil
MetallicOxides

XXVII.
BENZOIC ACID.

The same as in No. 26.

XXVIII.
SUCCINIC ACID.

The same as in No. 26.

XXIX.
SACCHO-LACTIC ACID.

The same as in No. 26.

XXX.
ACETIC ACID.

Barytes
Potash
Soda
Ammonia
Lime
Magnesia
Argil
MetallicOxides

XXXI.
PRUSSIC ACID.

Potash
Soda
Ammonia
Lime
Barytes
Strontites
Magnesia
Argil
MetallicOxides

XXXII.
OXIDE OF GOLD.

Æther
Acids
Muriatic
Nitric
Sulphuric
Arsénic
Fluoric
Tartaric
Phosphoric
Prussic
Fixed Alkalies
Ammonia

XXXIII.
OXIDE OF SILVER.

Acids
Muriatic
Oxalic
Sulphuric
Saccho-lactic
Phosphoric
Nitric
Arsénic
Fluoric
Tartaric
Citric
Acetic
Succinic
Prussic
Carbonic
Ammonia

XXXIV.
OXIDE OF PLATINA.

Æther
Acids
Muriatic
Nitric
Sulphuric
Arsénic
Fluoric
Tartaric
Phosphoric
Oxalic
Citric
Acetic
Succinic.

XXXV.
OXIDE OF QUICKSILVER.

Acids
Muriatic
Oxalic
Succinic
Phosphoric
Arsénic
Sulphuric
Saccho-lactic
Tartaric
Citric

Nitric
Fluoric
Acetic
Boracic
Prussic
Carbonic

XXXVI.
OXIDE OF COPPER.

Acids
Oxalic
Tartaric
Muriatic
Sulphuric
Saccho-lactic
Nitric
Arsénic
Phosphoric
Succinic
Fluoric
Citric
Acetic
Boracic
Prussic
Carbonic
Fixed Alkali
Ammonia

XXXVII.
OXIDE OF IRON.

Acids
Oxalic
Tartaric
Sulphuric
Saccho-lactic
Muriatic
Nitric
Phosphoric
Arsénic
Fluoric
Succinic
Citric
Acetic
Boracic
Prussic
Carbonic

XXXVIII.
OXIDE OF TIN

Acids
Tartaric
Muriatic
Sulphuric
Oxalic
Arsénic
Phosphoric
Nitric
Succinic
Fluoric
Saccho-lactic
Citric
Acetic
Boracic
Prussic
Fixed Alkali
Ammonia

XXXIX.
OXIDE OF LEAD.

Acids
Sulphuric
Saccho-lactic
Oxalic
Arsénic
Tartaric
Phosphoric
Muriatic
Nitric
Fluoric
Citric
Acetic
Boracic
Prussic
Carbonic
Fixed Alkali

XL.
OXIDE OF ZINC.

Acids
Oxalic
Sulphuric
Muriatic
Saccho-lactic
Nitric
Tartaric
Phosphoric
Citric
Succinic
Fluoric
Arsénic
Acetic
Boracic
Prussic
Carbonic
Ammonia

XLI.
OXIDE OF NICKEL.

Acids
Oxalic
Muriatic
Sulphuric
Tartaric
Nitric
Phosphoric
Fluoric
Saccho-lactic
Succinic
Citric
Acetic
Arsénic
Boracic
Prussic
Carbonic
Ammonia

XLII.
OXIDE OF COBALT.

The same as in NO. 41.

XLIII.
OXIDE OF MANGANESE.

Acids
Oxalic
Tartaric
Citric
Fluoric
Phosphoric
Nitric
Sulphuric
Muriatic
Arsénic
Acetic

XLIV.
OXIDE OF ARSENIC.

Acids
Muriatic
Oxalic
Sulphuric
Nitric
Tartaric
Phosphoric
Fluoric
Saccho-lactic
Succinic
Citric
Arsénic
Acetic
Prusssic
Ammonia

XLV. OXIDE OF BISMUTH.	Phosphoric	XLIX. OXIDE OF URANIUM.	LII. VOLATILE OILS.
Acids	Citric	Acids	Æther
Oxalic	Succinic	Sulphuric	Alkohol
Arsénic	Fluoric	Muriatic	Fixed Oil
Tartaric	Arsénic	Nitric	Fixed Alkalies
Phosphoric	Acetic	Phosphoric	Sulphur
Sulphuric	Boracic	Acetic	
Muriatic	Prussic	Prussic	LIII. FIXED OILS.
Nitric	Carbonic	Carbonic	
Fluoric	Sulphur	Sulphur	Lime
Saccho-lactic	XLVII. OXIDE OF TELLURIUM.	L. ALKOHOL.	Metallic Oxides
Succinic			Ether
Citric	Acids	Water	Volatile Oil
Acetic	Nitric	Æther	Fixed Alkali
Prussic	Sulphuric	Volatile Oils	Volatile Alkali
Carbonic	Sulphur	Ammonia	Sulphur
Ammonia	Alkalis	Fixed Alkalis	
	Quicksilver	Sulphur	
XLVI. OXIDE OF ANTIMONY.	XLVIII. OXIDE OF TITANIUM.	Muriates	
Acids	Acids	LI. ÆTHER.	
Muriatic	Sulphuric	Alkohol	
Oxalic	Nitric	Volatile Oils	
Sulphuric	Muriatic	Water	
Nitric	Prussic		
Tartaric			
Saccho-lactic			

To these tables may be added the tables of Kirwan, representing the quantities of the principal acids required to neutralize the alkalis and earths, and the quantities of these requisite to saturate the acids; the results in both, though not perhaps perfectly correct, being important both in themselves and in their relation to the question with regard to the forces of chemical affinity.

TABLE I.

100 Parts of	Potash.	Soda.	Ammonia.	Barytes.	Strontites.	Lime.	Magnesia.
Sulphuric Acid	121.48	78.32	26.05	200.	138.	70.	57.92
Nitrous Acid	117.7	73.43	40.35	178.12	116.86	55.7	47.64
Muriatic Acid	177.6	136.2	58.48	314.46	216.21	118.3	89.8
Carbonic Acid	95.1	149.6	— —	354.5	231.+	122.	50.

TABLE II.

100 Parts of	Sulphuric Acid.	Nitrous Acid.	Muriatic Acid.	Carbonic Acid.
Potash	82.48	84.96	56.3	105. almost.
Soda	127.68	135.71	73.41	66.8
Ammonia	383.8	247.82	171.	Variable.
Barytes	50.	56.	31.8	282.
Strontites	72.41	85.56	46.	43.2
Lime	143.	179.5	84.488	81.81
Magnesia	172.64	210.	111.35	200.—Fourcroy.
Argil	150.9	— —	— —	335.—nearly, Bergman.

A table founded on the experiments of Richter is likewise of value, from the simplicity of its construction, and its extensive power of application. It consists of two columns, one composed of the acids, the other of the alkalis and earths, with numbers annexed to each, and is thus to be understood: If an article in one of the columns be taken, suppose potash in the first, to which the number 1605 belongs, the numbers affixed to the names of the substances in the other column will show how much of each of these is requisite to saturate these 1605 parts of potash: they will require, for example, 427 of fluoric acid, 577 of carbonic acid, &c. If, again, we take an article of the second column, the first will indicate, in the same manner, how much earth or alkali will be required to neutralize it. It is easy by calculation to reduce these numbers in any case to 100 parts.

Bases.		Acids.	
Argil,	525	Fluoric,	427
Magnesia,	615	Carbonic,	577
Ammonia,	672	Sebacic,	706
Lime,	793	Muriatic,	712
Soda,	859	Oxalic,	755
Strontites,	1329	Phosphoric,	979
Potash,	1605	Formic,	988
Barytes,	2222	Sulphuric,	1000
		Succinic,	1209
		Nitric,	1405
		Acetic,	1480
		Citric,	1683
		Tartareous,	1694

BOOK II.

OF REPULSION, AND THE POWERS BY WHICH IT IS PRODUCED.

The attractions which are exerted between the minute particles of matter, are counteracted by certain forces of repulsion, and by these the arrangements and combinations to which the former give rise are modified or subverted. Their operation, therefore, is important in the production of chemical phenomena.

Of these repulsive forces, the most general in its agency is the power of Heat, or what chemists denominate Caloric. This power is present in all bodies : it is capable of being increased or diminished, and this increase and diminution are accompanied with corresponding changes in the distances at which the particles of bodies are placed. Galvanism, a principle lately discovered, likewise exerts a repulsive agency, and is even more powerful than heat in subverting chemical combination. With these agents, Light has an intimate connection. Its materiality is indeed more decidedly established, yet still it is doubtful if it exert any chemical affinities ; its particles are mutually repellent, and it is not improbable, that in producing chemical changes, it operates by the repulsion it communicates to the particles of bodies.

The materiality of all these agents has been maintained. The question, however, as it relates to some of them, is far from being determined, and they are so far peculiar, that their gravity cannot be ascertained; they can scarcely be procured insulated, nor can their combinations, if they enter into chemical union, be traced. They may therefore, without impropriety of arrangement, be regarded as general forces producing repulsion.

CHAP. I.

OF CALORIC.

Of the sensations we experience, none are more familiar than those of heat and cold. These are excited by bodies applied to the organs of sense, and with regard to this, no fact is more familiar, than that the same body excites at different times very different degrees of these sensations. The inference from this is obvious, that the power of producing the sensation does not strictly belong to the body applied, but depends on some principle or power which it contains, and which is capable of being increased or diminished; the increase or diminution of it in any particular substance being accompanied with corresponding changes in the power of producing these sensations. We thus arrive at the conclusion, that there exists a cause of heat,—a power or principle capable of

being communicated to bodies, and of being withdrawn from them. We can easily observe the transfer of it from one to another; for by bringing a cold body into communication with a hot one, the latter communicates to the former, to a certain extent, its power of exciting the sensation of warmth, losing at the same time proportionally the power it has of exciting the same sensation: and this communication may continue to be made over any number of bodies, until an equilibrium is established.

It is scarcely necessary to illustrate this by example. A piece of iron, which has been heated in the fire, if plunged into cold water, loses a portion of its heat, which the water acquires; the water may equally be deprived of this, and the power be transferred to another body.

So far the idea of the cause of heat is limited. It has been farther extended by the observation of other effects which it produces. When a body is heated, it is also expanded, or its volume is enlarged in every direction; when it is cooled, the volume is diminished; and the diminution or increase of volume bears a general proportion to the abstraction or addition of the peculiar power on which these effects depend.

It has, lastly, been proved, that when this expansion is carried to a certain extent, bodies change their forms, solids becoming liquid, and liquids being converted into vapours or airs.

These effects being thus connected, are justly considered as arising from the exertion of the same power. It has been distinguished by different appellations; as Fire,

Heat, the Matter of Heat, or the Igneous Fluid,—terms either ambiguous, or implying an hypothesis, and therefore superseded by the more unexceptionable appellation of Caloric.

By Caloric, then, is to be understood, a power present in bodies, the cause of their expansion, and of their conversion into the fluid and aëriform states, and which, when present in a certain quantity, excites in animals the sensation of heat, the sensation of cold being also the effect of its abstraction.

Some have considered this power as a peculiar subtle fluid diffused over matter, and capable of entering into every body; others have supposed all the phenomena exhibited by heated bodies to arise from a peculiar state of these bodies,—a vibratory motion, more or less violent, of their minute particles. The question on this subject will be more properly examined after the effects of Caloric have been considered. It is sufficient to remark, that whatever may be the nature of this power, its existence as the cause of certain effects is demonstrated; and these effects, their relations to each other, and the general laws according to which they are produced, may be investigated with sufficient precision, though the nature of the cause may be unknown.

Sect. I.—*Of the Distribution of Caloric, and the means of measuring Temperature.*

The state of a body with regard to its power of producing the effects which arise from the operation of caloric, is termed its Temperature. In every body the temperature depends on the quantity of caloric it contains. If, at any temperature, it contain a certain quantity, the addition of caloric raises its temperature, and its abstraction equally causes a reduction of temperature.

Some estimate may be formed of the temperature from the sensation it excites, but this is extremely defective. It is necessarily very limited with regard to the range of temperature, since, beyond a certain degree, either of heat or cold, there can be no discrimination; and it is also inaccurate, from the sensations being so much influenced by various circumstances, besides the direct cause by which they are excited.

The mode, therefore, of estimating the temperature of bodies by the expansion produced by the operation of caloric, was a valuable acquisition. On this is founded the construction of the thermometer,—an instrument of the first importance in all researches on the subject of heat. Sanctorius had observed the great expansion which air undergoes when heated, and it occurred to him that this expansion might afford a measure of the variations of temperature. The instrument he used was a hollow glass

ball with a long cylindrical stem; the open end of the stem being immersed in a liquid, and part of the air expelled from the ball, the liquid of course rises in the stem, and by its ascent or descent, as it is pressed on by the expanded or contracted air in the ball, shews the alterations of volume which the air suffers from change of temperature. This instrument is liable to be affected by variations from the atmospheric pressure: from the great expansibility of air, too, it is capable of measuring only a very limited range; from this cause, however, it is extremely sensible, and is hence sometimes used to indicate minute changes of temperature. It has been rendered much more perfect by an invention of Mr Leslie, in which two air thermometers are joined together, so as to form a curved tube with a ball at each extremity, represented fig. 17.; the elasticity of the air in one ball exactly counterbalances that of the air in the other, and the column of coloured liquid between them remains in equilibrium. But when one ball receives heat, the air inclosed in it being expanded, presses more forcibly on this liquid, causes it to descend in the stem connected with this ball, and to rise in the other. This Mr Leslie has named the Differential Air Thermometer.

The thermometer was rendered much more manageable, and capable of more extensive application, by substituting a liquid as the measure of expansion, and inclosing it in a tube hermetically sealed. Spirit of wine coloured, and quicksilver, are the liquids usually employed; the latter is the most accurate, as its expansions correspond most accurately with increments of temperature, and being

less volatile, it can measure much higher temperatures; the former again has the advantage of indicating lower temperatures, as it does not congeal even at the most intense cold hitherto observed. The instrument with either is constructed by filling a glass ball, from which a cylindrical stem of a very narrow diameter issues, with the liquid, so that it shall rise partly in the stem; the open extremity is then closed. If the ball of the instrument be placed in contact with a hot body, it receives caloric, the liquid within is expanded, and rises in the stem, the rise continuing until the thermometrical liquid attain the temperature of the matter around it. When in contact with a cold body, caloric is in like manner abstracted from it; the liquid contracts and descends in the stem; and by a measured scale attached to the stem, the rise and fall, and the precise point at which the liquid stands, indicating of course its temperature, as well as the temperature of the body applied to it, are ascertained.

A difficulty was experienced in the construction of the scale, that of rendering it uniform, so that the degrees on one instrument should correspond with those on another. This was remedied by the discovery of certain fixed points in the scale of temperature always the same, and from which the scale may be formed. The points usually taken are those at which water freezes, and at which it boils. If the thermometer be immersed in freezing water, or rather in melting snow or ice, the liquid will stand at a particular part in the stem. If it be plunged in water boiling under a mean barometrical pressure, it will rise and become stationary at another part; and however these ex-

periments be diversified, the liquid will always be stationary at these points. Now, it is obvious, that the space between them may be divided into any number of degrees; and if the instrument is graduated in this manner, the degrees in every thermometer, if the same number be observed, will always be the same; and the scale also may be prolonged in each by similar degrees below the freezing point of water, so as to denote low temperatures, and above its boiling point to express higher temperatures.

The scale thus constructed being arbitrary, different forms of it have been introduced. In this country we use generally the scale of Fahrenheit, a German artist. The space between the freezing and boiling points of water he divided into 180 degrees; but instead of commencing the numeration of its degrees at the lower point, the freezing of water, he began it still lower in the scale of temperature, or at that degree of cold which is obtained from a mixture of snow or salt. The space between this and the freezing point of water, when divided into degrees, such as those between the freezing and the boiling points, gives 32 degrees; the freezing point of water, therefore, is on this scale marked 32, and the boiling point 212°.

The scale of Reaumur is rather more simple. It commences at the freezing point of water, which is therefore marked 0, or, as it is named, zero. The space between this and the boiling point of water is divided into 80 degrees; the latter therefore is marked the 80th degree. More lately a similar scale has been introduced in France, only the space between the freezing and boiling of water is divided into 100 degrees; it is hence named the Centi-

grade scale. This last is perhaps the more natural division, and hence some of the Chemists of this country have been disposed to adopt it. Fahrenheit's scale, however, arbitrary as it is in its construction, has two very important advantages: its degrees are much smaller than those of the others, and observations with it are therefore more minute; and the commencement of its numeration being low, there is seldom any necessity of expressing degrees below this: we avoid therefore the ambiguity of negative degrees. If a new scale were attempted, we might find one perhaps uniting every advantage in taking the freezing and boiling points of quicksilver, the usual thermometrical liquid, as those from which the degrees are to be numbered, dividing the space between them into 1000 degrees. The division would thus be more simple than that of Fahrenheit: the degrees would be still smaller, without being too much so for observation; the commencement of the numeration would be lower, and it would correspond nearly with the lowest natural temperature. And although the scale was constructed in relation to these points, the actual graduation of the thermometer might still be executed in the usual manner, from the freezing and boiling points of water, it being only necessary to determine carefully with what numbers on the new scale these points correspond.

Two standard points being fixed in all these scales, it is easy to establish their correspondence. Each degree of Fahrenheit's is equal to $\frac{4}{9}$ths of a degree of Reaumur's. If, therefore, the number of degrees of Fahrenheit's, either above or below the freezing point of water, be multiplied

by 4 and divided by 9, the quotient will be the corresponding number in Reaumur's scale. To bring those of Reaumur to Fahrenheit's, they must be multiplied by 9, and divided by 4. Each degree of Fahrenheit's scale is equal to $\frac{5}{9}$ths of a degree of the centigrade scale: to find the correspondence, therefore, these numbers are to be used as in the above formula.

In employing expansion as a measure of temperature, one very essential point is to be determined, before the accuracy of the method can be admitted: it is whether the expansion and contraction correspond exactly with real increments and decrements of temperature. If a thermometric liquid, from a given augmentation of temperature, say 10 degrees, expand more at one part of the scale than at another, then the indications from its changes of volume cannot be accurate. This subject has often engaged the attention of Chemists, and the result of their researches is, that the different thermometrical liquids do not expand uniformly as the temperature rises, but in an increasing ratio, or that from a given increment of temperature they suffer a greater expansion at a high than at a low part of the scale of heat. The expansions of quicksilver are most regular, and hence it gives the most accurate indications. Even these are not perfectly so, but exceed progressively, as the temperature rises, the real temperatures. To render the thermometer, therefore, perfectly accurate, the degrees on its scale ought to be accommodated to the progressive expansion; but there is still some degree of uncertainty as to the amount of the error, and from the mode in which the scale is graduated,

its extent is less important; as the two extreme points, the freezing and boiling of water, are accurately fixed, and the amount of the error, from the progressive expansion between these, is divided among the intermediate degrees. It is greatest, therefore, at the mean degree; there it is equal, according to De Luc, to 3 degrees of Fahrenheit; according to Crawford, not more than one degree.

To measure very high temperatures, other methods must be employed. An ingenious one was proposed by Newton, founded on observing the times of cooling in a body which has been at a high heat, until the temperature to which it falls can be ascertained by a thermometer, proceeding on the assumption that the times being taken in arithmetical progression, the decrements of temperature are in geometrical progression. Various methods, too, of applying the expansions of solids to this purpose, have been contrived, furnishing different pyrometers. But the mode which has been regarded as most practicable and accurate is that afforded by the pyrometer of Wedgwood. This is founded on a singular property belonging to clay, that it contracts instead of expanding by heat, the contraction remaining permanent even when the heat has been withdrawn. To apply this a gage is employed, formed of two straight rods of brass, 24 inches long, divided so as to form a scale into inches, subdivided into tenths, and fixed on a brass plate so as to converge, the distance between them being five-tenths of an inch at one extremity, and three-tenths at the other. A small cylinder of clay is framed, so as to enter the wide end of the groove, after it has been baked by a moderate heat: when

it is exposed to an intense heat, it is contracted in volume, and of course enters farther; and the degree of heat can thus be estimated by the scale. The commencement of this scale is at the point of ignition visible in day light; which corresponds, according to Mr Wedgwood's estimate, with 1077½ of Fahrenheit; and each degree of the scale he considers as equal to 130 degrees of Fahrenheit's. There is reason to doubt if this pyrometer is accurate: it is not ascertained if the contractions of the clay are equable, and any error from this source is not guarded against by the graduation being made from certain fixed points. It is useful, however, in giving certain stages of temperature, marked by peculiar effects, as by the fusion of the different metals.

Since the employment of the thermometer, or rather of the expansion of bodies as a measure of their temperature, more just and enlarged views have been acquired of the distribution of caloric. While the property of exciting the sensation of heat was the only one by which that power was characterized, it seemed a just conclusion, that those bodies which did not excite that sensation contained none of it; and this was then the philosophical, as it is still, perhaps, the popular opinion. Its fallacy, however, is easily demonstrated.

That the sensation which bodies excite is no just indication of the quantity of caloric they contain, will be apparent from considering the manner in which these sensations are excited. The temperature of the human body is generally about 96° of Fahrenheit. When any substance at a higher temperature than this is applied to our organs,

it gives caloric to the part to which it is applied, and this excites the sensation of heat: when it is of a lower temperature, it abstracts caloric, and this gives rise to the sensation of cold. Our sensations, however, are all influenced by preceding impressions. Our body is surrounded with an air, at a temperature generally inferior to the animal temperature: it is therefore always abstracting caloric. Hence it happens, that if any substance is applied to the body inferior to its temperature, but superior to the temperature of the surrounding atmosphere, the abstraction of caloric which it produces is inconsiderable, and, compared with the impression which the air makes upon us, it seems positively warm. In general, therefore, it may be affirmed, that whatever communicates caloric to our body produces the sensation of heat, and that whatever abstracts it causes the sensation of cold; but this abstraction requires to be greater than that made by the surrounding atmosphere, in order to convey to us the sensation of positive cold.

It is to be observed too, that different bodies at the same temperature occasion different sensations, according to the rapidity with which they absorb, or give out caloric. A piece of iron at 32 feels colder than a piece of wood at that temperature, because the former abstracts caloric from the hand, or whatever part of the body touches it, more rapidly than the other.

From these circumstances, it is evident, that the sensation excited by a body is no accurate measure of the caloric it contains, and that the sensation of cold will be excited by any substance whose temperature is inferior to

that of the animal body, though that substance may, and actually does contain a large quantity of caloric.

That bodies at such a low temperature contain it, is evident from the fact that their temperatures can be still farther reduced. If the thermometer be immersed in water which is freezing, the mercury will stand at 32° on Fahrenheit's scale; but even in the cold of this climate, it falls occasionally much lower. At 32°, therefore, the mercury must have contained caloric, since it is only by the abstraction of this power that it could contract in volume, and of course descend in the scale. In northern climates it has descended to 46 degrees below 0 of Fahrenheit, or 78 below the freezing point of water. At all degrees, therefore, above this, the thermometer must have contained caloric; and even at that intense cold, of which it is difficult to form a just conception, it must have contained much caloric, since, by artificial means, a further reduction of it could be effected: And if the thermometer contained caloric at these extreme colds, all bodies must have contained it, since it is the invariable property of this power to diffuse itself, till an equilibrium of temperature is established.

Even at these low temperatures there is no reason to believe that bodies were near to being deprived of their caloric, since even then their particles must have been far from being in actual contact; and it is only by the repulsive power of caloric that these particles are kept asunder. This affords a more extensive view of the distribution of this power. A solid body is to be conceived of as consisting of a number of particles of the same nature, kept

at certain distances from each other by its agency or interposition: when a portion of caloric is withdrawn, these particles approach nearer to each other; and hence the diminution of volume that takes place. But any condensation hitherto effected, is far from that in which these particles would be in contact; nor, perhaps, is such a condensation possible.

It has farther been established, that the fluid and aëriform states of bodies are owing to the presence of caloric: and therefore, as many liquids require to be exposed to the most intense cold in order to freeze them; as there are even some which have not yet been frozen; and as the greater number of the airs have not been brought even to the liquid state, it is evident that the lowest temperature which has been produced, is far distant from that point at which caloric would be totally abstracted.

Sect. II.—*Of the Effects of Caloric.*

Caloric, by the repulsive agency it exerts, separates the particles of bodies from each other, and this operation, in progressive stages, gives rise to the three general effects of Expansion, Fluidity, and Vaporization. When a body is heated to a certain point, it becomes luminous: this state, named Ignition, is an effect apparently unconnected with the others.

Of Expansion.

When the temperature of a body is raised, its volume is enlarged in every dimension; when the temperature is reduced, it suffers contraction; and this expansion and contraction are, under a general point of view, proportional in each body to the caloric communicated or abstracted.

The expansion from a given augmentation of temperature is very different in different bodies. Generally speaking, it is greatest in those which are most rare, and which have least cohesion; hence, it is very considerable in aëriform fluids; it is less in liquids, but still it is more considerable in these than in solids.

In attending to the results more minutely, we find it to be very different in different solids, as for example in the different metals; and in these differences, we can discover little relation between the expansibility and any physical or chemical quality. It has none to the density; and the only property with which it can be connected is the fusibility; those which are most fusible suffering the greatest expansion, though to this also there are exceptions.

In liquids, the degrees of expansion from the same augmentation of temperature are not less dissimilar, and as their expansibility is greater, these differences are even more conspicuous. In general, those liquids that are most volatile are those which are most expansible. Thus, quicksilver in the rise of temperature from 50° to 100°

of Fahrenheit, is expanded about $\frac{1}{190}$ of its original volume, water $\frac{1}{113}$, and spirit of wine $\frac{1}{33}$.

It might be expected that a similar diversity would exist in the expansions of aërial fluids. Instead of this, however, it appears to be established, that the expansions of all airs are the same, from the same augmentation of temperature. This is the result of the experiments of Dalton and Guy-Lussac; the expansion, according to the former, amounting in all of them to $\frac{1}{483}$ of the volume, for each degree of Fahrenheit; according to the latter, $\frac{1}{480}$. The apparent differences which had been observed in preceding experiments appear to have arisen from small but variable quantities of water being present, which, assuming the state of vapour, added to the volume of the aëriform fluid.

Another important fact to be illustrated with regard to expansion is, that in many bodies it is progressive with regard to temperature, or is always becoming greater as the temperature rises. Hence, from a given augmentation of temperature, the expansion is greater at a high than at a low part of the scale of heat.

This is observed particularly in liquids. Thus, dividing the scale of temperature between 32° and 212° into two equal portions, the expansion in the higher portion, or from 122° to 212°, is to that in the lower, or from 32 to 122, in quicksilver, as 15 to 14, in oil as 15 to 13, in water saturated with salt as 15 to 11.6, and in alkohol as 15 to 10.9. In all these the expansibility is progressive, though in each to a different extent. The progression

becomes always more considerable too as the temperature is higher, or rather as it approaches nearer to the boiling point of the liquid.

Since there is this increasing expansion in liquids, it might be expected that it would also be found in aërial fluids. The reverse, however, appears to be the case. The expansion was even observed by Roy and Dalton to be rather a decreasing one, or to become less as the temperature rises. This apparent result, however, might be owing to the mercurial thermometer not being perfectly accurate, but indicating augmentations of temperature in the higher part of the scale less than the real augmentations; and making allowance for this, according to the correction of De Luc, already stated, the expansions of aërial fluids will be found to be precisely equable.

These apparently anomalous facts, I have endeavoured to connect and explain by the application of the following principle: Expansion is not to be considered as the result merely of the operation of caloric, but as arising from this power, prevailing so far over the force of cohesion, which, to a certain degree, always counteracts it where it exists. And considering it under this point of view, these facts may thus be explained.

The inferior expansibility of solids compared with that of liquids, must be referred to cohesion being exerted in the former with much greater force than in the latter; and the obstacle to the expansive energy of caloric being therefore more considerable: while the great expansibility of aëriform substances is evidently owing to there being no cohesion between their particles, there is therefore no resis-

tance, and enlargement of volume is produced, limited only by the pressure under which the augmentation of temperature acts.

The difference in the expansions of different solids from the same rise of temperature, is evidently to be ascribed to the various degrees of strength with which cohesion is exerted between their particles. The same cause must be assigned for the differences in the expansions of different liquids; for although in these cohesion is weak, it still exists to a certain extent, different no doubt in each. The equability in the expansions of aërial substances, must, in conformity to this view, be ascribed to the absence of the power of cohesion: there is in all of them no resistance to the operation of caloric, and hence the expansion must be simply in proportion to the rise of temperature, and must in all be the same.

Lastly, the uniformity in the expansions of aërial substances with regard to temperature, while the expansion of liquids is progressive, must be referred to the same cause. In the former, expansion is the effect merely of the operation of caloric, and must therefore be proportional to the augmentation of temperature: in the latter, it is modified by the force of cohesion, which is exerted to a certain extent: the power of this is progressively diminished as the temperature rises; the resistance therefore to the expansive power is becoming less, and hence the expansions must become greater. It follows from this view, that in solid substances the expansibility ought likewise to be progressive with regard to temperature. The fact on this point is not well ascertained, though there are some ob-

servations which appear to prove that it is so. And as the force of cohesion is so great in solids, an elevation of temperature, even to a considerable extent, can have less effect in weakening it: hence the progression may be so inconsiderable, that in the small portion of the scale that can be accurately measured, it may not be easily ascertained.

There remain to be stated some exceptions to the law, that expansion is produced by the communication of caloric.

A striking exception is in the enlargement of volume that accompanies the transition of bodies from the liquid to the solid form. This transition is occasioned by reduction of temperature: it ought therefore to be attended with diminution of volume, or, if no difference can be discovered between the temperature of the liquid, and that of the solid formed from it, at the moment of formation, there ought at least to be no expansion. The expansion, with regard to a number of substances, is however very considerable. Water in freezing expands so much as to raise a considerable weight, or even to burst metallic vessels in which it is confined. This has been supposed to arise from the disengagement by freezing of the portion of air which water holds loosely dissolved; but it takes place when this air has previously been abstracted as much as possible, by the action of the air pump. It probably depends, according to the hypothesis suggested by Mairan, on a polarity in the particles of the water, or a disposition to unite by certain sides in preference to others. It is accordingly observed, that in freezing the spiculæ of ice shoot out at a certain angle; and in consequence of this arrangement an enlargement of volume may be produced. The same phe-

nomenon is displayed by some other substances in their congelation, though not to the same extent; as by several saline solutions, sulphur, and among the metals by iron, bismuth and antimony, and it is no doubt to be referred to a similar cause.

A very singular phenomenon, however, peculiar, as far as has been discovered, to water, is expansion, not in the actual process of congelation, but for several degrees previous to the point at which the congelation commences, and of course while perfect fluidity remains. If water be cooled in a tube adapted to render sensible its changes of volume, it contracts as the temperature is reduced, until it has fallen to about 40 of Fahrenheit's scale: it then becomes stationary, and if cooled farther it expands, and continues to expand in an increasing ratio, until it freeze. If, by avoiding agitation, the freezing be prevented at the usual temperature of 32°, and the water be cooled lower than this, the expansion still continues to proceed: it has been cooled down to 20, and even to 10, and at the last temperature it had expanded as much as it would have done had the temperature been raised to 75. The same property is displayed when the freezing point of the water has been lowered, by dissolving certain salts in it; and in this case the expansion commences at about the same distance from the point at which such a solution freezes, as it does from the usual freezing point of pure water.

This singular property of water, with regard to expansion, had been observed at an early period; and Hooke suggested that it might be merely not a real, but only an apparent anomaly, depending on the contraction of the

containing vessel. The same explanation was given by Mr Dalton. The expansion of water being in an increasing ratio with regard to temperature, the contractions it suffers in cooling must always be becoming less as the temperature falls. They become at length inferior to the contraction of the containing vessel; whence apparent expansion will take place, and for the same reason this will appear to proceed in an increasing ratio as the temperature falls. It has been found, what appears to be in conformity to this view, that the apparent expansion commences at different points of the thermometrical scale, when the experiment is made in tubes of different kinds, appearing, for example, at a higher part of the scale in a metallic tube and ball, than in one of glass, the contraction which the metal suffers from reduction of temperature being greater than that of the glass.

The reality of this property in water has been established, however, by Dr Hope, by a series of experiments executed in a manner in which this source of fallacy can have no effect. Thermometers being placed near the bottom and top of a cylindrical jar containing water, he observed, that in cooling water until it arrived at 40°, the under thermometer always indicated the lower temperature; but in cooling it below 40, the reverse took place, the thermometer at the surface indicating the lower temperature,—a decisive proof, that in cooling below this point water expands, becomes therefore lighter, and ascends. Or, in reversing the experiment, by communicating heat to water which had been cooled down to 32, the thermometer at the bottom was always higher in temperature than that to-

wards the surface; the water as it became heated contracting and falling down. This continued until the temperature rose to 38°, then the arrangement was reversed, and the warmer water above this appeared at the surface. It is obvious that these experiments are liable to no fallacy from the contraction or expansion of the containing vessel; since, whatever this be, it must have operated equally on the whole column of water, and they fully establish the existence of this peculiar anomaly in water.

Can any cause be assigned for this peculiarity? Blagden suggested, that that polarity, or peculiar exertion of the attraction of cohesion which unites the particles of water in a determinate manner in congelation, might begin to operate some degrees above the point at which the actual solidification takes place, and give rise to enlargement of volume. There is reason to believe that this even happens with regard to some other substances which expand in becoming solid. Thus, if pieces of solid iron are thrown into melted iron, they at first float, from the greater density of the iron in the liquid state; but in proportion as they melt, they sink, probably from the temperature of the liquid iron being reduced by their fusion, and from this reduction being accompanied with expansion.

One other exception to the law that bodies are expanded by the action of caloric remains to be stated; it is that exhibited by clay and the pure earth, argil, which is its base, which, when heated above ignition, contracts instead of expanding as the temperature is raised, the contraction remaining permanent when the temperature is reduced. This might be supposed to depend on the dissipation of

volatile matter; but the reverse of this is established by the circumstance, that beyond a full red heat there is no loss of weight, though the contraction continues to proceed far beyond this. It is probably owing to the exertion of the attraction of cohesion being favoured by the high temperature, in consequence of which, the particles composing the mass enter into closer aggregation; and accordingly, what is in conformity to this view, a degree of hardness is acquired, greater as the heat has been more intense. Sir James Hall observed, that a similar contraction takes place in chalk heated under compression, and this is accompanied with increase of hardness.

Of Fluidity.

When a solid substance is heated to a certain temperature, the force of cohesion between its particles is so far diminished, or is so peculiarly modified, that its parts are moved easily with regard to each other, or it passes into the fluid form. By a reduction of temperature, the particles are again united so as to be subversive of this mobility, or the body returns to the solid state. These changes of form, therefore, may be regarded as depending on the relative action of caloric, and of the force of cohesion. Were cohesion only exerted, the particles of all bodies would be closely united, and all would exist in the state of greatest density and solidity. But this is counteracted by the repulsive agency of caloric, which, when in sufficient intensity, diminishes cohesion so far as to produce fluidity.

This effect, however, does not depend merely on the

force of cohesion being weakened, but also on its action being so far modified, as to give rise to a different arrangement of the particles from that which prevails in the solid state. Cohesion remains in the fluid, and it is not easy to determine to what extent; for the mobility characteristic of fluidity may be accounted for on the supposition, that the mutual action of its particles is equal in every direction at the same distance, though a strong force of cohesion is exerted between them. And that a peculiar arrangement of the particles does take place in the transition of form, is proved by the facts, with regard to the expansion bodies suffer in becoming solid,—facts inconsistent with the supposition that fluidity depends merely on a diminution in the power of cohesion. This peculiar arrangement, however, depends on the operation of caloric separating the particles to certain distances, and allowing these modifications in their mutual actions to be established. Fluidity is therefore strictly and invariably the result of the exertion of this power, and no body can be said to be more naturally liquid or solid than another. In common language, indeed, those bodies which are liquid at moderate natural temperatures, are said to be frozen or congealed when they become solid, and those which are usually solid are said to be melted when they have been rendered liquid, implying some distinction between them. But this distinction is merely relative, and depends on the different temperatures at which, from the different degrees of force with which cohesion is exerted, these states are assumed.

Though every substance would undergo the change of fluidity from the action of heat, it often happens, with re-

gard to compound substances, that they are decomposed at a lower temperature than that which is necessary to melt them. But if this decomposition be prevented, they may be fused. This is well exemplified in the fusion of chalk or limestone, by heat applied under compression, so to prevent the dissipation of the aërial matter which enters into the composition of these substances: and in this case, the aërial ingredient seems to share its facility of being acted on by caloric with the solid ingredient, and to communicate to it greater fusibility.

Fluidity differs from expansion in the circumstance that it is not progressive, but takes place suddenly, and at a precise temperature: the solid, even at one degree lower than its melting point, having no appearance denoting approaching liquefaction; and the liquid at as small a distance from its freezing point, retaining apparently unimpaired its characteristic mobility. This, however, is not universal, there being some substances which pass through an intermediate stage of softness and viscidity, of which we can even mark numerous shades.

The process of congelation is influenced by certain circumstances besides the reduction of temperature. If agitation be avoided, a liquid may be cooled a number of degrees below the temperature at which it usually becomes solid, without congealing; water, for example, can thus be cooled easily to 28°, or 25°; it has been cooled even to 15° or 10°; but the moment it is agitated when thus cooled, congelation takes place, and the temperature rises to the usual freezing point. The kind of agitation which has this effect, is rather that which produces a vibration a-

mong the particles of the liquid than that which moves the whole mass. Another circumstance, which has an important influence on congelation, is the presence of loose particles of solid matter, and especially of the same kind of matter with that which is to be congealed: thus the introduction of the smallest particle of ice into water cooled, even a little below 32°, causes it instantly to freeze.

The influence of these circumstances is to be explained by considering congelation as a species of crystallization arising from the particles of the liquid uniting in a determinate manner. Mere reduction of temperature causes the particles of the liquid to approach in that direction least favourable to the exertion of that modified attraction by which they are to be united in the solid. Agitation, by the various motions it impresses on the particles, places some of them in that direction in which they are more disposed to unite; and a solid particle, or rather a small solid mass, affords a surface whence attraction can be exerted with more effect, and which, when it does commence, will proceed rapidly through the whole mass.

During liquefaction, a quantity of caloric is absorbed without producing elevation of temperature,—an important phenomenon more strictly connected with another part of the history of caloric, and therefore to be afterwards considered.

Of Vaporization.

The term Vaporization is applied to denote that change in which a body passes into the form of vapour or air. It is the immediate effect of the action of caloric. The ex-

pansive energy of this power separates the particles of bodies to greater distances, until the force of cohesion progressively weakened is entirely overcome, and a repulsion is established between the particles. These receding from each other, the body becomes extremely rare, and highly elastic, and thus passes into what is named the Aëriform or Gaseous State.

In general, bodies pass into this state from the liquid form, and there is often a considerable range of temperature between the two stages at which these changes of form happen. In some cases, however, solids pass into the state of vapour without becoming previously liquid, though if their vaporization be prevented by pressure they suffer liquefaction.

Elasticity, or the capability of being reduced by pressure into a smaller volume, and of expanding when that pressure is removed, is the distinguishing property of bodies existing in this state. They all possess it in a high degree. A moderate compression very sensibly reduces their volume; an abstraction of external pressure is followed by a great degree of expansion. This elasticity, too, is much increased by the farther operation of caloric; hence, very moderate changes of temperature in the aëriform fluids are accompanied with very considerable changes of volume, and under high temperatures they become mechanical agents of great power, from the elastic force they exert.

Rarity is another property characteristic of this form. The particles are separated to such distances, that the portion of gravitating matter in a given volume is compa-

ratively small. So few rays of light, too, are reflected, that no impression is made on the organ of vision; hence bodies in this state are invisible, except in the example of one or two elastic fluids, which are distinguished by peculiar colour, or where, as in the atmosphere, from the largeness of the mass, some tint of colour is displayed. The vapours in condensing lose their transparency, from the union of their particles into minute globules.

The temperature at which different bodies suffer this change of form is extremely various. Some require a temperature comparatively high, and hence usually exist in the liquid or solid state. Of these some require even an intense heat: these are named Fixed, in contradistinction to those which are more easily converted into vapour, and which are hence denominated Volatile. There are still others which pass into this form at temperatures so low, that even the greatest cold which we can apply is insufficient to condense them into the liquid form.

Substances which assume the elastic form at temperatures so low as this, being incondensible by the methods we can employ, are considered as permanently elastic. In the language of modern chemistry, they are named Airs or Gases,—these two terms, strictly speaking, being synonymous, though the term Air is also sometimes used not in a generic sense, but is applied specifically to that elastic fluid which forms the atmosphere. Substances, again, which exist in the elastic form, but which, requiring a high temperature to maintain their elasticity, can be easily condensed, are named Vapours. The state in which each exists is precisely the same, and the distinc-

tion is only relative, referring to the temperature at which it is assumed.

A different view has sometimes, however, been taken of this subject. The aëriform state has been considered as natural or essential to some bodies; and when this opinion was exploded, and the principle established, that this state uniformly depends on the action of caloric, still it was supposed that in the gases, or those possessed of permanent elasticity, the combination of caloric is more intimate than in the vapours which are more easily condensed. There are no grounds for this opinion. The difference obviously depends on the temperature at which the state is assumed. If a body require a high temperature to become elastic, it will of course remain so only while that temperature is kept up; and when this is reduced, it will return to the liquid or solid form. But, if the elastic state is assumed at a temperature lower than any natural one, or than what can be reached by artificial arrangements, the body will appear permanently elastic as it occurs in nature; and if disengaged from combinations in which it exists, it will instantly assume that state. If water, instead of requiring a temperature of 212° to convert it into vapour, suffered that change at 200° below 0 of Fahrenheit, it would always have appeared to us as a permanently elastic fluid, and perfectly analogous, so far as regards its mechanical properties, to atmospheric air.

That this property of permanent elasticity is merely relative, is well established by the condensation of several of the gases, as they have usually been considered, having

been actually effected by the application of intense cold, aided by strong pressure.

On these views is established the chemical nomenclature of the permanently elastic fluids. Being regarded as composed of solid or gravitating matter existing in this form, the generic term Gas is applied to denote the form itself, and a peculiar name is assigned to the solid base of each. Thus, there is one elastic fluid named Oxygen Gas: this phrase is applied to it as it exists in the aërial form, and the term Oxygen is appropriated to its gravitating matter. This matter cannot be obtained solid in an insulated state, owing to the peculiar relation it has to caloric, but it exists concrete in many combinations, and it is only when disengaged that it assumes the elastic form. The affinities of oxygen gas and its specific properties are of course considered as depending on this base. The same nomenclature is applied to all the permanently elastic fluids.

The transition of bodies into the state of vapour is much influenced by mechanical pressure, which, resisting expansion, counteracts that enlargement of the distance between the particles at which cohesive attraction ceases to be exerted. Hence the variations in the boiling point of liquids, according to the pressure under which heat is applied to them. Water, under the usual atmospheric pressure, boils at 212°; when that pressure is withdrawn to a great extent, it boils at 180°: if, on the contrary, it be heated under increased pressure, its temperature may be much elevated; in a metallic vessel it has been heated even to 400°, and has still remained in the liquid form. Hence too, under an entire absence of pressure, every li-

quid evaporates, the quantity being less as it is less volatile. Even quicksilver, which is one of the least volatile, there is reason to believe passes into vapour in the Torricellian vacuum.

The transition into vapour is dependent thus ultimately on temperature, but it is also much influenced by pressure; and in those cases where a high temperature is required, the change is not limited to one point, but takes place more or less considerably through a considerable range, less being formed as the temperature is low, and less too as the pressure is greater. Hence the quantity of vapour which rises from a liquid is very variable under these circumstances. Mr Dalton, from an experimental investigation, found, that the vapour rising from water, and remaining in contact with it at the temperature of 212°, sustains a column of mercury 30 inches in height, or, under these circumstances, such a quantity of vapour is formed as exerts this force: at 122°, or the mean between 212° and 32, it sustains a column equal to 3.5 inches, and at 32 it is equal to .02 inches. He farther investigated the elastic forces of the vapours from other liquids, these of course being greater as the liquid is more volatile; and from these researches he concluded, that "the force of vapour from all liquids is the same at equal distances, above or below the several temperatures at which they boil in the open air;" so that the forces being known with regard to one substance, and the temperatures at which others boil being ascertained, compared with this, the vapour formed from each, measured by its elasticity, may be discovered. More lately Mr Dalton has inferred, that

all vapours in contact with their respective liquids, if these are homogeneous, increase in elastic force in geometrical progression to the temperature; the temperature, however, being measured by a scale, divided on the principle, that the expansion of the thermometrical fluid is as the square of the temperature from its freezing point,—a conclusion of course resting altogether on the truth of this assumption.

An absorption of caloric, producing no augmentation of temperature, attends vaporization, as well as liquefaction, —an important general fact, to be afterwards considered.

From the different tendencies which bodies have to pass into vapour, we are enabled to separate them from each other when they have been combined, or when they become products of chemical action; and peculiar arrangements being requisite for this purpose, constitute several chemical operations relative to vaporization, the consideration of which, with the description of the apparatus in which they are performed, belongs to this section.

When heat is applied to recover a solid substance dissolved in a fluid, without any arrangement being made to collect the fluid, the operation, which is named Evaporation, is performed in shallow vessels, which, presenting an extensive surface, proportioned to the depth of liquor, allow it to be quickly heated, and the vapour to escape without any resistance. These vessels are of glass, earthenware, or metal, according to the nature of the substances operated on, and the degree of heat which is to be ap-

plied. In chemical experiments on a small scale, basons of glass, or of Wedgwood's earthen-ware, sometimes also of silver or platina, are used, the heat being applied by the medium of a sand-bath. In pharmacy and the arts, they are more frequently constructed of iron or lead, and the heat is directly applied.

When the object is to obtain the volatile matter by evaporation, it is carried on in close vessels, constructed so as to collect and condense the vapour. This operation is named Distillation. Different kinds of distilling apparatus are employed, adapted to different purposes.

Where the process is conducted on a large scale, as in the distillation of ardent spirits, the common still, made generally of copper, is employed. The construction of this has usually been extremely faulty. Being made of a considerable depth, proportioned to its diameter, a large body of liquor is to be heated, while comparatively a small surface is exposed to the fire, and hence a waste of heat. And the tube issuing from the head of the still, and conveying the vapour into the spiral tube placed in the refrigeratory, being generally narrow, the vapour is retarded, and by its pressure on the liquor opposes the evaporation. In this country the construction of the common still has, within these few years, received great improvements, by the skilful application of the principles which regulate distillation. The height of the still of the new construction is inconsiderable, compared with its diameter, and the tube is so wide that a free escape is allowed to the vapour; the distillation is thus performed with a rapidity which would formerly have been thought impracticable.

In the greater number of chemical operations, metallic vessels are liable to be acted on, and hence glass or earthen vessels generally require to be employed in distillation. The Retort or conical bottle, the neck of which is bent at an angle of about 60 degrees A, adapted to a receiver B, (Fig. 1. Plate I.) is the most convenient apparatus of this kind. Sometimes it is convenient to have it tubulated, as in Fig. 2. A, and to have the distance between it and the receiver increased, so that the latter may be kept sufficiently cool, by an intermediate tube or adopter B. The heat is applied to it by the medium of a water-bath or sand-bath.

In some cases of distillation, the product is not entirely a vapour, which may be condensed, but there is disengaged an elastic fluid, which is incondensible. The receiver having a bent tube issuing from it, represented by C, Fig. 2. is employed in this case; the condensible part of the product is collected in the body of the receiver, and the elastic product issuing through the tube, which terminates in a vessel of water, may be collected in an inverted bottle or jar.

In certain cases, the product designed to be obtained by distillation, is an elastic fluid, not condensible by itself, but capable of being condensed by being transmitted through water. The apparatus invented by Woolfe, Fig. 3. is employed for this purpose. It consists of a series of bottles, A, B, C, D, connected with each other by bent tubes, and connected with a retort generally by the medium of an adopter. The first bottle A is designed to collect any condensible part of the product. In the other

bottles, water is placed to nearly one-half their height, represented in the figure by the dotted line, and the tube passing from the one into the other, dips into the water of the bottle into which it is inserted. The gaseous product is thus transmitted through the water, by which its absorption is promoted; and if any portion is not absorbed by the water, it passes off by the bent tube at the end, and may be collected in an inverted jar, in a trough of water. Each of the bottles except the first has a straight tube, which rises to the height of 8, 10 or 12 inches above its insertion into the bottle, and passes so far within it as to dip in the water nearly half an inch. This tube is termed the tube of safety, and the use of it is to guard against that reflux of fluid which might happen from a partial vacuum arising from condensation in any of the bottles, the air having been expelled at the beginning of the operation, and its place supplied by vapour, which is liable to condense; the consequence of this would be, that the water being more pressed on by the atmospheric air without, than by the gas within, would pass backwards from one bottle to another, by rising through the tubes, as from D to C and from C to B, and thus the whole would be mingled together. It is prevented by the tubes of safety, as, when any such partial vacuum happens, the atmospheric air is forced through the small quantity of liquid in which they are immersed, and rising into the bottles, preserves the equilibrium.

Various improvements have been made in this apparatus. One defect in it is, that we cannot have the advantage of the immersion of the tube which comes from the

first bottle A into the liquid in the second B; for as it is designed to collect the condensible product, and ought therefore to be without water, it can have no tube of safety; and hence, if the tube issuing from it dip into the liquid in the second, whenever condensation happens, from the gas ceasing to be produced, the liquor will pass backwards into it. The contrivance that has been used to obviate this, is the tube of safety of Welther, or bent tube with an additional curvature, and a spherical ball, represented Fig. 4. as intermediate between the globular receiver A, and the common Woolfe's bottle B, and connecting them. In this is put a small quantity of water, so as to rise, when the pressure without and within is equal, about half way into the ball. If the elasticity is increased in the internal part of the apparatus, during the distillation, by the production of gas, the water is pressed upwards to the funnel at the top; if there is a condensation, it is forced by the atmospheric pressure into the ball, but whenever it has passed the curvature beneath the ball, it is obvious that a portion of air must rise through it, and will pass into the globe or bottle, to the tube of which it is adapted, and preserve the equilibrium. This tube is rather inconvenient in its form, and liable to be broken, and we can employ no great pressure with it. A simpler contrivance, not liable to these inconveniences, is, having merely a spherical ball in the long leg of the common bent tube, of such a size, that when the liquid in which the extremity of the tube dips, rises into it, this extremity will no longer be immersed, but a portion of the air will

enter. The form of this is represented in the tube which comes from the bottle B, Fig. 4.

Another imperfection which attends the common Woolfe's apparatus, is the difficulty of adapting the tubes by grinding, so that it is necessary to secure the joinings by lute. I have sought to remedy this, by having a tube fixed or soldered when the bottle is made, into that orifice into which the long leg of the tube from the preceding bottle is to enter, of such a length that it is immersed in the liquor within the bottle, and the tube which enters it having a very slight curvature at its extremity, the gas which it conveys is propelled forward, rises through the water, and passes into the next bottle; and as there is no difficulty in grinding the tubes into the bottles *from* which they issue, the whole apparatus is easily constructed without the necessity of lute. There is another form of apparatus which has likewise this advantage, in which, instead of bottles, globes are employed, from which a tube issues, straight at the neck, so that it can be fitted by grinding into the neck of the globe into which it enters, but having such a curvature, that the extremity of it dips into the liquid which this globe contains. This, which is the best of these forms of apparatus, is represented Fig. 5.

A liquid obtained by distillation is sometimes not perfectly pure, or it is dilute from the intermixture of water that has been elevated in vapour along with it. By repeating the distillation of it a second or third time, it is rendered more pure and strong: and the process is then named Rectification, or sometimes Concentration.

When the product of volatilization is a substance which condenses in the solid form, the process is named Sublimation; and as such products are in general easily condensed, a simple apparatus only is required. The alembic with its capital, Fig. 18. Pl. III. is generally used. The alembic A is merely a conical shaped vessel of glass, in which the materials are put, and exposed to heat in a sand-bath, the sublimate condensing in the upper part of it, and forming a crust on its sides. The capital B is adapted to its mouth to prevent the escape of the vapour; a small groove or channel runs in the under part, terminating in a tube projecting from it, by which any liquid is collected and prevented from running down or dropping on the sides of the alembic.

A peculiar apparatus is required for operating on aërial fluids, which remains to be described.

The Pneumatic Trough is the principal part of this apparatus. It is a trough, made of wood, lined with lead, generally of an oval form, about 6 inches deep, from 20 to 24 in length, and at the greatest breadth 15 inches; a moveable shelf being placed in it, at the depth of 2 inches from the edge, in the longest direction, so as to occupy one-half of the breadth, as is represented in Fig. 7. If a glass jar be filled with water, and placed inverted on this shelf, the trough being filled with water to the edge, it is obvious that the mouth of the inverted jar being surrounded with water, the water within it will be sustained by the pressure of the atmosphere. If, while thus filled, the extremity of a retort, disengaging gas, be placed under it, as represented Fig 6. or if another inverted jar, con-

taining any air, be turned up, under the mouth of it, advanced a little over the shelf, the elastic fluid rises through the water, displaces it, and is collected in the jar; and while tne mouth of this jar continues surrounded with water, the included air cannot escape, nor will the atmospheric air find access to it. In this way, aëriform fluids can be collected, preserved, and easily submitted to experiment. Some of them, however, are rapidly absorbed by water. These must be received and kept over quicksilver; and as this fluid is expensive, and inconvenient from its weight, a smaller trough is employed, either hollowed out of marble, or of a solid block of hard wood. This is represented Fig. 8. with an addition which is convenient,—a small rod fixed in the wooden standard on which the trough is placed, which, by a ring attached to it by a sliding arm, serves to support, without any risk, the jar filled with quicksilver, and placed on the shelf.

The other principal part of the apparatus, for operating on the gases, is the Gazometer, designed to contain gases, so that measured quantities can be withdrawn. One of the most simple forms of it, and which answers sufficiently for all common experiments, is that represented Fig. 15. It is made of tinned iron, the surfaces of which are japanned, and consists of two principal parts; a vessel A, somewhat bell-shaped, which is designed to contain the gas, and a cylindrical vessel of rather greater depth, B, in which the former is placed, and which is designed to contain the water by which the gas is confined. To diminish, however, the quantity of water, this cylindrical vessel has

a cone within it, also of japanned tinned iron, C, adapted to the shape of the gas-holder, so that this latter, when pushed down, slides between this and the cylindrical vessel, and a small quantity of water fills up the space between them. The vessel designed to contain the gas, is suspended by cords hung over pulleys, to which weights are attached, so as to counterpoise it. From a stop-cock at the under part of the apparatus, D, there runs a tube under the cylinder, which rises and passes through the cone, the opening by which it passes being soldered so as to be air-tight: it terminates by an open mouth at the upper part of the bell-shaped vessel A. This tube, at the part where it is bent at right angles, to ascend as has been described, is connected with another which also runs under the bottom, and ascends on the outside, terminating in the stop-cock E, so that from the one stop-cock to the other, through the gas-holder, there is an uninterrupted passage. When the instrument is to be used, the stop-cock E is opened, and the vessel A pressed down, a sufficient quantity of water being in the outer cylinder; the air of the vessel is forced out by the pressure, and its place is occupied by the water in which it is thus immersed. When this is effected, the stop-cock is closed, and now, if we wish to introduce any gas into the apparatus, a bent funnel, the mouth of which is placed in a vessel of water, is attached to the tube of the stop-cock D, as represented in the figure, and the stop-cock is opened. If the extremity of a retort, or of a tube conveying gas, as represented in the figure, terminate below the orifice of the funnel, the gas will rise along the tube, will ascend to the top of the

gas-holder, and this being counterpoised, will, as the gas enters, rise in the water, until it is filled, a quantity of water remaining around the mouth of it, by which the air is confined. When we wish to expel the gas, the stop-cock at D is closed, that at E is opened, a flexible tube is adapted to it, and the gas-holder being pressed down, either by the hand, or by its own weight from the removal of the counterpoising weights, a stream of gas issues from the extremity of the flexible tube, and may be transferred into a jar, or be applied to any other purpose, and its quantity may be measured by the instrument being graduated by a scale marked on the brass rod F.

The instrument connected with the gazometer in the plate, Fig. 16. is a convenient one for procuring gases from any solid substance, by the application of a strong heat. It is an iron bottle A, into which is fitted, by grinding, a tube bent at an acute angle. To this a smaller tube is adapted, the extremity of which can be adjusted to various heights, by a circular joint in the middle of it, at *b*. The bottle containing the materials from which the elastic fluid is to be disengaged, is placed in a furnace, or in a common fire, so as to be raised to a sufficient heat; the gas issues at the extremity, and may be conveyed into the gazometer, or received in an inverted jar on the shelf of the pneumatic trough. At the end of the operation, the gas ceasing to be produced, as the heat diminished, the water would be pressed into the tube, and might rise into the bottle, if the joinings were not opened. The easiest way of obviating this, is by having a small stop-cock in the

tube as at *c*, which may be opened when the production of the gas has ceased.

When a gas is extricated, in consequence of chemical action, with the application only of a moderate heat, the flask or cucurbit, with a bent tube ground to it, Fig. 19. is the most convenient.

In all accurate experiments on gases, it is of importance that the quantities should be determined with precision; and as to weigh the gases requires a very delicate and complicated apparatus, and is troublesome in the execution, chemists measure them by their volumes, and find their weights by a reference to the tables of their specific gravities which have been constructed. Hence jars graduated into cubic inches and tenths are convenient, as are also, in other cases, jars graduated into equal arbitrary parts, as represented Fig. 20. In thus estimating the weights of gases from their volumes, several circumstances require to be attended to, particularly the temperature and the pressure. Elastic fluids being so expansible, it is obvious that a considerable change in their specific gravity will be made, by a trivial alteration of temperature; the volumes therefore are always reduced to the standard temperature of 54.5, at which their specific gravities are ascertained. It is also necessary to attend to the varying pressure, whether of the atmosphere, or of any fluid in which the vessel containing the gas may be placed. The weight of the gases is fixed at the mean barometrical pressure 29.85 inches of mercury; and if the atmospheric pressure vary from this, the correction by which it is reduced to the standard is to multiply the real pressure, under

which the gas is, by the volume of the gas, divide the product by the mean barometrical pressure, and the quotient is the volume under that pressure. The effect of the pressure of the fluid surrounding the jar, is most easily obviated, by bringing it, where this can be done, to the same height without and within, or if not making the necessary correction according to its height and specific gravity.

Of Ignition.

The effects arising from the operation of Caloric, hitherto considered,—Expansion, Fluidity and Vaporization, may be regarded as different degrees of one more general effect,—the increase which it occasions in the distances of the particles of bodies. Ignition, or Incandescence, cannot be referred to this cause, and it has apparently no connection with the others.

By Ignition is meant that illumination or emission of light, produced in bodies by exposing them to a high temperature, and which is not accompanied by any other chemical change. It is distinguished from combustion, a process in which there is also the emission of light and heat, by being the effect of the high temperature alone; while combustion is a process depending on the action of the air, of which certain substances only are susceptible, and which, when the process has ceased, cannot be renewed in the residual matter. Ignition is wholly independent of the air; all bodies, at least all solid and liquid substances, are susceptible of it; and if it has ceased from a reduction of temperature, it may be renewed by the temperature being raised.

Ignition appears to take place in all bodies at the same temperature. This is not far distant from 700° of Fahrenheit. Quicksilver boils at a temperature corresponding with 672° of Fahrenheit, and it, even when observed in the dark, does not while boiling appear luminous. Dr Irvine, from the heat which iron communicates to water, endeavoured to determine the temperature; the heat of a common fire he found to be about 790°; hence, the commencement of ignition must be between this and the boiling point of quicksilver. Wedgwood had fixed it at 947°, by measuring the expansions of silver in a pyrometrical gage: these being probably progressive with regard to temperature, would lead to the fixing it rather too high.

In the first stage of ignition, the red rays of light only are given out; as the temperature is raised there is an intermixture of others; and at the highest stage of ignition, there is the due proportion which constitutes white light. This continues undiminished as long as the temperature is kept up.

The aëriform fluids cannot be brought into a state of ignition, or rather cannot be rendered luminous, for at the due temperature their particles are probably ignited, but from their rarity a sufficient number of rays are not emitted from a given space to produce the sensation of vision. If a solid body be suspended in air at this temperature, it accordingly is soon rendered luminous.

Ignition is produced by friction and percusssion as well as by the communication of heat: a piece of glass, for example, can be rendered red hot by being pressed against a wheel of grit-stone made to revolve quickly; and the

spark struck from a flint by steel is a similar example. The ignition in these cases is probably produced by the high temperature which the attrition or percussion excites.

The theory of the production of ignition remains obscure; for it is not very obvious, how the raising the temperature of bodies should cause them to emit light. It has been supposed that the caloric is converted into light; but we have no proof of the possibility of this conversion, and, if it were possible, no cause is assigned, why it should take place at the temperature of ignition. A more probable opinion is, that the heat, by its repulsive agency, expels the light which the body contains; though with regard to this, also, there is the difficulty of accounting for the emission of light for an unlimited time. Where, however, the ignition is excited by the communication of heat, light is always communicated at the same time; where it is excited by attrition or percussion, it is not proved that the ignited state can be preserved indefinitely; and, if it were, there is the same difficulty in this case with regard to the unlimited evolution of caloric as of light. The subject will not be elucidated, until the relation between these two powers, at present so obscure, is better known.

Sect. III.—*Of the Communication and Diffusion of Caloric.*

All bodies are permeable to caloric, and its uniform tendency is to diffuse itself over matter, until an equilibrium of temperature is established. If a body, therefore, at a high temperature be placed in the neighbourhood of others at a lower, its excess of caloric passes off from it, until it arrive at the temperature of those around it; or, if a cold body is placed among others that are hot, it receives caloric until its temperature rise to an equality with theirs. This propagation of caloric takes place, even through the torricellian vacuum, and hence is evidently principally owing to its repulsive power, though, as it is also influenced by the nature of the medium in which it takes place, it depends, too, in part on some relation of the bodies which receive or part with it to this power.

This diffusion of caloric takes place in two modes. From a heated body a portion of caloric is always communicated to the matter in contact with it, and is diffused through that matter with a certain degree of celerity. But, besides this, a portion is projected from its surface in right lines with great velocity, and to considerable distances. The diffusion of caloric, therefore, must be considered under these two modes of radiation, and slow communication.

Of the Slow Communication of Caloric.

Caloric, when communicated by bodies to the matter with which they are in contact, is given out by them with different degrees of celerity, and is received by them with similar differences. There is a similar difference in the celerity with which it is diffused through them. Some, therefore, quickly assume the temperature of the surrounding bodies, and allow of this temperature being quickly established through their whole mass, while others do so much more slowly.

The property, in consequence of which, bodies thus receive caloric, allow it to be conveyed through their substance, and part with it to others, is named their Conducting power. Those which receive and part with caloric quickly, are those also through which it is diffused most speedily; and they are considered as better conductors than those in which the same effects are more slowly produced. In this property there are great differences, there being scarcely two bodies from or through which caloric is communicated with equal facility.

This property can scarcely be connected with any of the physical qualities of bodies. There is, indeed, a general relation between it and their density; those which are dense, as the metals, being the best conductors; and those which have much rarity conducting much less perfectly. But in examining more minutely the degrees of conducting power, we do not find that they are proportional to the densities, even among those bodies which have a similar nature, as among the different metals. In sub-

stances which are very porous, and in the interstices of which a quantity of air is lodged, the conducting power is very imperfect, which appears to be owing principally to the air being a bad conductor, and to its motion, by which it might distribute caloric more quickly, being impeded by the force with which it is retained.

It is to this cause, that the imperfect conducting power of fur, flannel, and other similar substances is owing, and on this depends their utility as articles of clothing, in preventing the abstraction of warmth.

To this difference, too, in conducting power, is owing the difference in the sensation either of heat or cold, excited by different bodies applied to our organs of sense, when the thermometer shews their temperature the same. Those which part with caloric most readily will be those which, when applied hot, will give the greatest sensation of heat; and the same bodies, being those which receive caloric most readily, will be those which, when cold, will abstract it most rapidly, and will therefore produce in greatest intensity the sensation of cold.

Many useful applications are made of this difference in conducting power, as in the various arrangements to prevent the waste of heat in chemical operations, or to guard against the effects which arise from sudden alterations of temperature.

The communication of temperature through liquids, is much accelerated by their mobility; the portion directly receiving heat having its density diminished, unless it occupy the surface changes its place; it is succeeded by another portion heated in its turn, and thus a circulation is

established through the whole mass of liquid, by which the increased temperature is much sooner established than it would be, were the caloric communicated, as in solids, merely from one particle to another.

Rumford, from some observations on the rapidity of the currents in a liquid heating or cooling, and on the slowness with which a liquid is heated or cooled when these are prevented, advanced the opinion, that it is by these motions that the uniformity of temperature in a liquid is established, and that liquids in themselves are non-conductors of caloric, or are incapable of communicating it from one particle to another. In support of this opinion, he brought forward a series of experiments designed to prove more distinctly, that when the motions of a mass of fluid are impeded, the transmission of caloric is extremely slow. He also endeavoured to establish, what would have demonstrated the truth of his opinion, that increased temperature cannot be communicated from the surface of a liquid, downwards to the rest of the mass. But, in all his experiments, the results are either inconclusive, or require so many assumptions to render them otherwise, that the opinion remained extremely problematical. The principal fact from which the question can be decided, that relating to the communication of temperature through a fluid from its upper surface, has been made the subject of experiment by various chemists, and in all of these the communication has been proved to take place. There is one source of fallacy, indeed, attending the experiment, from the conducting power of the vessel containing the liquid which may convey a portion of caloric, and com-

municate it to the under portions of the liquid. But, when this is guarded against by various arrangements, or still more effectually by making the experiment at the temperature of 32°, and in a vessel of ice, which not being capable of having its temperature raised above that point, is of course incapable of communicating any higher temperature, still the same general result is obtained, a result which sufficiently establishes the conducting power of liquids.

This conducting power, there is reason to believe, however, is not very considerable, since from the very mobility of a liquid, a particle of it, when heated, recedes from the others, and yields the caloric it had received less readily; and hence caloric is diffused through liquids, principally by the motions produced by the changes of density they suffer from changes of temperature. Still we can discover in liquids different degrees of conducting power: thus, quicksilver takes the temperature of any body with which it is in contact, and admits of this temperature being uniformly established through its mass, much more quickly than water or alkohol;—a difference which cannot be ascribed to its being more expansible or more mobile, for neither of these is the fact, and which must therefore be referred to superior conducting power,—a superiority in conformity to the general fact, that metals conduct caloric better than other substances.

A similar opinion was advanced with regard to aërial fluids,—that they also are non-conductors. It rested on observations and experiments still less conclusive than those adduced to establish the non-conducting power

of liquids; and the same conclusion that they are only imperfect conductors, is probably to be drawn with regard to them. We can even observe differences in the conducting power of different gases. Thus humid air conducts caloric better than dry air, and hence the greater sensation of cold we experience from it when at a low temperature. Mr Leslie has found, too, that bodies cool with different degrees of celerity in different elastic fluids, which he infers is owing to these having different conducting powers.

It is by the movements of fluids elastic and non-elastic, that caloric is distributed with more uniformity in nature, and that the temperature of the globe is preserved more equable than it otherwise would be. The atmosphere, when heated at the earth's surface, is expanded, becomes lighter, and recedes from it to the upper regions. An ascending current is thus formed, wherever the earth is much heated, which is replaced by cold air flowing at the surface, and this prevents that progressive augmentation of temperature which would otherwise happen. The warm air is, from the constant ascending current, propelled to colder regions, where it yields its excess of heat. A similar agency, though to a less extent, is exerted by the water of the ocean. When cooled at the surface, it becomes heavier and descends; and, from its saline impregnation, this continues to take place to a lower temperature than if it were fresh. A portion of warmer water of course ascends, and from the great depth of the ocean this circulation continues, communicating warmth, and the water at the surface does not freeze, except in latitudes where the most

intense cold prevails. From these movements it is not improbable that there is a general circulation in the ocean, as there is in the atmosphere; the water which has descended in colder regions spreading on the bottom of the sea, flows towards the equator, which must produce a current at the surface in an opposite direction, and thus the heat of the torrid zone may be moderated, as well as the cold of the polar circle.

Of the Radiation of Caloric.

Besides the caloric, which a body in cooling communicates to the matter with which it is in contact, a portion is thrown from its surface in right lines, moving with great velocity, capable of being rendered sensible at a considerable distance, and obeying the same laws of motion as the rays of light. This forms the radiation of caloric. It was observed more than a century ago, by Mariotte, and also by Lambert; and within a later period, it has been investigated by Scheele, Saussure, and Pictet, Herschel, and Leslie.

The experiment in which this radiation of caloric is best displayed, consists in placing a hot body, as a heated ball of iron, in the focus of a concave metallic mirror, opposite to which, at the distance of 10 or 12 feet, is placed a similar mirror, having the ball of an air thermometer in its focus *. The moment the hot body is introduced, the op-

* The differential air thermometer is well adapted to shew these effects, and to allow all the facts with regard to the radiation of caloric to be determined with much accuracy. It was applied to this purpose by Mr Leslie.

posite thermometer indicates elevation of temperature, the air in its ball being expanded, and pressing on the liquid so as to cause it to descend. If the hot body be withdrawn, or a skreen be interposed between the mirrors, the temperature falls, and the liquid in the thermometer rises to its former height. In this experiment, there has been projected a calorific matter from the heated body, on the surface of the mirror in the focus of which it is placed; this has been reflected in right lines from the surface of this mirror to the one opposed to it, it is again reflected from the surface of that mirror, and is collected in its focus where it produces a heating effect.

The effect is similar with a single mirror. If a hot body be placed before its concave surface, at the distance of a few feet, and a thermometer be placed in its focus, rays of caloric are projected from the hot body, and are reflected from the surface of the mirror on the thermometer, producing elevation of temperature.

That it is not the contiguity of the hot body to the thermometer that produces the effect in these experiments, is well shewn, not only by the distance at which it happens, but also by moving the thermometer a little out of the focus, even nigher to the heated surface, when its temperature, if it had been previously raised, immediately falls.

The rise of temperature produced by this radiation is greater, the hotter the body is from which it takes place. In using the apparatus of the double mirrors, and placing in the focus of one of them a ball of iron, two inches in diameter, at an obscure red heat, the elevation produced

in a thermometer, in the focus of the other mirror, at the distance of 12 feet, is equal to about 20 degrees of Fahrenheit's scale. From a glass matrass, containing about two ounces of water boiling, it does not exceed three degrees. From burning charcoal, the heat is such, that it can set fire to a burning body at the distance of several feet.

The velocity with which radiant caloric moves, is not capable of being measured at any distance at which we can make the experiment. In an experiment by Pictet, the effect appeared instantaneous at the distance of 69 feet. It appears to pass through the atmosphere without interruption; nor, according to Scheele's experiments, is its direction changed by a current of air. It is stopped, however, by liquids, even the most transparent.

Glass also intercepts a large portion of it. If a plate of clear glass be interposed half way between the two mirrors, a hot body being in the focus of the one, and the ball of a thermometer in the focus of the other, the effect on the thermometer is nearly entirely intercepted. The rays of caloric thrown on the glass, instead of passing through it, are absorbed by it. This result affords a method of separating the rays of caloric from the rays of light, when they accompany each other. Thus, if a burning candle be placed in the focus of the mirror, and a plate of glass interposed, a luminous image is formed on the ball of the thermometer in the opposite focus, from the light passing through the glass, but the calorific effect is greatly diminished, by the rays of caloric being arrest-

ed,—a fact which shews well the essential difference between radiant caloric and light.

Some bodies are more disposed to absorb radiant caloric than others, and hence are much more heated by it. Scheele observed, that when a glass mirror is used instead of a metallic one, the heat is not reflected, but is absorbed and retained by the glass; and the result is similar, if a metallic mirror have its surface blackened. Pictet found, that when the glass bulb of the thermometer is blackened, it is considerably more heated than when it is clean. But if the bulb be covered with tinfoil, the reverse happens, or the elevation of temperature is much less than when the glass bulb is opposed to the mirror.

The power of reflecting the rays of caloric is of course the reverse of the absorbing power. Metals reflect most perfectly, hence the calorific effect is greatest in these experiments when metallic mirrors are employed; it is less with a glass mirror, and is scarcely sensible when the surface is blackened. It is, for the same reason, least when the ball of the thermometer has a metallic surface, is greater when of glass, and still greater when blackened.

An important difference exists among bodies in the power of radiating caloric, the quantity thrown from different kinds of surfaces at the same temperature being very different. For the knowledge of this, we are indebted to Mr Leslie. The apparatus he employed to determine it is very simple. It is a canister of tinned iron in the form of a cube, the side being six or eight inches square; this is filled with hot water, a thermometer being

inserted in it, to shew the temperature during the continuance of the experiment. The sides of the canister are variously prepared; one, for example, is blackened, another is covered with paper, a third has a plate of glass applied to it, and the fourth is left clean. When thus prepared, it is placed before the concave surface of a mirror of tinned iron, at the distance of three or four feet; the ball of the differential thermometer being adjusted to the focus. All these surfaces being equally under the influence of the hot water in the canister, are at the same temperature, and their comparative powers, in radiating caloric at a given temperature, can be ascertained. In this respect they differ widely; as an average it may be stated, that the calorific effect from the blackened surface being 100, that from the paper is 98, from the glass 90, and from the clean metal not more than 12.

It thus appears, that those surfaces most disposed to absorb radiant caloric, when it is thrown upon them, are those likewise most disposed to radiate it when they are at a high temperature, and the absorbing and radiating property are opposed to the reflecting power.

It is an interesting question on this subject, does radiant caloric suffer refraction? This was attempted to be determined by Pictet, but the experiment was so imperfectly performed, that no conclusion could be drawn from it. Herschel found reason to conclude, that rays of caloric exist in the solar beam, apart from the rays of light, and that these are separated when the beam is decomposed, by being passed through the prism, the calorific rays being thrown beyond the red ray; this, if the experi-

ment were accurate, proved, that these calorific solar rays at least are subject to refraction. He farther submitted to experiment, the radiant caloric projected from heated bodies; and he found them to be refracted by a lens, and in the spot where they were collected by the refraction, to produce a heating effect.

Mr Leslie observed, that a considerable aberration happens in the reflection of heat; hence, when reflected from a mirror, the maximum of heat is not in the true focus, but is found to be considerably nearer to the surface of the mirror.

If the experiments of Herschel be admitted as accurate, they establish the important discovery, that radiant caloric exists in the rays from the sun, and that on this depends their heating power. In decomposing the solar beam by transmission through a triangular glass prism, it is resolved into different coloured rays, and these Herschel found were possessed of different degrees of heating power, the violet ray, which is the most refrangible, and which bounds the coloured spectrum on one side, being least powerful in exciting heat; and the calorific power, increasing towards the other side, bounded by the red ray, which far exceeds the others in heating power.

All this, however, might be considered as arising from a diversity of heating power in the visible rays of light; but Herschel farther found, that calorific rays which produce no illumination exist in the solar beam, which being less refrangible than any of the rays of light, occupy a space beyond the red ray, when the entire beam is decomposed by the prism. In this space, to the extent even of

half an inch beyond the visible light, the heating power is actually greater than in the space occupied by the red ray, which of any of the coloured rays produces the greatest heat, and it can be traced even to the extent of an inch and a half. This appears to prove the existence of rays of caloric in the solar ray, which, from being less refrangible, are capable of being separated from the visible light, and if the accuracy of the experiments be admitted, scarcely any other conclusion can be drawn. Herschel farther infers, that the heating power of the different coloured rays does not belong to the light of these rays, but depends on rays of caloric associated with them, there being, according to his hypothesis, rays of caloric as well as of light of different degrees of refrangibility, and the former being therefore spread over the space occupied by the prismatic spectrum as well as the latter. This being more intimately connected with the chemical history of Light, will be afterwards more fully considered. In one respect the calorific rays in the solar beam differ from those projected from heated bodies; they pass without interruption through transparent media: this is evident indeed from the intense heat produced in the focus of a lens when the rays of the sun have been transmitted through it. It was ascertained, too, with more accuracy by Herschel, the solar calorific rays, whether associated with light or separated from it, passing through transparent substances and producing heat; while the radiant caloric from heated bodies is almost entirely arrested.

An important subject of inquiry is still to be consider-

ed; What is the nature of Radiant Caloric, or what theory can be given of the phenomena it displays?

These phenomena appeared to prove the existence of a subtle calorific matter, projected from heated bodies, capable of moving in right lines with velocity, and obeying laws of motion similar to those of light; and this conclusion was accordingly generally drawn and received. Mr Leslie, however, advanced a different hypothesis; the apparent calorific emanation he supposed to be propagated entirely by the medium of the air. The heated surface, according to his view, communicates increased temperature to the portion of air in contact with it, this layer of air is expanded, and presses on the portion immediately before it. This is successively, but rapidly renewed; a chain of undulations is propagated from the heated surface to the mirror, reflected and concentrated in its focus, and each pulsation being accompanied, according to the hypothesis, with a discharge of the caloric by which the expansion exciting it had been produced; the whole is transported with the velocity of these undulations, and the calorific effect is obtained where they are concentrated on a solid substance. The degree of heat excited will, of course, be greater as the temperature of the surface communicating it is greater. And the diversity in the effect from different kinds of surface at the same temperature, Mr Leslie explains by the hypothesis, that they admit of a more or less perfect contact of the atmospheric air; those with which the air comes into closest contact, and this, of course, is supposed to be the case with the blackened surface, communicating the largest quantity of

caloric in a given time; and for a similar reason, the same surfaces will be those most disposed to receive caloric, and will therefore be those most heated by this kind of communication.

This hypothesis rests principally on certain facts observed by Mr Leslie with regard to the effect of skreens interposed between the hot body and the mirror on the calorific radiation. It had been observed, that when a plate of glass is interposed, the effect on the thermometer in the focus is greatly diminished. Mr Leslie found that this is much dependent on the distance at which the glass plate is placed from the heated body. In the apparatus with the single reflecting mirror, if the plate of glass be placed at about two inches from the blackened surface of the canister, a rise in the thermometer is produced equal to about one-fifth of what would be produced by the same surface, the glass being withdrawn; if farther removed from the heated surface, the effect on the thermometer diminishes, and when it is removed about a foot, it does not amount to one-thirtieth of what it is in the first position. Mr Leslie farther found that the effect was very different with skreens of different kinds; with one of paper interposed, it did not differ much from that with the glass, but if a metallic skreen was used, though extremely thin, as for example gold leaf, the effect on the thermometer was completely intercepted.

These results cannot be explained on the supposition that these skreens operate by intercepting more or less the calorific radiation, some doing so completely, others more imperfectly; for, were this the case, the action of

those which allow a certain degree of heating effect to be produced on the thermometer ought to be the same at whatever distance it is placed from the heated surface, while the fact is, that it is much dependent on its contiguity to it. They therefore, Mr Leslie conceives, establish the conclusion, that these skreens, in every case, arrest the radiant caloric, and that where any effect is produced on the thermometer, this is to be ascribed to the interposed skreen acquiring heat, and being thus enabled to display the same action as a similar radiating surface would do at the same temperature. Accordingly, when a skreen is employed which is not much disposed to receive radiant caloric on the one hand, or to radiate it on the other, as one of metal, no effect is produced; or if the skreen is such, that its temperature cannot be raised, as is the case for example with a plate of ice, there is also no effect; but, if the skreen be of a substance disposed both to absorb and radiate caloric, as in the case with glass or paper, then a certain effect will be produced, the side next to the hot body arresting the calorific radiation and having its temperature raised, and the other radiating proportional to this rise of temperature, — and this, of course, will be greater the nigher the skreen is to the heated body.

Now this effect of these interposed skreens, Mr Leslie farther conceives, can only be explained on the supposition that the air is the vehicle of the communication as already explained, the skreen arresting the chain of pulsations, and acquiring in its turn to a certain extent the power of transmitting these pulsations with the accompany-

ing discharges of caloric from the other surface; and on this assumption in a great measure rests his hypothesis.

It is one which does not appear necessarily to follow, and it is perhaps equally conceivable on the hypothesis of the existence of rays of caloric, that these may be arrested by the skreen, its temperature may be raised, and corresponding rays be projected to a certain extent from its other surface: it must, in fact, be supposed, that the interposed skreen receives caloric at the one surface, and communicates it from the other, whether the caloric be supposed to be propagated by pulsations in the atmosphere, or by actual projection of calorific particles; and in either hypothesis, those most disposed to receive it, and again to discharge it, will be those which will admit of the greatest heating effect being produced on the thermometer.

There is also some obscurity with regard to the principle of Mr Leslie's theory; for admitting, that a chain of vibrations, such as he supposes, may be established in an elastic medium from a heated surface, it is not very obvious how each pulsation should be accompanied with a discharge of the heat by which it had been excited. Or if there is any necessary connection between these events there remains the difficulty of accounting for the slow communication of caloric through elastic fluids. The theory, too, is incompatible with the results of the experiments of Herschel and Englefield; which, if they are admitted as accurate, establish the existence of a subtle calorific matter, capable of rapid projectile motion. These experiments, however, Mr Leslie considers as altogether fallacious.

It has sometimes been conceived that radiant caloric is

a species of light. Dr Hutton, assuming that the heating powers of the different species of visible light are not proportional to their power of exciting vision, supposed there might be a species of light capable of exciting temperature without exciting this sensation, and such he conceived to be the nature of radiant caloric. There appears little foundation for this hypothesis. So far as we can trace, radiant caloric has all the properties of caloric conveyed by slow communication, and the mere circumstance of its assuming a state of projectile motion, if it actually do so, is insufficient to identify it with light. It exerts none of the chemical agencies of light. And the very basis of the hypothesis is subverted; for, as is afterwards to be stated, it is uncertain if any of the rays of light apart from caloric have a heating power.

It is an interesting object of investigation, what is the relation subsisting between those two modes in which caloric is discharged from bodies, that by radiation, and that by slow communication? There appears, in general, reason to infer, that those which at a given temperature give off most caloric by communication, discharge least by radiation, and *vice versa*,—metals, for example, radiating imperfectly, while they yield caloric readily by communication, while glass is, with regard to these properties, precisely the reverse.

An inquiry of equal importance is, what proportion does the caloric discharged by radiation from a body suffering

reduction of temperature, bear to that given out by slow communication? The influence of each of these modes is established by numerous facts. That of slow communication is well shewn by the different degrees of celerity with which a body cools, according to the conducting power of the medium with which it is in contact, or according as the conducting power is favoured by frequent renewal of that medium, as, for example, by the application of a current of air, or agitation in a liquid. The influence of radiation is not less important, and has, in particular, been very clearly established by some very excellent experiments by Mr Leslie on the celerity of cooling in vessels, which radiate caloric unequally; water, for example, cooling more quickly in a tin vessel coated with lamp-black than when clean, the coating, though diminishing the conducting power, more than compensating for this by increasing the radiating power.

The proportion between the two must be considerably dependent on the temperature at which the estimate is made; for at high temperatures the cooling by slow communication will be accelerated by the more rapid current formed in the surrounding medium from the heated surface, while this can have no effect on the radiation. Mr Leslie concludes from his experiments, that at low temperatures the heat lost by the direct communication is somewhat less, and at higher temperatures considerably greater than what is lost by radiation.

The influence of these circumstances on refrigeration gives rise to some results rather singular, and to some practical applications of considerable importance. Thus

water cools more quickly in a metallic vessel, the outside of which is blackened, coated with varnish, or even covered with linen, than when clean and polished. Hence, in conducting the process of artificial refrigeration, vessels with such coatings will allow it to be performed most quickly; for the same reason, where the object is to condense vapour or steam, as, for example, in applying this condensation to procure heat, the external surface of the tubes through which the steam passes ought to be painted or blackened; while, if it is of importance to prevent as much as possible the condensation, as in conveying steam, or applying its elasticity as a mechanical power, the external surface ought to be clean and bright.

The law observed by a body in cooling, in whatever mode the caloric be given out from it, whether by radiation or communication, has been frequently a subject of investigation. The higher the temperature is, a larger quantity of caloric is given out in a given time, and, of course, the nearer a heated body approaches to the temperature of the surrounding medium, smaller portions are evolved. Newton supposed that the progression is geometrical, taking the times in arithmetical progression, and this law appeared to be established by the experiments of Kraft and Richman. Martine, on the contrary, inferred that the decrements of temperature in a body cooling are partly equable, and partly in proportion to the subsisting heats; and Mr Leslie has drawn the conclusion from his

experiments, that the rate of cooling follows a higher ratio than the difference of temperature.

A singular phenomenon connected with the radiation of caloric is the apparent radiation of cold. When a cold body, as a mass of ice, is placed in the focus of one of the mirrors, the thermometer in the opposite focus instantly suffers a reduction of temperature, greater as the cold of the body is more intense. The experiment was made at an early period by the Florentine Academicians, but it had not attracted notice until again performed by Pictet. Mr Leslie has since ascertained, that the phenomena, with regard to this apparent radiation of cold, are the same as in the radiation of heat, and the same laws are observed. It is greatest at a given temperature from a blackened surface, rather less from a surface of glass, and much less from one of metal; it is reflected by a metallic surface, but much less perfectly by a glass surface; and, in consequence of this, the frigorific effect is greatest when the bulb of the thermometer is of glass, and especially when it is blackened, while it is inconsiderable when the bulb is gilt. Hence the comparative powers of different surfaces in radiating, reflecting, and absorbing cold, are exactly the same as their powers of radiating, reflecting, and absorbing heat. The effects of interposed skreens too, Mr Leslie found to be similar. A metallic skreen completely arrests the frigorific effect, while one of glass al-

lows it to take place to a certain extent, more or less according to its proximity to the cold body.

Cold being merely the negation of heat, these results appear at first view extremely singular, and it becomes necessary to explain them in conformity to this principle. The diminution of temperature has been accordingly ascribed to the radiation of caloric from the thermometer; and in a general point of view this appears to be just, though there is some difficulty in explaining how the cold body acts in producing this radiation. Prevost supposed that there is a constant interchange of heat between bodies by radiation, the quantity radiated by each being less as the temperature is low; hence the thermometer in the focus of the mirror receives less caloric from the cold body in the opposite focus than it gives out, and its temperature falls,—an explanation liable to the difficulty of accounting for the effect of different surfaces in radiating cold; for according to the theory, the surface which radiates least caloric at a given temperature, that is, the metallic surface, ought to produce the greatest cold, while the fact is precisely the reverse. Pictet imagined, that while an equality of temperature exists among a number of contiguous bodies, the caloric is quiescent, or rather is in an equality of tension among them all, and there is no radiation from any of them, but when one is at a low temperature, caloric radiates towards it to restore the equilibrium. Hence the placing the cold body in the focus of the mirror, *causes* radiation from the bulb of the thermometer in the opposite focus, the mirrors serving to reflect it, and concentrate the effect. Mr Leslie has very happily applied his theory

of aërial pulsations to the same phenomenon,—the cold surface being supposed to abstract caloric from the contiguous layer of air, whence a momentary contraction follows, and a chain of pulsations, accompanied with discharges of heat, is established to the cold body by the medium of the mirrors from the thermometer. This hypothesis will of course be adopted only if the general theory of radiant heat depending on aërial pulsations be received.

Sect. IV.—*On the Comparative Quantities of Caloric contained in Bodies.*

Caloric has a tendency to diffuse itself over matter until it produce an equilibrium of temperature. Hence, when a number of bodies unequally heated are placed near each other, a communication of caloric takes place, until a common temperature is established.

From this tendency to form an equality of temperature, it might perhaps be inferred, that caloric diffuses itself equally over matter; that it will therefore be contained in bodies in quantity proportional to the quantity of matter, or that equal weights of different portions of matter will contain at the same temperature equal quantities of this power.

This law is observed in the distribution of caloric in homogeneous bodies, different portions of the same kind of matter containing it proportional to their temperatures

and quantities of matter; or, at least the deviation, with regard to temperature, is inconsiderable, if it even exist.

But in heterogeneous bodies a different law is observed; each contains a quantity peculiar to itself, requisite to produce its temperature; nor are there perhaps any two bodies, which, in equal weights and at equal temperatures, contain the same quantity of caloric. This was first observed by Boerhaave, with regard to quicksilver and water. The subject was prosecuted by Black, Wilcke, Irvine, and Crawford; and from their researches the general law has been established, that at any temperature, different bodies, in equal quantities, whether estimated by weight or volume, contain unequal quantities of caloric.

This truth is established, when we attend to the augmentation of temperature in different bodies exposed to a common source of heat. They are, after a certain time, raised to a common temperature; but in suffering this rise, it will be found that they have absorbed very different quantities of caloric. Supposing, therefore, that at the commencement of the experiment they contained the same quantity, they must, at the temperature to which they are elevated, contain unequal quantities. But it might equally be proved, that their quantities must have been unequal at the temperature from which they were raised; for in beginning the experiment lower in the scale of heat, they would have required unequal quantities to raise them to this; and this arising from some property in the bodies themselves, which will always continue to operate, we may conclude, that at any temperature the quantities they contain are unequal. The same conclusion is established by

communicating an equal quantity of caloric to equal quantities of two bodies at the same temperature,—water and quicksilver for example; the augmentation of temperature which this will produce will be very different in each; it will amount to 28 degrees in the quicksilver, when it is only one in the water: we infer, therefore, that water requires 28 times more caloric than quicksilver to raise its temperature, and, of course, that at a given temperature it contains a quantity so much larger.

The general form of experiment by which this truth is demonstrated, and by which also the comparative quantities of caloric that bodies contain are determined, consists in mixing together determinate quantities of bodies at different temperatures, and observing the result; for the hotter communicating a portion of its caloric to the colder, we can, from the temperature that is established in the mixture, discover how much the temperature of the one has been diminished by the abstraction of this caloric, and how much that of the other has been raised by its communication, and, of course, we discover what quantity each requires to produce a given change.

In homogeneous bodies, the temperature produced by the mixture of equal portions of them at different temperatures is always the arithmetical mean between the temperature of each; the excess of caloric which the one contains above the other being equally divided between them, and producing the same rise of temperature in the one portion, as it does of reduction of temperature in the other. But when the same experiment is made with two heterogeneous bodies, the result is different; the tempera-

ture produced never being the mean of the two original temperatures. Thus, if one pound of water, at the temperature of 156, be mixed with one pound of mercury at the temperature of 40, the temperature which results is not the arithmetical mean, 98, but is not less than 152. This proves, that the change of temperature produced in the one by a certain quantity of caloric, is entirely different from that produced in the other by the same quantity; for the water in this experiment having had its temperature reduced from 156 to 152, has suffered a reduction of only 4 degrees; but the caloric which produced these have raised the temperature of the mercury not less than 112 degrees. The quantity of caloric, therefore, necessary to raise the temperature of one pound of water 4 degrees, is sufficient to raise that of an equal weight of mercury 112 degrees; or the quantity requisite to raise the temperature of one of these fluids one degree, raises the other 28. This will be the case at every temperature; and therefore at any point in the scale of heat, the quantity of caloric contained in water is to that contained in the same weight of mercury as 28 to 1.

If the experiment is varied by mixing water at a low, and mercury at a high temperature, the result is the same. If one pound of mercury, at 156, be mixed with one pound of water at 40, the temperature produced is 44. The mercury has been deprived of a quantity of caloric, which has reduced its temperature 112 degrees, and this quantity has raised that of the water 4. In this manner, when equal weights of two different bodies are mixed together, the temperature produced is always nearer to the

temperature of that body which contains the greatest quantity of caloric, because it requires the greatest quantity to produce in its temperature any change. The proportion is also indicated by the experiment; the comparative quantities of caloric contained in the two bodies being in the inverse ratio to the change of temperature in each by their mixture. The general formula, therefore, is to multiply the weight of each body by the number of degrees between its original temperature, and the common temperature obtained by their mixture. The comparative quantities of caloric they contain are inversely as the products.

When, instead of comparing the quantities of caloric which equal *weights* of different bodies contain, we compare the quantities contained in equal *volumes*, we still find that a similar difference exists. Thus the quantity of caloric necessary to raise the temperature of a given volume of water any number of degrees, is to that necessary to raise an equal volume of mercury the same number of degrees, as 2 to 1. This is therefore the proportion between the comparative quantities of caloric which these two bodies contain, estimated by their volumes; and similar differences exist with respect to every other kind of matter. The comparative quantities of caloric in bodies are usually estimated from equal weights of them; the experiments for this purpose being more easily executed with accuracy, than those by which they are estimated from equal volumes.

In making these experiments on solid bodies, the solid, heated to a certain temperature, generally to 212°, by immersion in boiling water, is transferred into a measured

portion of cold water, and the change of temperature in each is observed. In experiments in which water would enter into chemical combination with the body submitted to trial, some other substance must be used.

The mode of ascertaining the comparative quantities of caloric in bodies by mixture, is difficult of execution so as to attain perfect accuracy, from the sources of error to which it is exposed. A certain time is required before the common temperature is established, during which, part of the heat is abstracted by the vessel, and by the external air; and this is different in different cases, being influenced by the difference of specific gravity in the substances operated on, the facility with which they mix, their conducting powers, the quantities operated on, and the agitation communicated. Hence other methods have been proposed.

The principal of these is by an instrument contrived by Lavoisier and La Place. Ice, in melting, absorbs a quantity of caloric, which does not raise its temperature; this quantity being uniformly the same, or equal to what would raise the temperature of the same weight of ice-cold water 135 degrees of Fahrenheit's scale. If, therefore, any body at a high temperature be inclosed in a sphere of ice, so that the caloric it gives out in cooling is communicated entirely to the ice, the quantity which has been given out may be inferred from the quantity of ice melted, or water produced. On this is founded the construction of the Calorimeter, represented Plate II. Fig. 10. It consists of three vessels, A, B, C, adapted to each other, and inserted the one within the other, so as to leave

a cavity between the sides of each. A is a cage of iron net-work, and is designed to contain the body which is to be subjected to experiment, which, if solid, is placed within it, heated to a certain temperature; if liquid, is inclosed in a glass matrass. The second vessel, B, is designed to contain the ice, from the melting of which the quantity of caloric given out by the body in the first vessel is to be estimated. The ice, broken into small pieces, is supported on an iron grating at the bottom, through which the water filtrates, and is conveyed off by a pipe with a stop-cock *a*, which comes from the bottom of the vessel. It has a double cover *b*, also adapted to it, capable of containing ice; the under part of this being perforated, so that the water which may be formed from the melting of any of the ice it contains may drop into the cavity itself, and can thus be collected to be measured. The third, or outer vessel, C, is similar in its construction to the second, and, like it, is to be filled with pounded ice, when the experiment is to be performed. The design of it is to prevent the agency of the external atmosphere, which, if above the temperature of 32°, would communicate caloric to the ice, and of course would contribute to its fusion, and prevent us from considering the quantity of water produced as a measure of the quantity of caloric which the hot body had given out; or if below 32°, it would abstract caloric, and lessen the quantity that would otherwise be melted. This is obviated, by placing pounded ice in the outer vessel, with a portion of water, the middle vessel being thus surrounded with a medium at the temperature of 32°. It has a double cover D, containing pounded ice,

and a tube and stop-cock, by which the water, when it accumulates, can be withdrawn.

This method is free from those sources of error to which the mode by mixture is liable. But it is exposed to others, which render its accuracy doubtful. It is difficult to estimate the quantity of water produced from the fusion of the ice; for a portion of it is retained by capillary attraction in the interstices of the mass; and from some observations, it appears, that a portion of the water produced in the upper part of the apparatus, in filtrating through the ice beneath, is again congealed, probably from the influence of the force of cohesion exerted from the surfaces of the fragments of ice.

The comparative quantities of caloric in bodies have been attempted to be estimated from observing the times equal volumes of them require to cool through a certain interval of the thermometric scale, the times being as their quantities estimated by the volume, and, if divided by the specific gravity of the substance operated on, as estimated by the weight. But the principle of this method appears not quite correct, the times of cooling being influenced by other circumstances, and particularly by the conducting and radiating power.

Some methods, too, have been proposed peculiar to the aërial fluids. The difficulties in ascertaining the quantities of caloric, corresponding with the changes of temperature in these by mixture, are extremely great, from the smallness of the quantity we can operate on, compared with the volume the air occupies. In the mode by the calorimeter, the errors from this source are some-

what diminished, from the quantity operated on being larger; the aërial fluid being passed through the instrument by a spiral tube, the temperature as it enters and passes out being ascertained by thermometers. But still the results are probably considerably remote from accuracy. Mr Leslie observed, that when a portion of air is rarified in a vessel, and time is allowed for its recovering the temperature of the surrounding medium, on admitting suddenly another portion of air into the partial vacuum, the rarified air is compressed; it hence gives out a quantity of caloric, and this, communicated to the air which has been admitted, raises its temperature. But the rise will be less, as this air requires more caloric to produce in it a given change of temperature; and therefore in operating on different aërial fluids, the comparative quantities may be discovered from the respective elevations of temperature. The method is extremely ingenious, but attended with considerable difficulties in the execution, so as to attain accurate results.

The property by which different bodies contain their respective quantities of caloric, has been termed the Capacity for Heat, or, adapting the expression to the modern nomenclature, the Capacity of a body for Caloric. This term is not designed to imply any theory with regard to the cause of this property, or the nature of it; nor does it present, as has been alleged, a vague or obscure idea. It is simply a general expression, to denote the property, in consequence of which, bodies contain at any given temperature, in equal quantities, peculiar quantities of caloric. That they do so is unquestionable, and it is convenient to

have a general term by which this can be expressed. The quantity contained in a body, and peculiar to it, has been named their Comparative, or their Specific heat. The phrase Specific Caloric is generally adopted.

What the nature of this property is, or from what cause different bodies require different quantities of caloric, to produce in them temperature to the same extent, is not easily determined. It is in general true, that bodies which are rare, have capacities for caloric greater than those which are more dense. It is even found, that we augment the capacity by diminishing the density of any body; the rarefaction of an aërial fluid, for example, in which this can be done to the greatest extent, being attended with a reduction of temperature from enlargement of capacity, and its condensation being followed by the opposite result. In liquids or in solids, condensation is likewise accompanied with a similar change from the same cause. But, although there is this general connection between the rarity of a body, and its capacity for caloric, it is not invariable or proportional; if it were, indeed, the quantities of caloric contained in bodies at given temperatures would be as their volumes,—a law which is far from being observed.

There must, therefore, be some other cause by which this is modified. If we regard caloric as a material substance subject to attraction, the attraction exerted to it by the substance in which it is contained might be supposed to be the cause modifying the law, which would otherwise be observed in its distribution, and by which, in consequence of its perfect elasticity, it would be contained in

bodies, in quantities proportional to the void spaces between their particles. But the relations of this agent are so imperfectly known, that no theory in which we can place much confidence can be given, and the fact must merely be stated as an ultimate one, that bodies require specific quantities of caloric for the production of temperature.

A question of some interest is, whether the peculiar relation of each body to caloric is the same at all temperatures; in other words, are their capacities for it uniform and permanent. It is possible this may not be the case; but that the rise of temperature itself, and the effects by which it is accompanied, may give rise to a change in the relation, so that a greater or less quantity of caloric may be required to produce a given rise of temperature, at a high than at a low part of the scale of heat. When the mechanical condition of a body is changed, when it passes to the fluid or aëriform state, this change of capacity actually happens. Does a similar change, though less perceptible at any particular stage, happen from the progressive expansion to which elevation of temperature gives rise?

The experiment by which this has been attempted to be determined, consists in mixing equal portions of the same body at different temperatures: if the capacity is permanent, the resulting temperature ought to be the arithmetical mean; for the hotter portion communicating the half of its excess of caloric to the colder, the one, if the capacity is the same in each, ought to suffer just as great a reduction as the other sustains an elevation

of temperature? But if the one portion had a greater capacity than the other, then the change it suffers must be less considerable, and the resulting temperature must approach nearer to its temperature than to that of the other, and of course deviate from the mean. The experiment is difficult of execution, so as to attain perfect accuracy, especially as no great range of temperature can be submitted to experiment, and as the difference in capacity, therefore, if it exist, cannot be expected to be great. Dr Crawford from his experiments was disposed to conclude, that the capacities of bodies are permanent; but he perhaps was somewhat influenced in drawing this conclusion by theoretical views. It appears to be more probable from theory, that the capacity should be progressive with regard to temperature, or should be greater in the higher than in the lower portions of the scale of heat; for this property is unquestionably to a certain extent connected with the density of bodies, being under a general point of view greater as they are less dense, and being increased in any body when its volume is enlarged; and, as rise of temperature is accompanied with enlargement of volume, this may be expected to give rise to augmentation of capacity. In any interval of temperature which we can measure this may not be considerable; but considered in relation to the whole scale, we cannot conjecture its amount, for we know not the extent of expansion from the commencement of the scale.

There is even reason to doubt if the permanence of capacity be established within the range of temperature at which bodies can be easily submitted to experiment. The

conclusion of Crawford rested very much on the previous assumption of the accuracy of the thermometer, and is invalidated if the expansions of the thermometrical liquid are progressive with regard to temperature, as this would counterbalance the effect from enlargement of capacity, if this happened, and give rise to an adjustment whence the effect of neither might be apparent. And, with regard to some bodies, it is ascertained, even by Crawford's own experiments, as well as by those of Gadolin, that the capacities are not permanent, but increase with the temperature, rendering therefore more probable the conclusion that this is a general result.

The law with regard to the distribution of caloric in bodies is of the first importance, as giving the theory of changes of temperature from chemical action. Combination is almost invariably attended with a change of capacity, the capacity of the compound not being the mean of the capacities of the bodies combined. When it is greater the temperature falls; when it is less the temperature is raised. On this principle are explained the production of heat in combustion, in respiration, and in a number of chemical combinations, and the production of cold in the solutions of salts in water, and in what are denominated freezing mixtures.

From the nature of the methods by which the quantities of caloric which bodies contain are ascertained, it is evident that we discover the comparative, not the absolute quantities. We find only how much caloric a body gives out, or absorbs, during a certain change of temperature; and by observing the change of temperature which the

body from which it has received, or to which it has given caloric, suffers, we may ascertain the comparative quantities necessary to produce equal changes of temperature in these bodies. But we do not learn the proportion which the quantity in each bears to the whole caloric which it contains; and therefore the capacities of different bodies are to be considered as merely comparative. Hence it becomes necessary to fix on one body as a standard to which the others may be referred. Water has been chosen as this standard; its capacity is stated at the arbitrary term of 1000, and with this the capacities of other bodies are compared. Thus the capacity of arterial blood is stated at 1030, indicating, that if at any temperature a certain quantity of water contain 1000 degrees of caloric, the same quantity of arterial blood at the same temperature will contain 1030 degrees. The capacities are usually referred to equal weights, not to equal volumes of bodies; but the latter are easily found, by multiplying the number expressing the specific caloric of any body estimated by its weight, by the number which denotes the specific gravity of the body; the product is the specific caloric estimated by the volume.

In the following table, the capacities of a number of bodies are stated as ascertained by Crawford, Irvine, Wilcke, Gadolin, Kirwan, Lavoisier, La Place and Dalton,—the initial letter annexed to each denoting the authority. I have inserted those only which have been ascertained by the method of mixture or by the calorimeter, those determined by other methods being more doubtful. I have also omitted several ascertained by the method

of mixture which still appear doubtful or unimportant. Where any difference in the capacity of the same substance, as ascertained by different experimenters, exists, this is pointed out by a reference to the different numbers. The table is subdivided, according as bodies exist in the aërial, the liquid, or the solid form, their capacities being different in these different states.

TABLE OF CAPACITIES.

Gases.

1 Hydrogen gas, - -	21.4000 C.
2 Oxygen gas, - - -	4.7490—
3 Atmospheric air, - -	1.7900—
4 Aqueous vapour, - -	1.5500—
5 Carbonic acid gas, - -	1.0454—
6 Nitrogen gas, - -	.7936—

Liquids.

7 Alkohol, (12, 34) - -	1.0860 K.
8 Arterial blood, - -	1.0300 C.
9 Water, - - -	1.0000
10 Milk, - - -	.9999 C.
11 Solution of mur. of soda, 1 in 10 of water,	.9360 G.
12 Alkohol, (7, 34) - - -	.9300 Ir.
13 Sulphuric acid, diluted with 10 of water,	.9250 G.
14 Solution of muriate of soda in 6.4 of water,	.9050—
15 Venous blood, - - -	.8928 C.
16 Sulphuric acid, with 5 parts of water, -	.8760 G.
17 Solution of muriate of soda in 5 of water,	.8680—
18 Nitric acid, (30) - - -	.8440 K.
19 Solution of muriate of soda in 3.33 of water,	.8208 G.
20 ——— nitrate of potash in 8 of water,	.8167 L.
21 ——— muriate of soda in 2.8 of water,	.8020 G.
22 ——— muriate of soda saturated, or in 2.69 of water, - -	.7930 G.

23	Colourless sulphuric acid, (41, 43, 44, 45)	.7580 —
24	Sulphuric acid, with 2 parts of water,	.7490 G.
25	Solution of sulphate of soda in 2.9 of water,	.7280 —
26	Olive oil,	.7100 —
27	Water of ammonia, specific gravity, 0.997,	.7080 —
28	Muriatic acid, specific gravity 1.122,	.6800 —
29	Sulphuric acid, 4 parts with 5 of water,	.6631 L.
30	Nitric acid, specific gravity 1.29895, (18)	.6613 —
31	Mixture of nitric acid with lime, $9\frac{1}{3}$ to 1,	.6189 —
32	Sulphuric acid, with an equal weight of water,	.6050 G.
33	——————— 4 parts with 3 of water,	.6031 L.
34	Alkohol, (7, 12)	.6021 C.
35	Nitrous acid, specific gravity 1.354,	.5760 K.
36	Linseed oil,	.5280 —
37	Spermaceti oil,	.5000 C.
38	Sulphuric acid, with $\frac{1}{2}$ of water,	.5000 G.
39	Oil of turpentine, (42)	.4720 K.
40	Sulphuric acid, with $\frac{1}{4}$ of water,	.4420 G.
41	Sulphuric acid, (23, 43, 44, 45)	.4290 C.
42	Oil of turpentine, (39)	.4000 Ir.
43	Sulphuric acid, concentrated and colourless, (23)	.3390 G.
44	——————— specific gravity 1.87058,	.3345 L.
45	——————— (23, 41)	.3330 Ir.
46	Spermaceti melted,	.3200 —
47	Quicksilver, specific gravity 13.30,	.0330 K.
48	—— ——	.0290 L.
49	———	.0290 W.
50	———	.0280 Ir.

Solids.

51	Ice,	.9000 K.
52	——	.8000 Ir.
53	Beef of an ox,	.7400 —
54	Rice,	.5060 C.
55	Pease,	.4920 —
56	Wheat,	.4770 —
57	White wax,	.4500 G.

58	Quicklime, with water, 16 to 9, -	.4391 L.
59	Barley, - - -	.4210 C.
60	Oats, - - -	.4160 —
61	Charcoal of birch-wood, (67) -	.3950 G.
62	Quicklime, (72, 74) - -	.3000 D.
63	——— saturated with water, and dried,	.2800 G.
64	Pit-coal, - - -	.2800 D.
65	——— - - -	.2777 C.
66	Chalk, (68, 75) - - -	.2700 D.
67	Charcoal, (61) - - -	.2631 C.
68	Chalk, (66, 75) - - -	.2564 —
69	Sea-salt, (73) - - -	.2300 D.
70	White oxide of antimony washed, -	.2272 C.
71	Oxide of copper, - - -	.2272 —
72	Quicklime, (62, 74) - -	.2239 —
73	Muriate of soda in crystals, (69) -	.2260 G.
74	Quicklime, (62, 72) - -	.2168 L.
75	Chalk, (66, 68) - - -	.2070 G.
76	Crown glass, - - -	.2000 Ir.
77	Agate, specific gravity 2648, -	.1950 W.
78	Flint-glass, specific gravity 287, (81) -	.1900 D.
79	Sulphur, - - -	.1900 —
80	——— (84) - - -	.1890 Ir.
81	White glass, specific gravity 2.886, (78)	.1870 W.
82	White clay burnt, - -	.1850 G.
83	Black lead, - - -	.1830 —
84	Sulphur, (79, 80) - -	.1830 K.
85	Oxide of antimony, - -	.1666 C.
86	Iron, (89, 91, 92, 95) - -	.1450 Ir.
87	Oxide of zinc, - - -	.1369 C.
88	White cast iron, - - -	.1320 G.
89	Iron, - - -	.1300 D.
90	White oxide of arsenic, - -	.1260 G.
91	Iron, (86, 89, 92, 95) - -	.1269 C.
92	Iron, specific gravity 7876, - -	.1260 W.
93	Hardened steel, - - -	.1230 —
94	Steel softened by fire, - -	.1200 —

95	Soft bar iron, specific gravity 7.724, (86, 89)	.1190 G.
96	Brass, specific gravity 8356, (98) -	.1160 W.
97	Copper, specific gravity 8.785, (99) -	.1140 W.
98	Brass, (96) - - -	.1123 C.
99	Copper, (97) - - -	.1111 —
100	Sheet Iron, - - -	.1099 L.
101	Zinc, specific gravity 7154, (107) -	.1020 W.
102	—— - - -	.1000 D.
103	Nickel, - - -	.1000 —
104	White oxide of tin, - -	.0990 C.
105	Hammered copper, specific gravity 9150,	.0970 G.
106	Oxide of tin, (104) - -	.0960 K.
107	Zinc, (101) - - -	.0943 C.
108	Sublimed arsenic, - -	.0840 G.
109	Silver, specific gravity 10.001, -	.0820 W.
110	Tin, (115) - - -	.0704 G.
111	Yellow oxide of lead, - -	.0680 —
112	White lead, - - -	.0670 —
113	Antimony, - - -	.0645 —
114	——— specific gravity 6107, -	.0630 W.
115	Tin, specific gravity 7380, (110) -	.0600 W.
116	Red oxide of lead, - - -	.0590 G.
117	Gold, specific gravity 1904, -	.0500 W.
118	Vitrified oxide of lead, - -	.0490 G.
119	Bismuth, specific gravity 9861, -	.0430 W.
120	Lead, specific gravity 1145, -	.0420 W.
121	—— - - -	.0352 C.

Sect. V.—*Of the Quantities of Caloric which Different Forms of the same Body contain.*

Besides the general law which has been demonstrated, that different bodies, in equal weights and at equal temperatures, contain unequal quantities of caloric, it has further been established, that a similar law exists with respect to the same body in its different states of aggregation: a body in the fluid form contains more caloric, or requires a larger quantity to produce a given change of temperature in it, than it does while solid; and in the state of air or vapour, it requires still more caloric than it does in the liquid form. Hence, when a solid is melted, or a liquid is converted into vapour, a quantity of caloric is absorbed, which has no effect in producing augmentation of temperature. This gives rise to the phenomena of what has been denominated Latent Heat, for the discovery of which we are indebted to Black.

The truth of the fact is sufficiently evident, when the phenomena attending liquefaction and vaporization are attentively examined. When caloric is communicated to a solid body, increase of temperature is produced, and this continues to proceed while the caloric continues to be added, until the body arrives at its melting point: but whenever it begins to melt, the rise of temperature ceases, though the addition of caloric be continued as before; and the fluid, as it forms, remains at one point until the fusion is completed. In this case, then, it is evident, that

a quantity of caloric disappears; for it continues to be added to the body, but has no effect in raising its temperature. The case is the same when a liquid is converted into vapour. Its temperature is first raised to the point at which it begins to boil, by the communication of caloric; but though the communication be still continued, the temperature, neither of the fluid which is evaporating, nor of the vapour rising from it, is farther raised, but remains stationary at that degree in the thermometrical scale at which the conversion into vapour commenced, until the whole be evaporated. It is evident, therefore, that in this case also a quantity of caloric is absorbed by the vapour formed, which has no effect in raising its temperature. The liquid or vapour, after it is formed, has its temperature raised by additions of caloric.

It was from considering these facts, that Dr Black concluded, that during liquefaction and vaporization a quantity of caloric is lost, becomes latent, or passes into the body without raising its temperature,—a conclusion which he established by very simple but decisive experiments, affording an admirable example of chemical research.

To prove it with regard to liquefaction, he placed equal portions of water in two vessels, cooling the one portion to 32°, and causing the other to freeze, but taking care that the ice should not be lower than this temperature. They were equally exposed to an atmosphere somewhat warmer, from which of course they received heat,—the temperature of the water soon rose, and, at the end of half an hour, the rise amounted to 7°. But the temperature of the ice remained stationary at 32, though it must have received caloric equally with the other. It merely began to

melt; it continued to do so slowly, and for its entire fusion 10¼ hours were required, during which its temperature continued the same. Now, judging from the rise of temperature which the water had sustained in half an hour, and assuming, what there can be no doubt of, that the ice received caloric equally with the water, in the time required to melt it, it must have absorbed a quantity of caloric equal to what would have raised the temperature of the same weight of water 139°, yet it suffered no augmentation of temperature. This result was confirmed by an experiment made in a different manner, in which the disappearance of a large portion of caloric is rendered still more striking,—adding a given weight of ice at 32° to the same weight of water at the temperature of 172. The ice was melted, but the temperature of the whole liquid was only 32; a quantity of caloric, therefore, which raised the temperature of water 140°, had in this, as in the former experiment, disappeared.

The caloric thus absorbed by ice in melting, Dr Black found is again given out when water is congealed. This, he observed, is evident from the temperature of freezing water being stationary at 32°, though the temperature of the surrounding medium may be much lower than this; the water, as it passes to the solid state, giving out the caloric it had absorbed when it was formed: whatever may be the celerity of the freezing from the cold of the surrounding medium, the evolution of caloric must always be proportional to it, and hence the temperature cannot be reduced until the whole is congealed. The temperature of the ice will then fall to that of the matter around it.

This evolution of heat in congelation, Dr Black rendered more sensible by direct experiment. Having added a little salt to a portion of water, so as to enable it to sustain reduction of temperature below 32° without freezing, he exposed it, with a similar portion of water in another vessel, to a cold atmosphere. Both were cooled with regularity to 32°; but at this temperature the pure water remained stationary, while that with the salt dissolved in it continued to fall lower; the former must equally have suffered an abstraction of caloric with the latter, but caloric being evolved from its congelation prevented its fall. In another experiment, Dr Black cooled water, by avoiding agitation, a number of degrees below its usual freezing point, 32°: on agitating it, it congealed, and the temperature instantly rose to 32° from the evolution of the caloric peculiar to it in the state of water.

Similar experiments were made by Irvine on spermaceti, wax, and tin; they have since been extended to other bodies, and with regard to all the same law has been established, a portion of caloric peculiar to each being absorbed when the body melts, without causing any rise of temperature, and this portion of caloric concealed in the liquid becoming sensible again when it is congealed.

Dr Black demonstrated, that a similar phenomenon accompanies the other change of state to which bodies are subject, that into vapour or air, a quantity of caloric being absorbed by the body passing into this state without raising its temperature, and being evolved when it returns to the liquid form. This, as has been remarked, is even evident from the usual phenomena of vaporization atten-

tively examined, neither the liquid nor the vapour rising from it suffering any increase of temperature after the ebullition has commenced, though caloric be constantly communicated. It was farther established by experiments ascertaining it with more accuracy, or placing it in a clearer light.

A portion of water in a cylindrical tin vessel placed on a heated iron plate, was raised in temperature from 50 to 212° in four minutes, when it began to boil; in that time, therefore, it had received a quantity of caloric capable of raising its temperature 162°. It continued to boil, and twenty minutes elapsed before it was dissipated; neither its temperature, nor that of the vapour into which it was converted, rose above 212°, yet it must have continued to receive caloric as before; that is, at the rate of 162° every four minutes; of course, in its vaporization, a quantity of caloric had been absorbed, which, applied at once, would have been equal to raising its temperature 810°.

A liquid heated under pressure may have its temperature raised above its usual boiling point, the transition into vapour being prevented. A quantity of water included in a strong phial closely corked, with a thermometer included, was heated to 222°: the cork was suddenly withdrawn, a small quantity only of vapour rushed out, and the remaining water instantly fell to 212°. This experiment Mr Watt repeated on a much larger scale, water being heated in a copper digester with a safety valve to a much higher temperature; yet, on opening the valve, instead of the whole escaping in vapour, not more than one-third of it assumed this state, and the temperature

of the remaining portion sunk as in the preceding experiment.

A similar absorption of caloric attends the vaporization of volatile liquids at a common temperature, producing therefore sensible cold, greater as the liquid is more volatile, or as the change is accelerated, as Cullen observed.

The caloric which is thus absorbed in the transition of a body to the state of vapour, is again evolved when the vapour is condensed. Dr Black found, that when steam, at the temperature of 212°, is condensed by being received in cold water, the temperature of this is much more raised, than by the communication of a weight of water at 212° equal to that of the steam. And Mr Watt having condensed steam in a metallic tube, by suddenly forcing down a piston accurately adapted to it, the end of the tube being placed in water, found a quantity of caloric communicated to the water, equal to what would have raised the temperature of a portion of it equal in weight to the steam 948 degrees. Yet the tube and the included steam, previous to the condensation, were at the temperature only of 212°.

All these facts prove the truth of the general proposition, that when bodies pass from the solid to the fluid, or from the fluid to the gaseous state, a quantity of caloric is absorbed, which has no effect in raising the temperature of the body in its new form, this caloric being again evolved when the body returns to its former state. This portion of caloric absorbed during these changes. and not discoverable by the usual effect of raising temperature, Black named Latent Heat, in opposition to the portion by which tem-

perature is produced, and which he denominated Sensible Heat.

In assigning the cause of these phenomena, Dr Black supposed, that the caloric which disappears or becomes latent, produces the change of form, losing at the same time its own characteristic properties, probably by entering into a species of combination with the matter on which it operates. "Fluidity," says he, "I consider as depending immediately and inseparably on a certain quantity of the matter of heat which is combined with the fluid body in a particular manner, so as not to be communicable to a thermometer or to other bodies, but capable of being extricated again by other methods, and of re-assuming the form of moveable or communicable heat." And, again, with regard to vaporization, "when a fluid body is raised to its boiling temperature by the continual and copious application of heat, its particles suddenly attract to themselves a great quantity of heat, and by this combination their mutual relation is so changed, that they no longer attract each other, but separating, compose a fluid elastic and expansive like air. This new form of aggregation, (taking the example of water,) is the effect of a new combination of heat with the primary particles of water, and is a sufficient indication of this union, in the same manner as fluidity was a sufficient mark of a sudden and copious combination of heat with the particles of ice."

A very different theory of these phenomena, and more approaching to a philosophical generalization, was advanced by Dr Irvine. Temperature depends not merely on the action of caloric, but on its action modified by that

peculiar relation of bodies to it which we denominate their capacity. If the capacity of a body be enlarged, the quantity of caloric communicated to it remaining the same, its temperature must fall; if the capacity be diminished under the same condition, its temperature must rise; or if the capacity be enlarged while caloric is proportionally communicated, this caloric will be absorbed by the body, and remain in it without any increase of temperature. Now this, Dr Irvine conceived, is what happens in fluidity and vaporization. The sensible caloric communicated, and raising the temperature of the body to its melting, or to its vaporific point, weakens progressively its cohesion, and at length so far changes its state of aggregation, as to admit of a new arrangement of its parts, constituting first fluidity, and afterwards the state of vapour or air. These changes, Dr Irvine supposed to be accompanied with a change of capacity, the capacity of the body in its liquid being greater than in its solid state, and becoming still larger in the state of vapour. If this be admitted, it necessarily follows, that a quantity of caloric must be absorbed by the body in passing into the liquid and aërial forms, which shall have no effect in augmenting its temperature, and which, of course, is not discoverable in it by the thermometer. But there is no reason to believe that this caloric has lost its properties, has entered into any peculiar combination with the body, or is in any state different from the rest of the caloric it contains. It goes with that caloric to sustain the temperature, and it has been absorbed without raising temperature, merely because the capacity of the body has been enlarged; and when

the capacity is diminished, as happens in the reverse change of form, it is, of course, again evolved. A body in one form, in a word, contains more caloric than in another form at a given temperature, exactly as one body contains more than another does; or, according to this theory, the cause why water contains more caloric than ice at 32°, is the same as that by which water contains more caloric than quicksilver; and were it possible to convert quicksilver into water by a process similar to that by which we convert ice into water, we should have precisely the phenomena of latent heat.

The whole question, therefore, on this subject, is with regard to the assumption on which the theory rests, whether an augmentation of capacity accompanies liquefaction and vaporization or not. No doubt can remain of its superiority *à priori*, to the opinion of Black. It explains the phenomena; for it is obvious, that if by fusion or vaporization the capacity of a body be enlarged, either its temperature must fall, or caloric must be absorbed without producing any rise of temperature: the first cannot happen; for, in this case, the temperature of the body falling below its fusing or vaporific point, the change of form could not proceed: the second event, therefore, must be that which will occur, or if, by applying caloric, we raise and preserve the temperature sufficiently high to cause the transition of form to proceed, if this be accompanied with an increase of capacity, the caloric applied must be absorbed and become latent, or occasion no increase of temperature. And the theory has farther the very important advantage, that while the opposite system

is an insulated hypothesis, framed to account for this particular case, Irvine's is an extension by generalization of a law, proved to exist with regard at least to different bodies, and not unlikely to operate in a similar manner on the same body in different forms.

The determination of the fact occupied the attention of Dr Irvine for a series of years, the experiments by which only it could be decided being attended with peculiar difficulties; for, in determining the capacity of the body, either in the solid or liquid state, it is necessary, that in the progress of the experiment it should not change its form. Ice, therefore, must be operated on at temperatures below 32°, and water at temperatures above this. Dr Irvine employed the medium of a third substance, such as quicksilver, river-sand, or iron-filings, which he added to each, and determined the capacity in the usual manner; and he uniformly found, that the capacity of water is greater than that of ice, and in a ratio which he inferred, from the average of his experiments, to be as 10 to 8. A similar augmentation of capacity Dr Crawford found to take place when water is converted into vapour. It is proved then, that the change in the relation of the body to caloric is not confined, as Dr Black's hypothesis supposes, to the moment of liquefaction or vaporization, but that at these changes the relation is so altered, that henceforth the liquid requires more caloric than the solid did to raise it every degree of the thermometric scale, and the vapour, in like manner, requires more than the liquid. In consequence of this, an absorption of caloric must take place at the moment of change, sufficient with the caloric

the body contained, to keep up the existing temperature from the point of absolute privation, according to the enlarged capacity of the body in its new state. And with the admission of these facts, the one theory is demonstrated, while the other cannot be maintained.

The only difficulty that has been urged against the theory of Irvine, of any seeming importance, is that of accounting for the change of form; for since the temperature of the liquid is not sensibly greater than that of the solid from which it is formed, nor that of the vapour greater than that of the liquid from which it rises, it has been contended, that the change cannot be ascribed to the operation of sensible caloric, and must therefore be ascribed to the action of at least a portion of that which becomes latent. The difficulty, however, is in a great measure, perhaps, entirely obviated by considering the change of form as arising from the expansive operation of caloric, increasing as it is accumulated, until it sufficiently modify or subvert the force of cohesion to admit of fluidity and vaporization being established; and this being progressively exerted, the ultimate effect may take place at a point in the scale of temperature indivisible, so that we shall be unable to discover a difference of temperature on the one hand, or on the other.

This view of the cause of the change of form is confirmed, by finding the change produced by causes which must operate solely by altering the distances at which the particles of bodies are placed. Thus, the transition into vapour is effected by withdrawing pressure, which can be an antagonist only to the expansive operation of sensible

caloric: Or, by applying pressure, a vapour may be reduced to the liquid state, though this pressure can have only a mechanical effect, approximating the particles, and cannot subvert any chemical combination of caloric, did it exist.

It may therefore be concluded, that the absorption of caloric which accompanies liquefaction and vaporization, is owing not to any chemical combination, but to the enlarged capacity which the body acquires by a change of form. It may be supposed, indeed, that the difficulty in this view of the subject is only avoided, not removed. May not this very difference of capacity in bodies, in whatever state they exist, proceed from a chemical combination of caloric? By saying that different bodies, or different forms of the same body, have different capacities for caloric, the general fact is merely expressed, that in equal quantities, and at equal temperatures, they contain unequal quantities of this power. But the cause of this is not assigned. May it not then be chemical combination of part of the caloric, of that part of it in each body which amounts to the difference of the quantity it contains, compared with another? This opinion is at once refuted by the consideration, that, were it true, the quantity of free caloric, or caloric of temperature, ought in all bodies to be the same, and that consequently in equal changes of temperature, equal quantities of caloric ought to be absorbed, or given out by all, since the very principle which is assumed is, that the cause of the difference in the absolute quantities of caloric which bodies contain is, that that portion in one body, which exceeds what is con-

tained in another, exists in it in a state of chemical combination.

Whether, therefore, the question be considered as relating to the cause, why different bodies contain, at the same temperature, unequal quantities of caloric, or to the cause why different forms of the same body follow the same law, in neither case is it probable that a chemical combination of part of that caloric gives rise to the difference. *And as the phenomena are in both cases the same, they must be ascribed to the same cause.* Until this is discovered, the general fact ought merely to be expressed: Caloric, whether matter or motion, is to be considered as a power diffused over matter, as the cause of that state of bodies termed their temperature, as having a tendency to diffuse itself, until a common temperature is formed; but for the production of this temperature in different bodies, and in equal forms of the same body, unequal quantities of this power are required. If it be a material agent, the difference in the quantity contained may be owing to the specific attraction exerted by each body; but still this attraction is merely the force by which the whole quantity is retained, and does not operate more on one portion than on another.

Some philosophers of eminence, indeed, without alleging that the difference in the quantities of caloric in different bodies, or the absorption of it during liquefaction and vaporization, is owing to chemical combination, have supposed, that there may be a portion of caloric existing in bodies in such a state of combination. Lavoisier and La Place inclined to this opinion, from finding by experi-

ment, that in different cases of chemical union, or of change of form, the quantity of caloric rendered sensible does not correspond with the changes of capacity that take place, but is sometimes greater, at other times less; whence they concluded, that a portion of caloric must exist in bodies in some other state, and probably in more intimate combination. They admit, however, that trivial errors in the estimation of the capacities might have given rise to the apparently discordant results they obtained; and when the sources of fallacy attending such experiments are considered, it will appear not improbable that such errors must have been present. Irvine and Crawford devoted much attention to this investigation, and uniformly found, that when bodies produce heat by mutual action, or change of form, their capacities are diminished, and that, on the contrary, when they produced cold their capacities were increased; nor were the results inconsistent with the law of the changes of temperature being proportional to the increase or diminution of capacity, making allowance for the inaccuracies to which such experiments are unavoidably liable. Gadolin executed a very extensive series of experiments with the same view, and drew from them the same conclusion. Nor are there any facts which, when duly considered, can be regarded as affording proof, that any portion of caloric exists in bodies chemically combined. The hypothesis, however, has often been maintained, and the language implying it is often used by chemists, as if it were established. It is therefore necessary to remark, that it rests on no just grounds. The different quantities of caloric contained in bodies, re-

gulated by what we name their capacities, cannot be referred to the operation of any peculiar force different from that by which the whole quantity of caloric is contained; neither can the absorption and latent state of the caloric, absorbed in liquefaction and vaporization, be referred to this cause. And we have no reason to believe that any other portion of caloric exists in bodies in a combined state. The agency and relations of this power are indeed so peculiar, that, even admitting its materiality, we can place little reliance on any conclusion with regard to its mode of existence, not established by direct evidence, but resting on analogies transferred from ponderable substances.

From the enlargement of capacity and consequent absorption of caloric, which attends liquefaction and vaporization, some interesting applications both to natural phenomena and to purposes of utility are derived.

Such, for example, is the fixity and uniformity of the temperature at which bodies melt. Ice melts at 32° of Fahrenheit, and, when raised to this temperature, the farther communication of caloric, however rapid, has no effect in raising its temperature, till the whole is converted into water; since, as quickly as the ice is melted, as quickly is the caloric absorbed by the fluid. Were it not for this absorption of caloric, the liquefaction of ice and snow, in the colder climates, at the approach of spring, would take place almost instantaneously, when the temperature of the atmosphere rose above 32°; whereas, from this, the

melting is gradual and progressive; the water that is formed is distributed more slowly, and the too sudden rise of temperature, which in such climates would prove fatal to vegetables, is prevented. The reverse of this, too, or the extrication of caloric, when water is converted into ice, is equally beneficial; since, were it otherwise, the freezing of large collections of water would be extremely rapid when the temperature of the atmosphere fell below 32°. But, from this extrication, the freezing is gradual, and a large quantity of caloric is given out by the water in passing to the solid state, by which the approaching cold is moderated, and the congelation rendered more slow.

Similar general effects arise from the operation of this law in vaporization. When the earth is much heated by the sun's rays, water is evaporated from its surface, and from rivers and the ocean, and the conversion of this into vapour is necessarily accompanied with the absorption of caloric. Hence evaporation is the most powerful agent employed by nature to moderate excessive heat. On the contrary, when the vapour of the atmosphere is condensed by cold, and descends in rain or snow, it gives out the caloric it had received, which is then beneficial rather than hurtful.

The process of artificial refrigeration is explained on the same principle. By allowing water to filtrate slowly through porous earthen vessels, so as to present an extensive humid surface to the atmosphere, it passes rapidly into vapour, and in this vaporization absorbs so much caloric as to produce a considerable degree of cold. Liquors are cooled, and in warm climates ice formed, by arrange-

ments of this kind, even when the temperature of the atmosphere is above 32°.

The theory of freezing mixtures is likewise deduced from the doctrine of latent caloric. These are mixtures of saline substances, which, at the common temperature, by their mutual chemical action, pass rapidly into the fluid form, or are capable of being rapidly dissolved in water, and, by this transition to fluidity, absorb caloric, and produce degrees of cold more or less intense.

The use of steam as a vehicle and source of heat, affords an example of the scientific application of these principles. By conveying it into water, it is condensed, and by the evolution of the latent caloric by the condensation, the temperature of the water is raised, so as soon to arrive at 212°. Where large quantities of water are to be heated, this method has superior advantages, as by having a common boiler, from which the vapour is conveyed by tubes, the loss of heat is much less than if fire was applied to different vessels, and the vessels are subject to less wear, and may be constructed at less expence. Another application of the same principles is that of heating apartments by conveying steam through tubes, proposed in an early volume of the Philosophical Transactions, and since revived. The steam in its progress is condensed gradually, and gives out its latent caloric, so as to produce an equable warmth.

The modern improvements in the Steam-engine, as they originated from Dr Black's discovery, so they afford a very striking exemplification of the doctrine of latent caloric. In the engine wrought previous to the improve-

ments of Mr Watt, the steam was received into a cylinder, to which a piston was adapted, which was raised by the introduction of steam: this was condensed by a jet of cold water, and the piston was of course forced down by the pressure of the atmosphere, and by these alternate actions the machine was worked. But this was attended with an immense loss of heat; for by the jet of cold water not only was the steam condensed, but the cylinder was likewise cooled, as it was also by the entrance of the atmospheric air, and the first portion of steam, therefore, that entered was condensed. At each stroke of the engine this waste is repeated, and thus, according to Mr Watt's calculation, at least half of the steam produced in the boiler is lost. His principal improvements consisted in condensing the steam, not in the cylinder, but in another vessel communicating with it by a pipe with a valve, and in excluding from the cylinder the atmospheric air, and depressing the piston by steam introduced above it, and condensed in the condensing vessel alternately with the steam beneath. The whole can thus be kept at the temperature of 212°, and the immense waste of heat in the old method is obviated.

Sect. VI.—*Of the Absolute Quantity of Caloric in Bodies.*

A PROBLEM which the Chemists have sometimes proposed for solution, is that of determining the whole quantity of caloric in bodies, and of course at what distance, mea-

sured by thermometrical degrees from a given temperature, the point of absolute privation, or what they have named the real zero, would be placed. It is obvious, that any reduction of temperature that we can command is far distant from the total abstraction of caloric, and it is only by calculation from certain known facts that the zero can be determined.

The possibility of this occurred to Dr Irvine, and the principles on which his method were founded are extremely simple. Assuming that the caloric contained in bodies is as their capacities, and knowing the difference between the capacity of a body in its different states, for example in its solid and liquid states, it is obvious, that if we ascertain, by experiment, the quantity of caloric which it absorbs or gives out in passing from one state to the other, we can determine the whole quantity of caloric it contains; for the quantity evolved bears a certain proportion to this, which proportion the difference of capacity gives. Thus, if the capacity of water be 10, and that of ice 9, and if the whole quantity of caloric which each contains be as its capacity, then water contains a quantity as 10, ice a quantity as 9, or water contains one-tenth more caloric than ice at the same temperature. This tenth part, of course, is given out when water passes into the state of ice; the quantity actually evolved by it we discover by experiment to be equal to what would raise its temperature 140° of Fahrenheit's scale. The water previous to freezing, therefore, contained a quantity equal to ten times this, or a quantity equal to what would elevate its temperature 1400°. Of course, at this distance from 32° of Fahrenheit, it

would be wholly deprived of caloric, or the real zero would be placed; and this would be the same with regard to all bodies measured by thermometrical degrees, according to the capacity of each; for although they contain different quantities, this is only because they require different quantities to produce the same elevation of temperature: the degrees of temperature are the same.

The calculation of Irvine was confirmed by the experiments of Crawford, and also by those of Gadolin, both made on the capacities of bodies combining together, the capacity of the compound formed, and the quantity of caloric absorbed or evolved during the combination. Crawford, by determining the capacity of water, the capacities of its constituent principles, and the quantity of caloric evolved when these combine, found the zero to be at 1532 below the freezing point of water; and Gadolin, from observing the changes of temperature in the solution of muriate of soda in water, and also in the combination of sulphuric acid and water, compared with the capacities of the respective substances, placed it at 1432 below that point. Other chemists, however, have obtained results extremely discordant. In the experiments of Lavoisier and La Place, the numbers are very remote from those above stated, and from each other; and, in the more recent experiments of Dalton, are so even to a greater extent; the zero being found, from some experiments, at 3000, others at 5000, or at 7000° below the temperature of freezing water. We can, of course, place little confidence in any of these calculations; and either the assumption on which the theorem rests, that the quantity of calo-

ric in bodies is as their capacity, is incorrect; or the experiments, so far as relates to the estimation of the capacities, must be liable to sources of error nearly unavoidable, and which, from being multiplied by the calculation, give rise, even though trivial in themselves, to errors so great. The latter is probably the case; for the methods of discovering the capacities of bodies, give us rather approximations than absolutely accurate results.

From the diversity of opinions which has prevailed with regard to the state in which caloric exists in bodies, several forms of expression have been introduced, and are still in use, which it may be proper to define.

Free caloric is caloric in that state in which it expands bodies, and, accumulated to a certain extent, occasions the sensation of heat. It is synonymous with the *sensible heat* of Dr Black, and with the *caloric of temperature* of other chemists.

Specific caloric is the quantity of caloric peculiar to any body compared with another, and therefore expresses the relative quantities of caloric contained in equal weights of different bodies at the same temperature. It is synonymous with the *comparative heat* of Dr Crawford. Others have used the phrase *relative heat* in a similar sense. This, however, is employed by Wilcke to denote the specific caloric of a body, estimated, not by the weight, but by the volume.

The disposition or property by which different bodies contain certain quantities of caloric, at any temperature, is termed their *capacity* for *caloric*.

Latent caloric, or *latent heat*, is the expression used to denote that quantity of caloric which a body absorbs, when it changes its form. *Combined caloric* is that portion supposed to be contained in any body, in a state of chemical combination. The *Absolute Heat* of Crawford denotes the whole quantity of caloric which any body contains; and is expressed, according to the modern chemical language, by saying, the absolute quantities of caloric present in bodies.

Sect. VII.—*Of the Nature of Caloric.*

By the ancient philosophers, the cause of heat was considered as a peculiar subtle fluid or element; and this opinion was received until the time of Bacon. From observing that the circumstances which cause augmentation of temperature are such as excite motion, and that in general whatever produces motion produces heat, he advanced the hypothesis, that the heated state of bodies depends merely on vibration of their particles. Though this opinion was adopted by some chemists, particularly by Boyle, Newton, and Macquer, the other, which considers the phenomena of heated bodies as depending on the presence of a peculiar material principle, continued to be more generally received.

The general phenomena which are produced by the action of caloric, are sufficiently explained on the hypothesis of its being a subtle highly elastic fluid, capable of pene-

trating bodies, with the exception of one familiar phenomenon,—the excitation of heat by friction, percussion, or any species of motion producing vibration in the particles of bodies. On the hypothesis of temperature depending on the presence of a material agent, it is difficult to conceive how it should be raised by the operation of these causes, and it is from this difficulty that the hypothesis of its depending on motion has originated.

The difficulty has appeared greater, too, since the excitation of temperature by friction has been investigated with more precision; for it appears to be produced without limitation while the friction is applied, and without any external source whence it may be supplied. Rumford observed, that in the boring of cannon, much heat is rendered sensible by the friction. To ascertain its quantity with more accuracy, he placed a solid cylinder of brass in a trough with water, and applied the borer to it in the usual manner. In an hour the temperature had risen from 60 to 107, and in two hours and a half the water was brought to boil, its quantity being 18 libs., and the apparatus immersed in it, which was of course likewise heated to 212°, being equal to 15 libs. This excitation of heat, it was obvious, was independent on any action of air, as this was excluded by the manner of making the experiment: the water does not appear to have exerted any chemical agency, as it suffered no change: the caloric, Rumford supposed, could not be derived from the surrounding matter, as this was actually receiving heat from the body submitted to friction, and it could not, he conceives, be derived from this body itself from any diminution of capacity produced by

the friction, as the capacity of the borings of the metal he found to be the same with that of the mass of metal. He concludes, therefore, that what was thus furnished, apparently without limitation, could not be material, and that it is difficult to conceive of any thing capable of being excited in the manner the heat was excited and communicated in these experiments, except motion. Experiments giving a similar result were published nearly at the same time by Mr Davy.

In comparing the two hypotheses thus advanced on the nature of caloric, little doubt can remain of the superiority of that which regards it as a material principle; for the general phenomena connected with its operation receive a satisfactory explanation from this assumption, at least with the exception of the difficulty now stated; while, on the opposite hypothesis, that it arises from vibration or motion of the particles of matter, these phenomena are very imperfectly explained. Expansion, fluidity, and vaporization, may be conceived to arise from the introduction of an elastic fluid counteracting the mutual attraction of the particles of matter: this fluid, it is sufficiently probable *à priori*, may have peculiar relations to different bodies, may therefore be propagated through them with different degrees of facility, be contained in them in a given state in unequal quantities, or may act upon them unequally, so as in equal quantities to produce unequal effects. Considering caloric, on the other hand, as arising from vibration, it is not obvious how this should produce even the most general effect, that of expansion: we do not perceive how, when accumulated to a certain

extent, it should give rise to permanent repulsion: we are equally at a loss to account for the law which regulates its distribution in bodies, as producing temperature, or the laws of its communication, which are different from those of motion.

To establish this superiority more decidedly, there remains to be explained, on the assumption of the materiality of caloric, its excitation by friction. Is the following hypothesis adequate to this? By friction, or similar causes of motion, the particles of bodies are thrown into a state of vibration; they alternately approach to, and recede from each other. In their approach, the common law with regard to the effect of condensation on temperature must be observed, or heat will be excited; in the corresponding retrocession, heat will, no doubt, from the same cause, be absorbed. Now, is it possible, that in this retrocession the layer of matter, in the state of vibration, may rather receive caloric from the contiguous layer, and ultimately from the rest of the mass, than re-absorb that which had been evolved in the preceding approximation, that in this way a current of caloric may flow towards the vibrating surface, and a constant evolution of it be kept up? The possibility of this will perhaps be established by proving, that an analogous case occurs in which this happens. The excitation of electricity by friction affords it. The surface affording electricity is in a state of vibration from the friction applied to it; and the phenomena of electricity prove, that the electric fluid forced out, probably by the approximation of the particles from the vibration, is not re-absorbed in the following retrocession, but forms

an atmosphere around the electric body, or is carried off by the surrounding matter, while a new portion is received from the mass in contact with the excited surface, and ultimately from the earth, so that a constant evolution of it can be continued, while the friction is applied. Caloric may follow the same law, though, from not having that relation which electricity has with regard to conducting and non-conducting matter, this is not so easily established. If it do operate, it may give rise to similar phenomena, at least to a less extent.

The evolution of caloric, from this cause, is no doubt connected with diminution of capacity; and that this should happen, is even rendered extremely probable, from the effect of condensation on the capacities of bodies, as already illustrated. But this diminution of capacity is only momentary, though constantly renewed; and the experiment, therefore, by Rumford, of ascertaining the capacity after the friction has ceased, is wholly inconclusive. It is farther to be remarked, that a very slight diminution of volume may be sufficient to produce a considerable elevation of temperature. Berthollet has justly remarked, with regard to Rumford's experiment, that a very large addition of caloric is requisite to produce even a small augmentation of volume in a mass of solid metal, and that of course a small reduction of volume, and therefore an approximation of the particles, during friction, far from considerable, may evolve a large quantity of heat.

The conveyance of caloric through a vacuum has been advanced as a proof of its distinct existence as a material principle; but no perfect vacuum probably can be formed,

and the proof therefore is defective. The phenomena of radiant caloric appears to demonstrate the actual existence of a subtle matter projected in right lines from heated bodies, capable of exciting temperature, and this would afford a conclusive proof of its materiality, were it unequivocally established that these phenomena are wholly independent of the air; but on this point the speculations of Mr Leslie leave some doubt. The existence of calorific rays in the solar beam might be considered as affording similar evidence; but the degree of uncertainty under which the fact still remains with regard to this, leaves an equal uncertainty as to the force of the conclusion. Tho' the hypothesis, therefore, of the materiality of caloric, is superior in its adaptation to the phenomena to that which assigns the production of these phenomena to motion of the particles of matter, it can scarcely perhaps be considered as fully established.

It may be added, that those who have denied the materiality of this power, have limited the discussion, by embracing the hypothesis of Bacon, that the heated state of bodies arises from vibration of their particles,—an hypothesis which gives no adequate explanation. But the question need not be considered under this restricted view. Caloric, if its materiality be not admitted, may be considered as a general force producing repulsion; and if we set aside the facts with regard to its apparent radiation, this perhaps would not be the most improbable opinion on the nature of this power. Our knowledge, however, is not sufficiently advanced on this subject, and, in particular, while the relations of caloric to light and to electricity

remain imperfectly developed, and the nature of these agents is unknown, any hypothesis with regard to the former must rest on imperfect grounds.

The question with regard to the materiality of caloric has been attempted to be determined, by discovering if it is subject to gravitation, or has weight. The investigation of this has given rise to very discordant results, some experiments appearing to establish its gravity, others favouring even the opposite conclusion, that it counteracts gravitation, and, communicated to bodies, renders them positively lighter. These differences arise from the difficulties attending the experiments; and from the subtility of this agent, it is not to be expected, even if it were subject to gravitation, that this could be discovered by any apparatus we can employ. We might probably as well attempt to weigh the particles of light. In some of the experiments, accordingly, made with the greatest care, and with the most delicate apparatus, no sensible difference in weight in a body could be discovered when caloric was communicated to it, and when it was withdrawn.

Sect. VIII.—*Of the Sources of Variations of Temperature, and the Applications of these to Practical Chemistry.*

The tendency of caloric being to diffuse itself over matter, until an equilibrium of temperature is established, this would at length be attained, did no external causes operate by which it is counteracted. Such uniformity of

temperature, however, would be incompatible with the varied operations of nature; it is therefore prevented by certain general arrangements, constant in their action, giving rise to, and bounding that extent of variation which these operations require.

The great source of natural heat is the action of the solar rays. As every part of the earth's surface is not equally, and at all times exposed to this action, inequality of temperature, giving rise to variety of climate, and change of season, is established. The extreme of heat, which might accumulate where the action of the solar rays is most powerful, is preserved within due limits by changes to which the operation of this heat itself gives rise, and which, so perfect is this adjustment, are even rendered subservient to moderating cold, where it might become intense.

These important effects are obtained, principally by changes in the atmosphere, and in the distribution of water. When the surface of the earth is heated, a portion of this heat being communicated to the air incumbent on it, this is expanded, and of course ascends; an ascending current is established, which is supplied by colder and more dense air pressed from every side; the accumulation of heat is retarded, and the warmer air, propelled to colder climates, gradually gives out the heat it had received. The agency of water is scarcely less important. As the temperature is elevated, it evaporates in greater quantity, and in passing into vapour absorbs caloric, from its increasing capacity, without rising in temperature: when the heat diminishes, or the vapour is carried to

colder regions, it is condensed, and this latent caloric is rendered sensible. Where the cold becomes more intense, water is congealed, and in the congelation gives out the large portion of latent caloric peculiar to it in the liquid form: at the return of warmth, the ice is melted, and caloric absorbed. The transitions of seasons are thus moderated, sudden and extreme variations guarded against, and the temperature of the globe is every where preserved more uniform.

The range of natural temperature is comparatively moderate, extending only from a few degrees above 100 of Fahrenheit to about 50 below the commencement of the scale. In tropical climates, the heat in the shade rises occasionally to 110°. In the north of Asia and of America, the cold, in the winter season, is sufficiently intense to freeze quicksilver, and must therefore be lower than —40; the spirit thermometer has been observed to indicate —50, and there is no reason to believe that any natural cold much exceeds this. The medium heat of the globe, and which, at a sufficient depth from the surface, is stationary, is about 50 of Fahrenheit.

The range of temperature as excited by artificial methods is much greater. We cannot indeed exceed greatly the greatest natural cold, the reduction of temperature by the most powerful freezing mixtures not being more than —90, or 122 below the freezing point of water. But our power of exciting heat is less restricted; it has been measured so high as 160° of Wedgwood's pyrometrical scale, or 21,877° of Fahrenheit; and as at this temperature effects were not produced, which can be obtained

from the concentration of the solar rays by a powerful lens or speculum, or by the heat excited by a current of oxygen gas directed on burning charcoal, heats more intense than this are of course under our command.

An important subject in practical chemistry, is that which relates to the processes for obtaining and applying artificial heat and cold. An account of these, and a description of the apparatus adapted to them, concludes the chemical history of caloric.

THE sources of heat are, the Solar rays, Electricity and Galvanism, Condensation, Mechanical action between solids, including Friction and Percussion, and, lastly, Chemical action, to which Combustion belongs.

From the action of the solar rays without concentration, the thermometer is raised to above 100, and when protected from a current of air, even to above 200. When concentrated by a lens or mirror, the heat is of extreme intensity, equal nearly to any that can be excited by artificial arrangement, all the metals and earths nearly being melted by it, and many of them even dissipated in vapour. It admits, however, of very limited application from the quantity of matter on which it can be made to operate.

The electric spark produces heat sufficient to kindle a combustible body, and the discharge from a battery raises the temperature of the matter through which it is transmitted to a degree more or less intense, according to the strength of the discharge. The galvanic discharge, which

is merely a different form of electricity, produces heat still more intense, melting the most refractory of the metals, and causing all of them to burn. These are afterwards to be considered.

The effect of condensation in producing heat is most conspicuous in the compression or rarefaction of elastic fluids, as in these a considerable change of volume can be suddenly produced. By condensing a gas, its temperature is always raised, and by a forcible and rapid condensation, this extends even to the temperature of ignition, a piece of tinder being easily kindled by condensing the air in a metallic tube. In rarefying any elastic fluid, cold is always produced.

Friction and Percussion are well-known sources of heat. Two solid bodies rubbed against each other always become warm, and frequently so much so, that if inflammable they are kindled; the heat excited varies according to the hardness, elasticity, and other qualities of the body; the hardest are not those that are most heated. Of heat from percussion, the spark struck by steel from a flint is a familiar example, in which the temperature is raised to ignition.

Chemical action is perhaps invariably attended with a change of temperature; it is often productive of heat, and in some cases in a state of high intensity. Combustion is an example of this, this process being the combination of one of the aërial ingredients of the atmosphere, oxygen gas, with the combustible body, and the heat produced arising directly from this combination. It is therefore

much regulated by the rapidity with which the combination is effected.

If oxygen gas, in its pure form, be supplied to the combustible matter, the combustion is extremely rapid, and, of course, the heat is intense, and by this method, indeed, we obtain the highest degree of heat which appears to be capable of being excited by artificial arrangements. The oxygen gas is either directed in a stream on ignited charcoal, or a current of it is mingled with a current of an inflammable elastic fluid, hydrogen, and the mixed gases are kindled. By either of these modes, a heat is excited superior to that in the focus of the most powerful burning lens, and almost every substance may be fused or dissipated by it.

In exciting combustion, merely by supplying atmospheric air to the burning body, it is accelerated, and of course the heat is increased by certain arrangements, causing the air to be more freely and rapidly supplied. On this principle, in particular, is founded the construction of furnaces, a kind of apparatus extensively employed in chemical experiments, as applying heat.

The essential parts common to every furnace, are the body or fire place in which the fuel burns, and where the vessel containing the materials to be operated on is placed,—the chimney by which the smoke and heated air escape,—and the ash-pit designed to receive the ashes of the fuel, and by apertures in which air is admitted to regulate the combustion. The advantage from an apparatus of this kind in exciting combustion, is derived from its causing a more rapid circulation of air. The air in the

upper part of the furnace is rarefied by the burning fuel; it therefore ascends by the chimney, and colder air being pressed in beneath, rises through the interstices of the fuel, and produces a rapid combustion. From this it is evident, that the higher the chimney is, (at least to the extent of the air within it not being much cooled,) the more rapid the current of air will be, for the difference will be greater between the specific gravity of the column of heated air, and the corresponding column of the external atmosphere. On this, therefore, principally depends the power of the furnace to produce intensity of heat.

It is necessary, too, to confine the heat and prevent its dissipation. This is accomplished by coating the inner surface with some substance which transmits the heat slowly, as a lute of clay and sand, which likewise serves to defend the furnace, when constructed of metal, from the action of the fire. When fixed, and built of brick, the building is a sufficiently imperfect conductor to confine the heat.

A very convenient general furnace, applicable to most of the operations of chemistry, was contrived by Dr Black. It is represented Plate II. Fig. 11. A is the body of the furnace, of an elliptical form, which contains the fuel, and frequently the substance to be operated on, made of plate-iron, and lined to the thickness of two or three inches, first with a mixture of clay and charcoal, beat into a paste with water, and over this, next to the fuel, with a coating of clay and sand. On the top of the body is fixed an iron-plate, having two apertures, one, *a*, placed over the cavity, and designed to receive an iron-pot with sand, the other

smaller, to which the chimney, B, made of a tube of iron, is fixed. C represents the grate, in a plate of iron which is fixed to the bottom of the body of the furnace, nearly, but not exactly opposite to the larger aperture in the upper plate. D is the ash-pit, the body of the furnace being received into it, and resting on a strong ring round the cavity, at about half an inch deep. In this ash-pit is a door, *b*, turning on hinges, to remove the ashes; and a register, *c*, designed to regulate the admission of air. It is a plate of iron, in which are six apertures, filled with plugs; the size of them increasing in geometrical ratio, so that by opening them singly, or in combination, the supply of air to pass through the fuel, and consequently the heat to be excited in the furnace, can be regulated with precision. The fuel is introduced at the top, but as it cannot easily be supplied this way in the progress of the process going on in the furnace, at least when the sand-pot is used, the furnace is sometimes constructed with a door in the side, though this renders the regulation of the admission of air less perfect. When the furnace is used for fusion, or similar purposes where a sand-pot is not required, the upper aperture is covered with a dome.

In operations on a larger scale, a fixed furnace of brick, and capable of exciting an intense heat, is required. Fig. 12. represents the usual form of a melting furnace of this kind, the structure of which is obvious from the figure. A is the cavity of the furnace, terminating by a passage in the chimney B, which is raised to the requisite height. At C is an aperture covered with a plate of iron, or of fire-brick, through which fuel is introduced. On the grate, D,

is placed a covered crucible, on a pedestal of baked clay, and in the passage of the chimney, at *a*, a muffle is sometimes placed; E is the ash-pit, through which the air is admitted to the fuel.

When solid substances are to be exposed to these intense heats to fuse them, or to favour their mutual chemical action, crucibles are the vessels generally employed, for experimental purposes. The Hessian crucible, as it is named, is a species of earthen-ware or baked clay, which stands the most intense heat without fusing; the only disadvantage attending it is, that it is liable to be cracked by very sudden alterations of temperature. The black-lead crucibles, made of plumbago and clay baked, are not liable to this, and are, therefore, often used, especially in fusing metals; from a number of saline substances, however, they suffer corrosion. The usual form is represented Fig. 13. Crucibles of platina are sometimes used. Cupels are small cups made of bone-ashes, very porous: they are used principally in refining the more precious metals, which are not oxidated by heat and air, any oxidable metal combined with them soon suffering this change, and the vitrified oxide being absorbed by the cupel. They are placed under an arched earthen vessel, open at the end, named a Muffle, Fig. 14. by which, while the fuel is excluded, the air which is necessary in the process is freely admitted.

In applying a more moderate and equable heat to favour chemical action, the medium of sand, forming the Sand Bath, is generally employed, and glass vessels named Matrasses or Cucurbits are used. The cucurbit is represented, with the alembic, Pl. III. Fig. 18. as the ap-

paratus which is used in sublimation. The matrass is represented Fig. 9. Pl. II. : from being blown thin and equable, it sustains alternations of temperature with less risk of breaking, and from the length of its neck any vapour which is formed is condensed and falls back.

A convenient method of applying heat from combustion, where it is not necessary that it should be very intense, is by the Lamp-furnace. A lamp with a concentric wick, and internal supply of air, on the principle of Argand's, affords a heat which has the advantage of being easily regulated; the elevation or depression of the wick, and the distance at which it may be placed from the body designed to be heated, allowing the application of various degrees of heat, and their speedy change. By having a double circular wick, the heat is rendered more powerful, at least three times more so than when the lamp with a single wick is used.

The lamp is sometimes attached to an iron or brass rod, on which it slides, and to which are attached rings of different diameters, to support a retort or matrass above the flame, as is represented Pl. I. Fig. 6.

A mode of applying a very strong heat at a small point, is that by the Blow-pipe. This instrument is a conical tube, with a small aperture at its narrow extremity, and having towards that extremity a moderate curvature. It is made of brass, or of glass. By blowing through this tube on the flame of a candle or lamp, in a horizontal direction, the flame is urged in a conical form, and at the extremity of it, or rather at the extremity of an internal blue flame, which is surrounded by one of white light, a

heat comparatively intense is excited. It is used by the chemist and mineralogist to ascertain the fusibilities of bodies, and by the artists, in enamelling and in working on glass, which is melted by it, so as to be capable of being moulded into any shape, or blow into vessels of a small size.

The facility of blowing through the blow-pipe, so as to keep up a constant stream of air, is not easily acquired, and it is fatiguing to continue it for any length of time. Different contrivances have been had recourse to, to obviate this inconvenience. The instrument is sometimes connected by a flexible tube with double bellows worked by the foot, by which a uniform stream of air is forced through the tube. The vapour of spirit of wine has been applied to the same purpose: a quantity of spirit being put into a small vessel, which is heated over the flame of a lamp; and the vapour conducted through a curved tube is directed on the flame of a candle, or that of a wick placed in a different part of the same tin lamp as that by which the spirit is heated. A safety valve is adapted to the vessel containing the spirit, to render the flame more regular.

The sources of Cold are Rarefaction, Evaporation, and Chemical Action.

The operation of the first is scarcely conspicuous but in elastic substances, as in these only can the volume be suddenly changed to any considerable extent. When a gas is rarefied by removing pressure from it, its temperature always falls, and the more sudden and great the

rarefaction is, the cold produced is greater. By allowing air, previously compressed, to expand suddenly, the temperature is reduced below 32°.

In the transition of substances to the aërial form, an augmentation of capacity always happens, whence an absorption of caloric follows. Evaporation, therefore, is always attended with cold, and is greater, according as the liquid passes more quickly into the aërial form, or as this is accelerated by circumstances. Thus, the bulb of a thermometer being moistened with water, and the evaporation being promoted by directing a current of air on it, the temperature falls 5 degrees, with alkohol under the same circumstances 12 degrees, and with sulphuric ether 30 degrees. On removing the pressure of the atmosphere, the evaporation is of course more rapid, and hence the cold is greater.

Chemical action is a source of much more intense cold, by the rapid change of form to which it gives rise, solid substances, by combining, passing into the liquid form, and this being attended with enlargement of capacity.

The most simple example of this, is in the solution of a salt in water, which is always attended with a fall of temperature, in some cases to the extent of 20, 30, or 40 degrees. When mixtures of salts are dissolved, the reduction is still greater, and these form what are usually named Freezing Mixtures. Equal parts of muriate of ammonia, and of nitre in powder, added to water in the proportion of 5 parts to 8, reduce the temperature from 50° to 11°, and this forms one of the most economical of

these mixtures, as the solid matter recovered by evaporation, and dried, answers equally well as before.

By dissolving salts in acids more or less diluted, greater degrees of cold are obtained. Sulphate of soda, added to sulphuric acid, previously diluted with an equal weight of water, depresses the temperature from 50° to 5°. Mixtures of salts cause a still greater depression. From phosphate of soda, and nitrate of ammonia, added to diluted nitric acid, a reduction is obtained from 50 to —21.

The cold from similar actions exerted between these substances, and ice or snow, is still more intense; as in the change which results, the absorption of caloric from the liquefaction of the ice is added to that from the solution of the saline matter. Acids, in a certain state of dilution, poured on snow or ice, reduce the temperature to 10, 20, or 30 degrees below the freezing point of water. Solid salts mixed with snow are often equally powerful. A mixture of common salt and snow, afforded Fahrenheit the temperature at which he commenced his scale. A mixture of dry potash and snow reduces the temperature to —53°, and a mixture of muriate of lime and snow to —56°.

From the application of these freezing mixtures, the effects of intense cold on a number of substances have been ascertained. Quicksilver is easily rendered solid; the most ductile of the metals lose their ductility; liquids that resist freezing most powerfully, as wines, brandy, ether, and nitrous acid, are congealed; and some of the gases that appear permanent, as ammonia, and oxy-muriatic acid gas, have been brought to the liquid form. This

process of artificial refrigeration requires to be conducted with attention to several circumstances. The solid salts ought to be recently crystallized, dry, and reduced to fine powder, the due proportions observed, the materials accurately mixed, the vessel employed an imperfect conductor, the air excluded as much as possible, and, to attain extreme cold, the materials must be previously cooled, taking care only not to cool them below that temperature at which they can act on each other.

The theory of the action of freezing mixtures ultimately rests on the principle, that the reduction of temperature arises from the augmentation of capacity, produced by the rapid liquefaction of the solid ingredients. There are some general facts, however, connected with this of considerable interest, particularly as enabling us to point out what substances are best fitted by their mutual action to produce cold, what degree of cold may be expected from their mixture, what will be the maximum of refrigeration, and what the best proportions of the materials.

It is obvious, that those substances will produce the greatest cold, which, by their mutual action, produce the most rapid solution,—which, during that solution, suffer the greatest augmentation of capacity,—and which form a compound that at low temperatures remains liquid. There is perhaps no individual mixture in which these circumstances are present to the greatest extent; yet the knowledge of them enables us to point out the respective powers of the mixtures usually employed.

Thus, in the solution of a salt in water, there is merely the gradual transition of the solid to the fluid form; hence

the cold produced is not considerable. When two salts are mingled together, these, by their reciprocal action, both accelerate the solution of each other, and enable a given quantity of water to dissolve a greater quantity: as more solid matter, therefore, passes to the liquid state, and does so more quickly, a greater portion of caloric is absorbed in a given time, and a greater degree of cold is produced. The attraction of acids to water, or rather to the solid particles of water, is strong, and their mutual action energetic; ice too is a substance which, in its transition to fluidity, suffers a large augmentation of capacity; hence it may be concluded, what experiment proves to be just, that from the action of acids on snow or ice, a great degree of cold will arise. Lastly, in the mixture of two solid substances, which by their mutual action pass to fluidity, the comparative enlargement of capacity must be greater, and a greater diminution of temperature produced, though this is in some measure limited by the greater slowness with which two solids act on each other.

Another principle is to be attended to, which in these mixtures modifies the quantity of caloric that is absorbed from the liquefaction. Although the indirect consequence of the chemical action between the substances mixed is absorption of caloric, in consequence of the liquefaction it occasions, yet its direct tendency is to evolve caloric, by the increase of density which chemical action, independent of change of form, always occasions. Hence two effects result from the mutual action of the ingredients of freezing mixtures,—evolution of caloric, as the immediate result of the combination, and absorption of caloric, as the

result of the liquefaction to which the combination gives rise; and the ultimate effect is compounded of these, or the actual change of temperature is only the excess of the one over the other. This is generally cold, but the reverse sometimes happens, as in pouring a concentrated acid on snow, or dissolving solid potash in water; and where cold is produced, it is always lessened by this cause. It is therefore sometimes advantageous to diminish the energy of the more active substance by previous dilution, as in employing the acids; and in all cases there is a certain state of concentration of the materials, and a certain proportion of them, from which the greatest cold will be obtained.

Lastly, it is to be remarked, that we do not obtain the reduction of temperature to the lowest point in the thermometrical scale from those mixtures which, during their mutual action, absorb most caloric. If we take two freezing mixtures at 32°, the one muriate of lime and snow, the other diluted sulphuric acid and snow, the former will produce more cold than the latter; it will sink the thermometer to —40° or —50°, while the other will sink it to not more than—25°. But we may reach a lower point in the scale of temperature, by successive application of diluted sulphuric acid and snow, than we can do by muriate of lime and snow; for, past a certain temperature, the latter mixture does not liquefy, but, on the contrary, were it liquid would become solid, while the former remains liquid at lower temperatures than this. If we cool, therefore, previous to mixture, muriate of lime and snow to —73°, no advantage is gained; we even rather diminish their mu-

tual action, by adding to the cohesion of each. But by previously cooling diluted sulphuric acid and snow, an important advantage is gained; the same limit is not placed to their mutual action, and the lower the temperature is reduced, the lower will the temperature be that results from that action, down to the point at which the liquid formed by the action of the acid on the snow would congeal.

This furnishes us therefore with the general rule, that the temperature can never be reduced by a freezing mixture beyond that point at which the liquid combination resulting from that mixture congeals or crystallizes, and must indeed always be a degree or two above it. It also, in some measure, determines the proportions in which the substances should be mixed together; those being best, in which the action shall be most rapid, without being too energetic to evolve heat from the combination, and in which the resulting solution is of that strength, that is least liable to congeal or crystallize.

In the following Table, without including all the mixtures that have been employed, I have inserted, from the experiments of Lowitz and Walker, a few, which are either economical, easily managed, or capable of producing very intense colds.

TABLE OF FREEZING MIXTURES.

	Temperature reduced,
Muriate of ammonia, 5 parts, nitrate of potash 5, water 16,	from 50° to 10°
Muriate of ammonia, 5 parts, nitrate of potash 5, sulphate of soda 8, water 16,	50 to 4
Sulphate of soda 8, muriatic acid 5,	50 to 0
Sulphate of soda 5, sulphuric acid diluted with an equal weight of water 4 parts,	50 to 3
Sulphate of soda 6, muriate of ammonia 4, nitre 2, diluted nitric acid 4,	50 to −10
Sulphate of soda 6, nitrate of ammonia 5, diluted nitric acid 4,	50 to −14
Muriate of soda 1, snow 2 parts,	32 to −5
Nitric acid diluted, snow	32 to −10
Concentrated sulphuric acid, snow,	32 to −10½
Muriate of soda 2, muriate of ammonia 1, snow 5,	32 to −12
Carbonate of potash, snow,	32 to −17
Muriate of soda 10, nitrate of potash 5, snow 24,	32 to −18
Sulphuric acid diluted with one-half its weight of water, 2 parts, snow 3 parts,	32 to −23
Concentrated muriatic acid 5, snow 8,	32 to −27
Concentrated nitrous acid 4, snow 7,	32 to −30
Muriate of lime 5, snow 4,	32 to −40
——— 3, —— 2,	32 to −50
——— 5, —— 3,	32 to −53
Potash 4, snow 3,	32 to −51
Muriate of lime 2, snow 1,	0 to −66
——— 3, snow 1,	−40 to −73
Sulphuric acid diluted with half its weight water 10, snow 8,	−68 to −91

These observations on the range of temperature, natural or artificial, may be concluded with a Table, exhibiting the principal points that have been marked in the scale of heat.

	Wedg.	Fahren.
Extremity of the scale of Wedgwood's thermometer	240°	32277°
Greatest heat of an air furnace, which neither melted nor softened Nankeen porcelain	160	21877
Chinese porcelain softened, best sort	156	21357
Cast iron thoroughly melted	150	20577
Hessian crucible melted	150	20577
Cast iron begins to melt	130	17977
Greatest heat of a smith's forge	125	17327
Flint glass furnace (strongest heat)	114	15897
Welding heat of iron, greatest	95	13427
Welding heat of iron, least	90	12777
Fine gold melts	32	5237
Settling heat of flint glass	29	4847
Fine silver melts	28	4717
Swedish copper melts	27	4587
Brass melts	21	3807
Red-heat fully visible in day-light	0	1077
Iron red-hot in the twilight		884
Heat of a common fire		790
Iron bright red in the dark		752
Zinc melts		700
Quicksilver boils		672
Lowest ignition of iron in the dark		635
Linseed oil boils		600

	Fahren.
Lead melts	594°
Sulphuric acid boils	590
Sulphur burns	——
Phosphorus boils	554
Bismuth melts	476
Tin melts	442
Nitric acid boils	242
Sulphur melts	226
Water boils (the barometer being at 30 inches)	212
Alkohol boils	174
Phosphorus melts	100
Ether boils	98
Heat of the human blood	98
Medium temperature of the globe	50
Ice melts	32
Strong wines freeze at about	20
A mixture of alkohol and water, equal parts, freezes	—7
A mixture of 2 parts of alkohol and 1 of water freezes	—11
Melting point of quicksilver	—39
Liquid ammonia crystallizes	—42
Nitric acid, spec. gr. about 1.42, freezes	—45
Sulphuric ether congeals	—47
Natural temperature observed at Hudson's Bay	—50
Ammoniacal gas condenses into a liquid	—54
Cold produced from diluted sulphuric acid and snow, the materials being at the temperature of —57	—78½
Greatest artificial cold yet measured (Walker)	—91

CHAP. II.

OF LIGHT.

The materiality of Light, and its insulated existence, are sufficiently demonstrated. Its emission from bodies, its motion even to the most distant regions of space independent of any medium, the changes which may be produced in that motion by reflection and inflection, and the chemical effects it produces, are proofs of this material existence, free from all doubt. We cannot easily, however, trace the combinations of light: we observe only its evolution and absorption, and the effects arising from these, without being able to discover how far it influences the constitution of bodies in which it exists, or to what extent it is liable to the laws of chemical attraction. Its chemical history, therefore, falls to be considered under a point of view nearly the same as that under which caloric is regarded. And with that power it may justly be associated as a repulsive agent, the particles of light being mutually repellent, and operating perhaps as much in producing chemical change by the repulsion they communicate, as by the affinities they exert.

Light has been regarded as consisting of particles of extreme minuteness, projected from luminous bodies, and moving in right lines with the utmost velocity. It has also been considered as a continuous fluid of perfect elasticity and extreme tenuity, diffused through space, in

which vibrations are excited by luminous bodies, so as to produce its peculiar phenomena. The former opinion has been more generally received, as better adapted than the other to the explanation of the physical affections and relations of light; and it appears to be more directly established by the chemical agencies of this power,—its absorption by bodies, and its subsequent evolution. If it be admitted, the minuteness of the particles of light must be extremely great, beyond even what the imagination can clearly conceive, as is evident from the velocity of their motion, and their not being interrupted, though moving in space through which innumerable rays are constantly projected.

The particles of light are mutually repellent. So perfect is its elasticity, that it is reflected from a body at an angle equal to the angle of its incidence. It is subject to the attraction exerted between masses of matter, as is proved by the inflection it suffers in passing near to any body, or in passing obliquely from one medium into another, giving rise to its refraction.

A ray of light is not homogeneous, but consists of particles suffering refraction in different degrees, and hence capable of being separated. These excite the sensation of vision under different modifications, giving rise to different colours, and produce different chemical effects. An entire ray of light is thus, by transmission through a triangular glass prism, divided into seven rays, the red, orange, yellow, green, blue, indigo and violet, the red being the least refrangible, and therefore falling on a space least distant from that on which the undivided ray would have im-

pinged, had its direction not been changed; the violet being the most refrangible, and falling therefore on a space most distant from this; the others being arranged between these; the whole forming the prismatic spectrum. In this the different coloured rays occupy unequal spaces, and their limits are not perfectly defined.

Of these coloured rays some have been supposed primary, the others being formed by their intermixture. Each, indeed, suffers no change by farther refraction, but this is not to be expected even on this hypothesis, since, if any of them is composed of two kinds of rays, these must be of the same refrangibility, as it is only from this coincidence that they could have remained associated after the first refraction. The red, yellow, and blue, have been supposed primary, as they give rise to the other colours by their intermixture: this distinction has also been assigned to the red, green, and violet, the intermediate colours in the spectrum being formed by the union of these two and two, and white light being obtained by combining the three. The differences in the properties of the coloured rays have been supposed by some to depend on the different magnitudes of their particles, by others on the different velocities with which they move,—suppositions which, however they may be adapted to the physical relations of these rays, scarcely explain the differences in their chemical powers.

Light is differently affected by different bodies. It passes through some with little interruption; by others it is reflected; some reflect one ray retaining the others,—an effect giving rise to the colours which bodies exhibit;

there are, lastly, some in which the light is absorbed, and is lost by numerous reflections and refractions.

Light forms, too, a more intimate union with bodies, of which there appear to be different degrees. By some it is absorbed, and is again slowly emitted without any sensible change: in others it occasions alterations of temperature, or of composition, acting as an important chemical power.

The property which has been named Phosphorescence, appears to depend on the first of these kinds of combinations. There are a number of substances which, when exposed to light, appear luminous when removed from it, and continue so for a longer or shorter time. These are named Solar Phosphori, and the luminous appearance in them appears to arise from the light being imbibed, and again slowly emitted.

This property is conspicuous in a number of natural substances, particularly in earthy minerals, as the gems, marble, heavy spar, fluor spar, and others; and also in bodies belonging to the vegetable and animal kingdoms, as in sugar, paper, the shells of marine animals, &c. Solar phosphori can be prepared by artificial processes still more powerful. The Bolognian phosphorus, in which the property was first observed, is prepared from sulphate of barytes made into a paste with mucilage, and calcined in contact with ignited charcoal. Canton's phosphorus, which is still more powerful, is formed from calcined oyster shells, mixed with sulphur, and exposed to the heat of ignition in a crucible for an hour.

There is much diversity in the degree of phosphorescence. Some, even after exposure to solar light, shine so feebly, that the eye requires to be rendered sensible by previous darkness to perceive it. Others are illuminated by the mere light of day; and some become phosphorescent when exposed to the light of a lamp. Some are rendered luminous by an electrical discharge. The light emitted is not always white; it is frequently yellow or red, and some exhibit the prismatic colours.

Temperature has a marked effect on the emission of light by these bodies. When they are shining, the luminous appearance ceases if they are exposed to the cold of a freezing mixture. It becomes more vivid by applying heat; and if it has ceased, it may be renewed by applying a stronger heat, so that a piece which has been for some time quite dark, may be made to shine. When the phosphorescence, however, has been excited by heat, it ceases proportionally sooner, and is not renewed but by exposure again to light.

This property is quite independent of the action of the air; a phosphorescent substance shining clearly when inclosed in a mass of glass.

The phenomena of solar phosphorescence appear to lead to the conclusion, that light is absorbed by the phosphorescent body, and is again emitted, this emission being promoted by the repulsive agency of heat. There is an objection, however, to this in the fact, which appears to be sufficiently established, that, in exposing the phosphorescent body to a particular coloured ray, it is not this coloured light it emits, but merely the light which usually

proceeds from it; one which shines with a white light continuing to do so, whatever ray of the spectrum it has been exposed to; or one which usually exhibits the prismatic colours when rendered luminous, still doing so whether it has been submitted to white light, or to the coloured light of any individual ray. These facts are singular, and not easily explained on any theory; but it is not impossible that one species of coloured light may be capable of being converted into the others,—a supposition which would, in some measure, reconcile them with the obvious theory of phosphorescence.

Another species of phosphorescence is that excited by heat, independent of any previous exposure to light, and incapable of being renewed. It is exhibited particularly by fluor spar, by several of the gems, and by a number of earthy fossils, the luminous appearance being more or less vivid when heat is applied. The light emitted is often coloured; that from fluor spar is purple; in some the luminous appearance is momentary, in others it continues longer; it is equally, with the former, independent of any action of the air.

Phosphorescence, apparently similar to this, is excited by attrition; two pieces of quartz, for example, appearing luminous in the dark when rubbed against each other, and other fossils shining even from very slight friction. From some the light is colourless, from others coloured: its production is independent of any action of the air, as it is equally bright under water; it is not accompanied with any signs of electrical excitation. The attrition might be supposed to excite the light by the heat it may

produce; but the very slight friction that is often sufficient to produce the luminous appearance, that, for example, by rubbing a feather on the surface, is unfavourable to this opinion: there are fossils, too, rendered phosphorescent by friction and not by heat, and *vice versa;* and in those which are phosphorescent from both causes, if the luminous appearance has been excited by heat until it cease to appear, it may be produced anew by attrition.

A kind of phosphorescence, different from any of the preceding varieties, is that exhibited by animal matter. Marine animals are remarkable for this property; almost all the species of sea fish becoming luminous after they have been removed for some time from the water, and continuing to shine for some days. The same appearance has been occasionally observed from the flesh of quadrupeds. It does not appear until the animal has been for some time deprived of life, but it is always apparent before there are any signs of putrefaction, and it ceases when that process is fully established.

The most important fact with regard to this species of phosphorescence is, that the matter having the luminous quality can be extracted in a state of solution. If the substance of any marine animal in the phosphorescent state be macerated in a saline solution, as that of sea-salt, or indeed any other neutral salt of a certain strength, a lucid ring soon appears at the surface of the liquid, and the whole becomes luminous when agitated; this continues for several days, becoming gradually more faint until it is extinguished. Fresh water is incapable of extracting this luminous matter; the luminous appearance in salt water

is extinguished by acids, alkalis, ardent spirit, and other substances. A certain degree, too, of saline impregnation is necessary to its appearance; for it is suspended by a solution either too dilute or too concentrated, being revived in this case when the proper state of concentration is restored.

This phosphorescence is augmented by agitation: it is impaired and even extinguished by cold, but is revived by heat: if the heat, however, be too high, such as that of boiling water, it is irrecoverably extinguished. Exclusion from the atmosphere prevents its appearance, and a number of elastic fluids not only prevent it from appearing, but extinguish it when it has been produced. It is not brighter, however, in oxygen gas than in atmospheric air; neither is it accompanied with any sensible heat.

The light from rotten wood appears to be of a similar kind, observing, in its production and extinction, very nearly the same relations.

Light is emitted from certain insects, as from the glow-worm, or the lantern-fly: the light is variable, being at one moment brilliant, at another faint. The luminous appearance depends on a peculiar secretion, and may even be obtained from its receptacle by compression; it continues to shine, too, for some time after the death of the animal. It had been observed, that the light of the glow-worm becomes more vivid when it is placed in oxygen gas, which gave rise to the suspicion of its being produced by the chemical action of oxygen. The gas, however, appears to act rather by exciting the secretion, for the oxygen is not impaired in purity; and the luminous appear-

ance is obtained when the animal is under water. This species of phosphorescence, like that from marine animal matter, is extinguished by hydrogen gas, carbonic acid gas, and various other elastic fluids, reviving, however, on the admission of atmospheric air.

An important part of the chemical history of light relates to its power of elevating temperature. The solar rays are the great source of natural heat; and when concentrated, excite a very intense heat.

Different kinds of matter are unequally heated by solar light; through transparent bodies the rays passing with little interruption, the temperature is not so much raised as in those which are opaque, and those which are white are less heated than those of a darker shade.

A still more important fact connected with this property is, that the different coloured rays of light have different heating powers. Hutton observed, that the red ray of light has more heating power than white light. Rochon found that an air thermometer, exposed successively to the action of the different coloured rays, separated by a prism, rose higher as it was moved from the violet to the red, the difference in the two extremes being nearly 8 to 1. Herschel and Englefield have demonstrated the same general fact, and shewn the relative heating powers of the coloured rays with more precision. The rise of a delicate mercurial thermometer placed in the focus of a lens, and exposed to the coloured rays obtained by a prism successively, is shewn in the following table, as established by the experiments of Englefield.

In the blue ray	in 3′	from	55° to 56°
In the green ray	in 3	from	54 to 58
In the yellow ray	in 3	from	56 to 62
In the full red ray	in $2\frac{1}{2}$	from	56 to 72
In the confines of the red	$2\frac{1}{2}$	from	58 to $73\frac{1}{2}$
Quite out of visible light	$2\frac{1}{2}$	from	61 to 79

From the last number in the table it will be perceived, not only that the fact is proved of the different coloured rays having different heating powers, but that the not less important result is established, that there exist in the solar beam invisible rays which are powerful in producing heat, these being accumulated beyond the red ray when the entire beam has been decomposed by the prism, and being, of course, less refrangible than the red ray. This had been previously shewn by the experiments of Herschel. Exposing a thermometer to the different rays of the prismatic spectrum, each ray being allowed to pass successively through a piece of pasteboard with a slit in it, so as to exclude the others, he found not only that the heat increased progressively from the violet to the red ray, but that when the aperture in the pasteboard was brought to coincide with the space beyond the red ray, the heat continued: it was even greater at the distance of half an inch than in the red ray itself, and is here at its maximum; as is apparent, also, from the numbers in Englefield's table: at the distance of an inch, the rise of the thermometer amounted to $5\frac{1}{4}°$, being 7 in the red ray, and the heating power was sensible at the distance even of an inch and a half. Beyond the violet ray there is no sensible heat.

Admitting the accuracy of these experiments, it is established, that in the solar rays, there are invisible calorific rays, as well as visible rays of light. Now this bei g proved, the hypothesis, it is evident, may be proposed as not improbable, that the apparent heating power of the visible rays of light is not a property belonging to them, but depends on the presence of calorific rays associated with them. The entire beam of visible light is not homogeneous, but consists of rays, which, being of unequal refrangibility, are capable of being separated, forming, when thus refracted, the visible or coloured spectrum. But the calorific matter in the solar beam, it is equally probable *à priori*, may not be homogeneous, but like light may consist of rays of different refrangibility. If so, these rays will also be separated by the prism, and an invisible calorific spectrum be formed, the rays composing which may differ in heating, as the rays of light differ in illuminating power. If this happen, the one spectrum will be in some measure blended with the other, and thus the visible rays of light will appear to have different degrees of heating power, though in themselves they may have no power whatever to produce heat.

Herschel endeavoured to establish this conclusion, by experiments resting on the following assumption: Taking the illuminating power as the property characteristic of visible light, if the heating power of any ray be a property belonging to it, and not depending on any calorific ray associated with it, it seems obvious, that when the coloured ray is transmitted through a certain medium, as, for example, through glass, its illuminating and heating powers

must be diminished exactly in the same proportion. It is not to be expected, that it will pass through without a certain degree of interruption; but it may be presumed, and appears indeed to be a necessary inference, that if both properties depend on the same matter, they must be diminished to the same extent, while, if the illuminating power depends on one kind of ray, the heating power on another, it is possible, *à priori*, and indeed to be expected, that these will be unequally intercepted, and of course the powers will be unequally impaired.

To ascertain the fact with regard to this, a very extensive series of experiments was executed by Herschel, and the general result established, that the two powers, that of illumination, and that of heat, are very unequally impaired by transmission of light, either entire, or in the state of the different coloured rays through transparent media, as different liquids, or glass of different colours. In some the heating power was considerably more impaired than the illuminating power, and in others the reverse was the case.

It appears to follow, therefore, that the two properties do not depend on the same agent: the illumination depends on rays of light, the heat on calorific rays; and in any coloured ray the two properties appear, merely because from the correspondence in the order of refrangibility, certain of the calorific rays are associated with certain of the visible rays of light. Herschel has pointed out some other discordant results in comparing these, which strengthen the conclusion; the interruption, for example, of the rays of heat becoming less, as the experiment of its transmission

is continued; while this does not happen with regard to light: and the effect of rough surfaces in scattering the rays of light being much greater than it is on the rays of heat.

The agency of light in producing chemical decomposition still remains to be stated. This may, in a great measure, be generalized; all the changes of this nature produced by its action arising from the separation of the principle, oxygen, from states of combination. And as this element enters into the constitution of an extensive series of compounds, a number of substances are changed by light exerting its de-oxidating power. Thus, several of the acids are decomposed. If nitric acid, which is colourless, be exposed to the rays of the sun, it becomes of a yellow colour, and oxygen is disengaged from it. Oxymuriatic acid, under a similar exposure, likewise yields oxygen, either the oxygen peculiar to it, or derived from the water. A number of compounds of metals with oxygen, either alone, or in combination with acids forming metallic salts, undergo a similar decomposition: in some of them this is partial; in others of them, as in the salts of gold or silver, it is complete, so that the metal returns to its metallic form. Some of these compounds are extremely sensible to the chemical agency of light: muriate of silver, for example, is darkened in its colour by the mere light of day, without direct exposure to the rays of the sun. The changes of metallic pigments from exposure, appear in general to arise from this action of light.

The process of bleaching, too, appears to depend chiefly on the chemical power of light, the colouring matter of

the vegetable fibre apparently receiving oxygen from the decomposition by light of the water with which it is moistened; and the new method of bleaching which has been substituted, owes its superiority principally to oxygen being afforded to the colouring matter in a more condensed state.

The changes which growing vegetables suffer under exposure to the solar light, display its power in modifying, even by its chemical agency, the processes of animated nature. If light is excluded, or very partially supplied, they are in general feeble, of a pale colour, and do not afford their proper products fully formed: if it is freely admitted, they soon acquire a green colour and their natural vigour: the plants which grow under a clear sky and an intense solar light, are even in general more aromatic, and afford more rich and elaborated juices than those which grow under the opposite circumstances. With these results we can connect the usual chemical change from the action of light, oxygen being exhaled from plants while under exposure to the rays of the sun. Even on animals light perhaps exerts its chemical power: those who are natives of the arctic regions, being, like vegetables secluded from light, usually of a pale or white colour, while those who inhabit tropical countries are marked by deep or brilliant hues.

It might be supposed that these chemical effects depend not on any peculiar action of light, but arise from its power of exciting heat; some of them, at least, being produced by an elevation of temperature. An experiment of Scheele's appears to set aside this supposition; nitric acid, exposed to

the sun's rays in a phial painted black, not undergoing the usual change it does from their action, though its temperature must have been more elevated than if it had been exposed in a clear phial. Berthollet also found, that the oxymuriatic acid, exposed to the light in a phial covered with black paper, did not suffer its usual change, though it must have been at least equally heated. But these experiments are not perfectly conclusive; for we cannot estimate correctly the heat produced by the solar rays from the elevation of temperature in the entire mass of matter exposed to them, as this may be moderate, while it may be intense in the minute points on which the rays impinge, and at these points it may, from its intensity, give rise to the decompositions which are produced. The hypothesis, however, that light acts in producing these decompositions by the heat it excites, is refuted by the fact to be immediately stated, that those rays most powerful in exciting heat, are least powerful in giving rise to chemical changes.

The comparative powers of the different coloured rays in producing chemical decomposition, were submitted to experiment by the illustrious Scheele, muriate of silver, the substance which is so rapidly affected by light, being exposed to their action; it became sooner black, he observed, in the violet ray than in any of the others. Sennebier ascertained the differences more minutely. The shade produced in the muriate of silver by exposure to the violet ray for 15 seconds, required for its production, exposure to the indigo ray 23 seconds; to the blue 29; the green 37; the yellow 5½ minutes; the orange 12 mi-

nutes; and the red not less than 20 minutes. The blue ray too is superior to the others in exciting phosphorescence.

The discovery of the existence of invisible calorific rays in the solar beam might suggest the conclusion, that there may also exist in it invisible chemical rays, to which the chemical powers of these visible rays is to be ascribed. Ritter submitted this conjecture to experiment. Placing muriate of silver without the coloured spectrum beyond the violet ray, it was blackened; while, on placing it beyond the red ray at the other extremity, it not only did not suffer this change, but if previously blackened became white. Phosphorus was kindled in the space beyond the red ray, but was extinguished when transferred to that beyond the violet. In the violet ray itself the muriate of silver received a less deep shade than in the space beyond it. Dr Wollaston had nearly about the same time made similar experiments, and with the same results, except that when the muriate of silver had been blackened, however slightly, it did not recover its whiteness from exposure to the red rays.

From these experiments, then, the existence in the solar beam of invisible rays not calorific, but distinguished by their chemical action, and more refrangible than the visible rays of light, is demonstrated. Reasoning by analogy, from the law which has been proved to exist with regard to the calorific rays, it might be concluded, that the matter composing what, for distinction, may be named the Chemical Rays, is not homogeneous, but consists of rays of different refrangibilities; that from this difference

they are spread to a certain extent over the space occupied by the prismatic spectrum, and that, as the calorific effect of the visible rays does not belong to them, but to rays of caloric intermixed with them, so the chemical powers of these rays may not arise, strictly speaking, from the action of light, but from the action of chemical rays blended with the others. It has accordingly been affirmed, that Ritter, by transmitting the coloured rays through different prisms, has separated them from the chemical rays, and thus produced a coloured spectrum without any chemical power. Another interesting experiment performed by him, is that of combining the two species of invisible rays. The power of the chemical rays appeared to predominate in the mixture, and the experiment is an important one, as proving, that from the union of these invisible rays no species of visible light is produced.

From the relation which subsists between light and caloric, it has sometimes been supposed that they are ultimately the same, or are modifications of one matter, light being this matter in a state of rapid projectile motion, and acting as caloric when it becomes quiescent. Though it may be difficult to explain fully the nature of that relation, there seems to be little reason for admitting this hypothesis. The essential properties of light, and particularly its chemical agencies, are very different from those of caloric,—differences which the hypothesis does not explain; more especially taking into consideration the important fact, that these chemical agencies are exerted most powerfully by those rays of light which are least powerful in pro-

ducing heat. And, on the other hand, there is no proof of the assumption, that caloric, in any state of motion, can assume the properties of light.

CHAP. III.

OF ELECTRICITY AND GALVANISM.

The agent on which the phenomena of electricity depend, operates as a chemical power. There is every reason too to conclude, that the galvanic principle is merely electricity under a peculiar form, and in this form its chemical action is still more powerful, and indeed nearly unlimited. The operation of this principle cannot be ascribed to affinities which it exerts, considering it as a material agent; but rather to its action as a general force communicating repulsion or modifying attraction. It is therefore properly classed with light and caloric, and with these it has, besides, very intimate relations, being capable, under peculiar arrangements, of producing the utmost intensity, both of heat and illumination.

Though electricity and galvanism are modifications of the same power, yet, as their mode of excitation is different, and the chemical effects obtained from each are peculiar, they require to be considered apart.

Sect. I.—*Of Electricity.*

Certain bodies submitted to friction exhibit the phenomena denominated Electrical. A dry glass rod, for example, rubbed with a piece of silk, will give sparks of light from its surface, and will attract light bodies and again repel them. These effects, however, are not obtained from the friction of every substance; a metallic rod, for example, does not exhibit them. Hence the distinction of bodies into electric, or those capable of being excited by friction, and non-electric, or those which are incapable of this electrical excitation.

If, when an electric has been excited, a non-electric be applied to it, the signs of electricity in the former instantly cease, while this does not happen from the application of a non-electric of a different kind. Hence the origin of another distinction, that of Conductors, and Non-conductors of Electricity; the former affording a passage to the electrical principle, and carrying it off where it has been accumulated, the latter being impervious to it. Electrics are non-conductors; non-electrics are conductors; glass resinous substances, oils, and sulphur, are the principal substances belonging to the first class; metals, water, and a number of earthy bodies belong to the other.

If an electric, while excited, be supported on a non-conductor, the electricity it gives out is limited. But if a communication be established with the earth by the me-

dium of a conductor, this conveys electricity as long as the exciting cause is applied. If a conductor insulated, that is placed on a non-conductor, be brought nearly in contact with the excited electric, it receives the electricity evolved, and retains it in an accumulated state. On these principles the electrical apparatus is constructed; this consisting of a glass plate or cylinder which revolves against a cushion supported on a glass pillar, but connected with the earth by a metallic chain; and a large metallic tube, named the Prime Conductor, being placed insulated before the plate or cylinder, to receive from it the electricity evolved by the friction.

With regard to the excitation of electricity, a very important distinction still remains to be stated, that of what has been named Positive and Negative Electricity. If a glass rod be rubbed with an woollen cloth, on approaching to it a light body, as a bit of cork, the cork is first attracted, and then repelled; but if a rod of sulphur be excited by friction with the cloth, the cork in the state in which it is repelled by the glass is attracted by the sulphur, and it is repelled by the sulphur when in that state in which it is attracted by the glass. If a pointed conductor, as a needle, be presented to the glass, a round lucid point appears on its extremity in the dark; but if presented to the sulphur, a pencil of rays seem to issue from the needle. And if two bodies in these different electrical states be brought into contact, the electricity in the one appears to destroy that in the other, and the electrical phenomena cease. These two electricities being first obtained, the one from glass, the other from resinous bodies, by

friction, were named the Vitreous and the Resinous, and were regarded as essentially different.

It was discovered, however, that when two electrics are rubbed against each other, the one acquires always the one electricity, the other the other. Thus, in the common electrical machine, when the cushion is insulated, on friction being made it exhibits the resinous, while the glass gives the vitreous electricity. And, by employing different substances to excite friction, or by altering the surface, the same electric may be made to exhibit, either electricity, glass the resinous, and sulphur or sealing-wax the vitreous. Franklin, from these facts, was led to explain the phenomena on a more simple hypothesis,—that there exists only one agent by which they are produced, a fluid highly elastic, or repulsive of its own particles, but attracting and attracted by the particles of other matter; —that in all bodies a portion of this principle is present, and when present, in the proportion natural to each, they exhibit no electrical phenomena; but, if subjected to certain operations, as friction, the equilibrium is disturbed, and the body acquires more, or has less, than its natural proportion. In the former case it is said to be electrified *plus*, and presents the phenomena ascribed to what was called vitreous electricity: in the latter it is said to be electrified *minus*, which corresponds with the state of resinous electricity; and hence, instead of these terms, the phrases Positive and Negative electricity are employed in the Franklinian theory. This hypothesis accorded with the phenomena of electricity, and in particular gave a happy explanation of the discharge of the Leyden phial.

Hence electricians have in general been disposed to prefer it, though it has never been established by any rigorous evidence, nor has the opposite hypothesis been disproved, or shewn to be inconsistent with facts. The principal advantage which the system of Franklin can claim, is its superior simplicity. On the other hand, the phenomena of galvanism prove that the two electricities, whatever may be their nature, exert different chemical agencies; and hence, whatever theory be adopted, it has become more necessary, in their chemical history, to distinguish between them.

Electricity is connected both with light and caloric. In its passage through certain media, it is often highly luminous, and it is capable of exciting intense heat.

Under the form of what is named the Electrical Spark, it produces an elevation of temperature sufficient to kindle inflammable bodies, as spirit of wine. And when discharged in a state of higher intensity from a coated jar, or from an entire battery, a much more intense heat is excited, so as to melt the most refractory substances. Its power of increasing temperature appears in part to depend on the resistance opposed to its conveyance through bodies. Hence, if it is not rapidly accumulated, no sensible heat is produced; as, for example, when the bulb of a thermometer is placed in an insulated metallic plate, and electricity is communicated. But, if the bulb be placed in a less perfect conducting medium, the temperature is raised. Or, if a discharge of given intensity from an electrical battery be transmitted through a metallic wire of considerable thickness, it will not produce much heat,

while, if transmitted through a wire of the same metal of less diameter, an intense heat is excited.

The fusibilities of different bodies, of the different metals for example, estimated from the action of electricity on them, are different from their fusibilities, estimated from the direct communication of caloric, no doubt from the heat excited by electricity, being dependent not merely on the quantity communicated, but on this modified by their relative conducting powers, and perhaps on their elasticities, in consequence of which vibrations are more or less easily established among their particles.

Electricity, from its power of exciting heat, is applied to favour chemical combination: it affords the most convenient mode of promoting by heat the combination of elastic fluids. The apparatus employed is a strong glass tube, Pl. III. Fig. 22. closed at one end, the sides of which, at about the distance of two inches from this extremity, are perforated with small holes, in which are fixed by cement two metallic wires, the extremities of which within the tube are distant one-fourth of an inch. This instrument being filled with water or quicksilver, and inverted, the gases intended to be combined, mixed in the due proportion, are introduced, so as to depress the fluid an inch or more beneath the wires. The electric spark is made to pass from the one wire to the other, by connecting one of them with the conductor of the common electrical machine, and hanging a chain on the other. Or it may be made to pass from a wire inserted in the top of the tube, to the fluid confining the air beneath, as represented Fig. 23. In the mixture of some gases, a single

spark is sufficient to cause the combination to proceed through the whole mixture, the temperature being raised by it sufficiently. In other cases, a stream of sparks requires to be transmitted to produce the combination to any perceptible extent.

By the same agency, electricity is able to effect chemical decomposition. If the spark is taken in a compound gas, it separates its constituent parts; if an interrupted electrical discharge be sent through water, it is attended with the disengagement of a small quantity of elastic fluid, which is a mixture of the two gases which form water. Some solids are decomposed in a similar manner.

The electric fluid is intimately connected with light, and to this some of its chemical effects may probably be attributed. When it passes through the air from one conductor to another, it exhibits a luminous spark; when discharged through a vacuum the most perfect the air-pump can produce, it presents vivid corruscations: these appear even, though more faintly, in the Torricellian vacuum. In transmission through any fluid, if the quantity be not large proportioned to the discharge, it is rendered luminous; or if discharged over the surface of a solid, a brilliant illumination is produced. This electrical light is heterogeneous, or consists of the different refrangible rays. Priestley observed these by a prism; and Morgan has remarked that the electric light may be made to assume different colours according to the medium in which it is taken; sometimes the more refrangible rays being separated, sometimes the less.

The chemical agencies of electricity are as yet but imperfectly developed, and there are a number of facts which prove it to be absorbed or evolved in chemical changes where its influence has scarcely been traced. The electrical phenomena exhibited by the tourmalin shew that electricity is excited, and its different states produced, in some cases merely by variations of temperature. Even its excitation in the electrical machine is promoted by chemical action, as on this appears, in a considerable measure, to depend the effect of the amalgam applied to the rubber, the power of which is greater when it is composed of oxidable metals than of those not so susceptible of oxidation. The experiments of Wilcke and Æpinus shew that in fusion and congelation the different electricities are excited, and the states of *plus* and *minus* produced in the body which has suffered the change of form, and the matter with which it has been in contact during the change: this happens too in the formation and condensation of vapour, and Volta traced it in different cases of chemical action. The observation of such facts becomes more important since the connection of electricity with galvanic phenomena has been established, and that connection itself more clearly demonstrates the importance of electricity as a chemical power.

Sect. II.—*Of Galvanism.*

Galvanism, there is every reason to believe, is the same principle as electricity. Its effects, however, its mode of production, and the laws which it observes in its action, are so far dissimilar, that it is proper to consider it under a separate section. Our knowledge of this agent is of recent date. Galvani, an Italian physiologist, observed the first striking phenomenon which led to the discovery of the principle which has from him derived its name. He observed it only in its power of affecting the animal system, and it is to Volta that we are principally indebted for the just theory of its production, and the development of its chemical powers. It had been discovered by Galvani, that contractions are excited in the irritable parts of animals, when a communication is established by a metallic arc between the nerve and the muscular fibre; and he concluded, that this is owing to the communication of electricity generated by the animal system. Volta supposed, that the electricity producing the contraction, and producing likewise sensations in sentient organs, is produced not from the living system, but by the action exerted between the metal and the humid animal fibre,—a conclusion which he soon demonstrated, by the discovery that it is evolved by arrangements wholly unconnected with any process of vitality. This discovery also gave a

method of augmenting the galvanic energy, enabled us to investigate its effects with more precision, and led to the discovery of its chemical agency.

The Voltaic arrangement consists of a series of metallic plates arranged in a determinate order, with the interposition of certain humid conductors of electricity. The pile, which Volta principally employed, is constructed by commencing with a plate of silver or copper: on this is placed a plate of another metal, as zinc, and on this a piece of card moistened with a saline solution: this series of copper, zinc, and moistened card, is repeated, preserving alwyas the same order, and when 30 or 50 pieces of each have been accumulated, terminating with a plate of zinc at the top, as represented Fig. 27. Pl. III. Between each pair of plates a certain quantity of electricity is generated; in the whole arrangement, we have the accumulated action; and the effects are proportionally great. The extremities of the series are in different electrical states, that commencing with the copper being negative, that with the zinc positive. Another arrangement similar in principle, employed by Volta, is that which he named *Couronne de Tasses*, represented Fig. 26., consisting of a series of cups, in each of which are placed a plate of zinc, and a plate of silver or copper, surrounded with a solution of salt; the plate of silver in the one cup being connected with that of zinc in the other, and the same order being preserved as in the construction of the pile.

An apparatus, still the same in principle, was invented by Mr Cruickshank, the Galvanic Trough as it is named, which, being possessed of every advantage, is now always

used. It consists, Fig. 28. Plate III. of a hollow box or trough, of hard wood, in the sides of which are cut grooves, at the distance from each other of from $\frac{1}{4}$ to $\frac{3}{4}$ of an inch, according to the width of the box. Plates of two metals, generally of copper and zinc, from 3 to 6 or 8 inches square, are soldered together, and this soldered or double plate is inserted in the first groove of the box, and fixed in it by a cement of resin and wax, so well applied that no liquid can pass through. This is repeated, fixing a double plate in each groove, and taking care that the order in which they are inserted shall not be reversed, but that the copper side shall always be towards one hand, the zinc to the other. The cells or cavities between the grooves are designed to contain the fluid by which the galvanism is excited, or serve the same purpose as the moistened cards in the pile of Volta.

The metals used are generally zinc and copper, and these, on the whole, answer best. The number of plates and their surface is regulated by the purpose to which the trough is to be applied. Different liquids are employed to fill the cavities of the trough, and differ much in power. With water the effect is inconsiderable; with a solution of muriate of soda, or muriate of ammonia, it is greater; it is still more so, though it ceases sooner, with muriatic or nitric acid, largely diluted, and, for different purposes, liquids of peculiar composition and strength are best adapted, as is immediately to be stated.

An improvement has been made in constructing the trough. Instead of soldering the plates together, they are kept detached, and are connected only at the upper edge

by a metallic arc; the cells of the trough are formed by partitions of glass, or the entire trough with its partitions is made of earthen ware. The plates of copper and zinc are introduced, so that the one shall be on one side of the partition, the other on the other, the connecting arc passing over it, and a plate of each metal being thus placed in each cell. This arrangement has the advantage, that both surfaces of each plate being acted on, a greater power is obtained, while, in the former method with the soldered plates, one side of each was lost.

Though arrangements, such as have now been described, are most powerful, there are others productive of galvanism to a certain extent. The action between a single metal and a liquid gives signs of it, extremely feeble, and displayed therefore only in the most delicate test of this power,—the contractions it produces in living irritable parts, but no accumulating series of this kind can be formed. If, however, the metal be acted on at its opposite sides by two different fluids, a galvanic arrangement is formed, the power of which increases by repetition. Even charcoal, in contact with one of its surfaces with one liquid, and at another with a different liquid, forms a weak galvanic power; and one, still weaker, is formed from the contact of different kinds of animal matter. Metallic matter, therefore, is not essential to its production.

The properties of galvanism remain to be stated. It passes through those substances which conduct electricity, though with less facility. Metals conduct it rapidly, but there are other substances which admit of the passage of electricity, which at least partially insulate galvanism; such

is water, or dry animal membrane. Glass is a perfect non-conductor.

Its effects on living animal matter are similar to those of electricity. It excites contractions in irritable parts, and sensations in sentient organs, more or less considerable, according to its intensity.

In its transition from one conductor to another, especially when the conductor is an imperfect one, it produces intense light, as, for example, in bringing into contact the wires from each extremity of the battery, or pieces of charcoal or plumbago in communication with each wire. This light appears to be the result of the accumulation of the galvanism, and not of any combustion, for little of the charcoal is consumed, and it can be made to appear under water and other liquids.

Galvanism is the source of intense heat. If a very fine metallic wire be stretched between metallic rods, connected with each extremity of the galvanic battery, its temperature is raised, and if the distance be not too great, to such an extent as to melt even the most refractory of the metals. Fine metallic leaves, suspended from the one rod, are made to burn when touched with a metallic plate in communication with the other. From this arrangement, even gold and silver enter into vivid combustion, and the least fusible of the earths have been melted.

The most important chemical property of this power is that of producing decomposition. Very soon after the invention of the Voltaic battery, it was observed by Messrs Nicholson and Carslisle, that when wires, connected with the two extremities of the battery, are placed in a portion

of water, a stream of gas arises from each wire, an appearance which they found owing to the decomposition of the water. The subject was immediately prosecuted, and a number of chemical compounds were found to be decomposed in a similar manner. Still more lately, Mr Davy, led by the knowledge of the law which regulates these decompositions, and employing galvanic arrangements of great power, has succeeded in discovering the composition of a number of substances, the nature of which was before unknown to us,—discoveries which have materially changed the aspect of the science, and to the prosecution of which scarcely any limits can at present be assigned, for our power of increasing the galvanic force appears to be nearly unlimited, and with this its energy, in counteracting chemical attraction, appears progressively to increase.

The decompositions produced by galvanism consist in the separation of the elements of a compound from their state of combination, by the attraction uniting them being suspended by the galvanic force. But it was not very obvious how this effect is produced, and a difficulty likewise presented itself with regard to them, from the very singular fact, that the elements of the decomposed compound are not evolved together, but the one appears at the wire connected with the one extremity of the galvanic battery, and the other at the wire connected with the other extremity. To account for this, different hypotheses were proposed, not very satisfactory; at length Messrs Hisinger and Berzelius, from a number of experiments, drew the general conclusion, that by attractive forces

exerted at the galvanic poles, certain elements are brought to the positive side, and others to the negative side of the galvanic series; oxygen and acids being attracted to the former; inflammables, metals, alkalis and earths being attracted to the latter. Hence the decomposition of compounds, consisting of substances belonging to these opposite classes, and the distinct evolution of their elements.

This law has been more clearly developed by Mr Davy's researches. The transfer of the elements of the decomposed compound to a distance, and through interposed matter, has been accurately traced, and a number of interesting facts with regard to it established. The apparatus he employed consisted generally of two vessels of glass, or, as less liable to be acted on, of agate, or of gold, connected by a few fibres of the mineral substance named asbestos, moistened with water (Fig. 24. Pl. III.) The solution of a compound substance, of a salt for example, composed of an acid and an alkali, was put into each vessel thus connected, and they were subjected to the action of the galvanic apparatus, a wire from the positive side being inserted in the one, A, and a wire from the negative side in the other, B. In a short time, when a sufficient power is employed, the principles of the salt are separated, the acid is collected in the one vessel, and the alkali in the other. If the solution of a salt were placed in one vessel, and distilled water in the other, either the acid, or the base of the salt, might be transferred through the communicating substance to the distilled water, according as the solution was connected with the positive or the negative side of the galvanic trough: if with the positive side, the

acid remained, and the base was conveyed to the water; if with the negative side, the reverse was the result. In this way, even metals could be transferred, as silver from nitrate of silver, or insoluble earths, as magnesia, from sulphate of magnesia.

When the vessels themselves were composed of substances susceptible of decomposition, such as earthy compounds, sulphate of lime and others, the same separation of elements was effected, though, from the state of cohesion, more slowly. Even glass was found liable to this decomposition. And such is the force of this agent, that the most minute portion of a substance attracted by either of the wires is collected around it,—a circumstance which has frequently been the source of deception in galvanic experiments, with regard to the apparent formation of new products.

So completely is the matter conveyed by the galvanic influence protected by it, that it may be transmitted through a substance to which it has a chemical affinity, without being retained; as, for example, if a third vessel be interposed between the two, and connected with them in a similar manner by moistened asbestos; if an acid liquor be placed in it, an alkali may be conveyed through this without interruption, and be collected round the negative wire; or *vice versa*, if an alkaline solution be put into the intermediate vessel, an acid may be conveyed through it, and collected at the positive wire. If a strong force of cohesion, however, interfere, the substance is intercepted: thus, sulphuric acid is not transmitted through solutions of barytes or strontites, nor these earths through sulphuric acid. The che-

mical affinities of the conveyed substance are suspended by the galvanic influence; an acid, for example, not reddening a vegetable colour in its progress, but only where it is collected around the positive wire; and an alkali, in like manner, exerting its chemical action only at the negative side.

These decompositions appear to be always complete, or the law of chemical affinity so often observed, that an ingredient of a compound, when separated from a combination, retains a portion of the ingredient with which it had been combined, is counteracted; the transferred substance, Mr Davy found, being perfectly pure.

By these researches, then, the general law is established, that certain substances, oxygen and acids, are attracted by positively electrified metallic surfaces, and repelled by similar surfaces negatively electrified; while inflammable bodies, metals, metallic oxides, alkalis and earths, are attracted by negatively electrified metallic surfaces, and repelled by those which are in a positive state. Hence the phenomena of the decomposition of bodies by galvanism, one of the elements of a compound bring forcibly attracted to the one galvanic pole, the other to the other, while each is at the same time repelled from that side to which the other is attracted. And these attractions and repulsions are exerted at considerable distances, producing therefore the transfer of the bodies acted on through any medium in which they are capable of being diffused. Mr Davy has supposed, that the positive electrical state may be communicated at the one pole to the one element, and the negative electrical state to the other at the opposite pole: this

state may be communicated to the particles of each through the whole column interposed between the two poles, and, in conformity to the law, that bodies similarly electrified repel each other, while those in opposite electrical states attract, the particles of the body in the one state will be attracted to one pole, and repelled from the other; a chain or series of particles will thus be established, moving in this direction, while, for the same reason, the particles of the other element will move in the opposite direction, and the motion of each will continue until the whole is collected around that pole to which it is attracted. Or, perhaps, what is equally probable, the particles receiving the charge at each pole, instead of communicating part of the charge to its contiguous particles, may be at once repelled from that side, and attracted to the other. In atmospheric air, we know that bodies, rendered positively or negatively electrical, are attracted and repelled at considerable distances. From the low state of intensity in which electricity exists in galvanic arrangements, water is a medium with regard to it very nearly as atmospheric air is to electricity evolved in the common electrical apparatus, and it may therefore allow electric attractions and repulsions to operate in a similar manner.

Mr Davy has suggested the hypothesis, that even chemical affinity itself may be a modification of electrical energy. Bodies in the same electrical states repel each other; but when in opposite electrical states, they mutually attract. It is conceivable, that some kinds of matter may be naturally positively electrical, others negatively electrical; and if such bodies are presented to each other, their particles will be disposed to unite, and these different elec-

trical energies being present perhaps in different degrees, may give rise to different forces of attraction. The phenomena of galvanism undoubtedly establish the important influence of electrical energy on chemical affinity.

In the production of the different effects arising from the operation of galvanism, a different law is observed with regard to each, in relation to the structure of the galvanic apparatus. By increasing the number of plates in a battery, its power is enlarged, and, by having these plates of a large size, it is likewise obvious that the quantity of power generated must be greater. But the fact, rather singular, has been established, that an increase in the number of plates, without a proportional increase in their extent of surface, does not equally augment all the effects from galvanism, a different law being followed in the power of elevating temperature, of exciting sensations in the organs of animals, and of producing chemical decomposition.

This is apparent from a very simple fact. If a few large metallic plates, of a large surface, as 12 or 15 square inches, be employed as a galvanic battery, it will be powerful in producing light and heat, and will therefore illuminate charcoal vividly, or cause metallic leaves, placed in the circuit, to burn with great brilliancy. But it will display little power of electrical attraction and repulsion, and act feebly on imperfect conductors in producing decomposition. If the same plates be cut down, each being divided into four, and a battery be constructed with these, though there is, on the whole, the same quantity of surface, yet the relation of this to repetition or number being changed, the effects are different; it has little power in burn-

ing the metallic leaves; while it exhibits more evidently the different electrical states, it excites more forcibly sensations or contractions in animal organs, and is much more powerful in giving rise to chemical decomposition.

This has been in particular investigated by Ritter, and he, from a very extensive series of experiments, has endeavoured to establish the relation between number and surface in the metallic plates in a galvanic battery, adapted to the production of each of the effects obtained from galvanism. That of exciting sensations and contractions in animals, he found to be principally dependent on number; that of producing combustion is principally dependent on extent of surface; that of producing chemical decomposition is, in its relation to surface and number, intermediate between these. But with regard to all of them, a certain relation exists, or a certain proportion between number and surface gives the maximum, and, increasing either indefinitely, according to Ritter, diminishes the power. If the due proportion be observed, the galvanic energy displayed in all these effects may probably be indefinitely increased.

The theory of these differences probably is, that a peculiar state of intensity of galvanism is required for the production of each of these effects. The quantity of electricity generated in the apparatus will be proportional to the surface acted on, but its state of intensity is produced by its accumulation, and will therefore be regulated by the quantity of imperfect conducting compared with perfect conducting matter in the arrangement. The liquid interposed between the metallic plates is the least perfect conducting matter: the repetition, therefore, of the

metallic plates, the absolute surface remaining the same, forms an arrangement in which the imperfect conducting matter is most abundant, in which there is the greatest resistance to the evolution of the electric force, and in which therefore this will acquire the highest state of intensity. Now, a considerable intensity is requisite to enable the electricity to penetrate the animal membrane, which it must do to excite sensations or contractions, this membrane being an imperfect conductor: at a lower intensity, it will penetrate liquids, and act in decomposing them; and metals are conductors so perfect, that in the lowest state of intensity it will penetrate them, and produce effects proportional to its quantity. Hence the cause of the peculiar relations of number and surface to these different effects which have been proved to exist; the extent of surface giving quantity, and the repetition of surface in the series or number increasing the intensity.

In conformity to the difference of power thus required to produce these different effects, it has been found that different liquids are adapted to each. To excite that effect by which intense heat and light are excited, measured by the length of metallic wire which is melted, nitric acid, diluted with from 20 to 30 parts of water, is most powerful; sulphuric acid diluted is inferior in power, and the action of both in producing excitation is soon exhausted. For producing chemical decomposition, muriatic acid is better adapted, and it has the farther advantage of its power continuing longer; eight ounces may be added to a gallon of water, or a smaller quantity to a solution of sea-salt.

It remains to consider the theory of Galvanism. What is its nature? And how is it produced by galvanic arrangements?

There can remain little, if any doubt, that Galvanism is Electricity. Not only are they similar in their general properties, and in the laws they observe, but their identity has been more strictly established. If two metallic plates be applied to each other, an arrangement which we know to be productive of galvanism, they are found to pass into different electrical states, the one becoming positive, and the other negative. The two extremities of a galvanic battery are likewise in these opposite states, that connected with the more oxidable metal, the zinc, in the common arrangement being positive, and that with the other metal negative. These states can even be communicated to other bodies; a weak electrical charge being given to a coated jar, and even to an entire battery, by communication with a galvanic trough, the charge being communicated with great velocity, and very nearly to the same intensity as that of the electrical force in the trough itself. And the electricity thus communicated gives precisely the same sensation or shock as electricity in its usual form: all the other electrical phenomena too, such as the passage from one conductor to another at a sensible distance, the discharge through an imperfect vacuum, and the attractions and repulsions of light bodies, have been obtained from the action of a very powerful galvanic battery.

The differences which have been observed between electricity and galvanism are principally that the galvanic influence does not so easily penetrate imperfect conductors

as the cuticle, charcoal, water and other liquids, and that its chemical action is much more energetic, compared with its electrical energy, than in electricity evolved by friction. The cause of these differences appears to be, that galvanism, considering it as electricity, is in a low state of tension. That it should be in this state, appears to follow from the nature of the arrangement by which it is generated, which, consisting of a series of conductors, it is little accumulated, but is carried off as rapidly as it is produced, while, from the nature of the electrical apparatus, which consists of less perfect conducting matter, this does not happen; it is evolved less rapidly, and accumulates to a higher state of intensity. That galvanism does exist in this state of low intensity, appears from the spark from a galvanic battery being so small, and unable to overcome the resistance of the air, if the points of the conducting wires be at a very small distance. And its rapid evolution in this state appears from this, that a charge of low intensity can be communicated from the pile to a connected series of coated jars of very extensive surface by a single contact, while to give a similar charge from a very powerful electrical machine would require repeated contacts. It is farther found, that when arrangements are formed which produce a stream of electricity in constant evolution, its effects are perfectly similar to those of galvanism; Wollaston, by whom the experiment was first made, having shewn, that from very fine silver wires coated with wax, and connected with an electrical machine in action, effects were obtained in decomposing chemical compounds similar to those which they would have produced if connected with a galvanic

battery; and Davy, employing a similar arrangement, has even demonstrated that the principles of the decomposed substance are conveyed to a distance, and collected around the positive and negative wires, as they are by galvanism in its usual form.

On the hypothesis that electricity and galvanism are the same, it remains to be determined by what cause it is evolved, and put in motion in the galvanic arrangements. Two explanations have been given of this subject, one originally proposed by Volta, the other originating with the British chemists.

Volta's hypothesis rests on a fact, which he proves by experiment, that "if two different metals, perfectly dry, insulated, and having only their natural quantity of electricity, be brought into contact, on removing them from that contact, they are in different electrical states; the one is positive, the other negative." In the example of the metals now generally used in galvanic arrangements, the zinc is in the former state or *plus*, the copper in the latter or *minus*. The difference is not very considerable; it is perceptible, however, and, when accumulated in an electric condenser by repeated application of the plates, becomes sufficiently strong to cause the electrometer to diverge. Electricity, therefore, is developed by the mere contact of different metals, independent of any foreign action on them; or one metal, by its contact with another, forces part of its electricity into that other, and this inequality of distribution continues while they are in contact, and no conductor is applied to them. On this principle the action of

the usual galvanic arrangements is explained in the following manner.

If a series of metallic plates were constructed, without any intermediate substance, no accumulation of power would be obtained. The copper, for example, commencing this series, and in contact with a plate of zinc above it, would yield to it part of its electricity, and the zinc would become positively charged. But if another plate of copper were placed above the zinc, this action would be interrupted; the zinc being in contact at each of its surfaces with the two plates of copper, two equal forces would act in opposite directions, and destroy or counterbalance each other. The difference in the electrical state, therefore, of a series thus formed, would not be greater in the whole, than in a single pair of the plates, and would even amount to nothing if the arrangement began and ended with the same metal. But if a piece of moist card or cloth be placed between the plates, that is, between the zinc plate and the second copper plate, the effect of the latter on the former is interrupted: the liquid in the card having comparatively with the metal little of this peculiar electro-motive power, or property of breaking by contact the equilibrium of electricity, does not check the motion, but acting as a conductor, conveys the positive electricity from the zinc to the next copper plate; and accordingly, on this addition of the moistened card, Volta finds, by experiment, that signs of electricity are manifested. By continuing the series the power is always increasing, the action is renewed at each pair of plates, the electricity communicated is always given at the expence of the pieces beneath; these

therefore become negatively charged in a progressive order downwards; the others become positively charged in a similar order upwards: the two plates in the middle of the column are in the natural state; and as highly negative as the copper commencing the series is, as highly positive is the zinc plate which terminates it, the difference being greater according to the number of plates. The different powers of the different metals in affording galvanism, Volta ascribes to the different degrees in which they possess this electro-moving power, or to the effect of breaking the electric equilibrium, being greater in some than in others, zinc taking electricity from every other, and gold yielding it to the rest. The powers of different liquids in exciting galvanism, he supposes owing to their greater conducting power, modified as they have less of the electro-motive quality; and he shews by experiment, that saline liquors, which are superior to water in exciting galvanism, are superior in conducting power. The action which puts the electrical energy in motion, though greatest between the metals, is not peculiar to them; it exists, though to a less degree, in other substances, and hence a galvanic series can be constructed without metallic matter. And were we possessed of any solid substance capable of conducting electricity without having the electro-motive property, we might by means of it construct a galvanic battery without the intervention of any liquid.

The hypothesis opposed to this, considers the excitation of galvanism as the consequence, not of the action of the metals on each other, but of the chemical action of the liquids employed in the construction of the galvanic series

on the metals composing it. The following is the mode in which its evolution, and the determination of its motion are explained on this hypothesis. The commencing series is copper, zinc, and liquid either a saline solution or a diluted acid; a chemical action is exerted between this liquid, and the contiguous surface of zinc, and in consequence of it the electricity is evolved, or passes from the substance of the zinc to the surface acted on; the plate, therefore, becomes negative,—a state which is communicated to the copper on its opposite side. The electrical current is thus determined, or it passes from the zinc through the liquid; it is brought to the next plate: were this zinc, a chemical action would be exerted between it and the fluid, and a current in an opposite direction, by which each would be neutralized, would be formed; but being of copper, and the chemical action being always on the more oxidable metal, the copper merely conducts the electricity to the next plate of zinc; at the other surface of this zinc plate, a fresh portion of electricity is added to the current, by the chemical action which is there exerted; this is repeated at each of these plates; the quantity of electricity is increased as the current proceeds; and hence the last zinc plate of the battery must be in a positive state, while the other extremity is negative.

There is some difficulty in deciding on the merits of these hypotheses, though that of Volta is on the whole superior to the other. It has the important advantage of resting on a principle which is sufficiently established, that two metals by mere contact alter their electrical states. And, from this principle, combined wtth the fact, which

appears also to be proved, that the interposed liquids have little of this electro-motive power, while they are conductors of electricity, it appears to follow that from such an arrangement as that which constitutes the galvanic apparatus, a stream of electricity must be put in motion, and the two extremities of the series must be in the opposite electrical states.

The principal difficulty which attends it, and which affords some ground for the opposite hypothesis to rest on, is that the power of the interposed liquids, in exciting galvanism, does not appear to be proportional merely to their superior conducting power, but to be connected with the chemical action they exert; those being most powerful in exciting it which act chemically with greatest energy, and the excitation in a great measure ceasing when that action ceases. Yet this difficulty is perhaps counterbalanced by the opposite fact, equally established, that the power of certain liquids in exciting galvanism is more than proportional to their chemical action; alkaline solutions, for example, or solutions of sea-salt or sal-ammoniac, affording, next to diluted acids, the liquids best adapted to excite galvanic, though they do not exert any great chemical energy; and in comparing them with these acids, their exciting power is unquestionably much greater than their chemical action. If chemical changes, therefore, at all operate in the production of galvanic electricity, it is probably only as a subordinate cause, modifying the more important one from the electro-motive power.

PART II.

OF THE CHEMICAL PROPERTIES AND COMBINATIONS OF INDIVIDUAL SUBSTANCES.

THE Science of Chemistry divides itself into two great departments,—the one including its general principles, or the statement of the phenomena and laws of those forces from the operation of which chemical changes arise; the other comprising what relates to the operation of these forces on individual substances, embracing therefore the history of the combinations of matter, and the chemical agencies of all known bodies.

I have given the outline of the methods, according to which substances may be classed, in conformity to their chemical relations. The table of the arrangement I have framed is prefixed to the first part of this volume, and it is unnecessary to repeat the observations with which it is accompanied. The first place is given to Atmospheric Air and its Elements, as there are no substances, the chemical actions of which are more important and extensive, and none therefore with which it is more necessary to be acquainted, in proceeding to the details of the science.

BOOK I.

OF ATMOSPHERIC AIR AND ITS ELEMENTS.

THE atmosphere is that mass of elastic fluid which surrounds the globe. This aërial fluid was regarded as an element in the system of ancient philosophy; and one of the most brilliant discoveries of modern chemistry is that of its composition, first clearly demonstrated by Scheele. It consists of two aëriform bodies, oxygen gas, and nitrogen gas; with which are mixed, a small portion of another elastic fluid, carbonic acid, probably originating from accidental sources, and watery vapour in variable proportions derived obviously from the evaporation of water at the surface of the earth. The two latter substances are therefore scarcely regarded as essential to its constitution.

The composition of atmospheric air is demonstrated both by analysis and synthesis. The analysis is performed by submitting it to the action of substances which combine easily with oxygen, and reduce it from the aërial form, such as phosphorus, or the compound liquor formed by boiling sulphur with lime and water: a diminution of volume, amounting to about a fifth part, is produced, and the remaining air is wholly changed in its properties

being incapable of sustaining combustion or animal life. It is nitrogen gas; and the oxygen with which it was united is found to be combined with the substance by the action of which the change has been effected. The synthetic experiment consists merely in mixing oxygen and nitrogen gases in the due proportions, about 21 of the former with 79 of the latter by measure, when an elastic fluid is formed perfectly similar to atmospheric air. To be enabled to explain the chemical agencies of the compound, it is necessary, first, to describe the properties of its constituent parts.

CHAP. I.

OF OXYGEN GAS.

This elastic fluid was discovered nearly about the same time by Scheele, Priestley, and Lavoisier. It received the appellations of Fire Air, Dephlogisticated Air, Pure Air, and Vital Air,—terms superseded by the name of Oxygen, derived from a chemical property eminently characteristic of it, that of giving sourness or acidity to the compounds in which it predominates. Oxygen denotes its gravitating matter or base; Oxygen Gas is the name given to it in its elastic form.

This aëriform fluid is extensively diffused. It not only exists as a constituent principle of the atmosphere, but it

is also the principal component part of water; it exists in all acids, and is found in numerous forms of combination in mineral substances, and in the products of the vegetable and animal systems.

It is from some of its compounds that it is obtained insulated. That which affords it most readily is the mineral substance known by the name of Black Manganese. This consists of a peculiar metal, manganese, united with oxygen. If exposed to a full red heat, a large portion of the oxygen is expelled in the aërial form; the elevated temperature weakening the affinity between the metal and the oxygen, and allowing the latter to escape from the combination, until the increase thus produced in the relative quantity of the manganese to the oxygen that remains, adds so much to the force of its attraction, that the farther decomposition is prevented. The expulsion of the oxygen from the black oxide of manganese is much facilitated by the introduction of another affinity, so that if mixed with its own weight of sulphuric acid, a large quantity of oxygen gas is disengaged from the mixture by the heat of a lamp: the acid favouring its escape, by the attraction which it exerts to the manganese, in a low state of oxidation. Other metallic oxides, as the red oxide of mercury, or the red oxide of lead, afford a portion of oxygen by similar processes; a large quantity is obtained when nitre is decomposed by heat in an earthen retort: another salt, the oxymuriate of potash, affords it, when exposed to a red heat, and in a state more pure than that in which we obtain it by other methods.

Oxygen gas is colourless, and destitute of smell or taste;

it is rather heavier than atmospheric air; being about 1127, the latter being 1000.

This gas is absorbed by water, but in very sparing quantity; 100 cubic inches of water, freed from air by boiling, absorbing not more than 3.55 cubic inches, under a common atmospheric pressure, and at the temperature of 60°. By increasing pressure, a larger quantity is absorbed, proportional to the pressure applied; and, under a great pressure, water may be made to take up about half its bulk of the gas, acquiring, however, from this impregnation, no taste or smell.

The most characteristic property of oxygen gas is its power of exciting and supporting combustion. When an inflammable body is kindled and introduced into it, the combustion is rapid and vivid; the combustible body burns longer, and is more quickly consumed, and much more heat and light are evolved, than when it burns in atmospheric air; and even bodies which do not suffer combustion, when raised to a red heat in atmospheric air, as iron, burn rapidly when they are at this temperature immersed in oxygen gas. Strictly speaking, it is the only gas that supports combustion, atmospheric air and others doing so only from the oxygen they contain. During the burning, the oxygen is consumed, or is absorbed by the burning body; and hence a given quantity of it can support the process only for a limited time. The result of the combustion is frequently the production of a substance having acid properties; and from this, oxygen has been regarded as the principle of acidity.

Oxygen gas is also distinguished by its power of sup-

porting animal life. If an animal be confined in a given quantity of it, it lives a longer time than it would do in the same volume of atmospheric air. A quantity disappears, or is consumed during respiration, and is indispensable to the continuance of life; and atmospheric air, or any gas, sustains life, only from the oxygen it contains and is capable of affording to the blood. Pure oxygen, however, does not appear to be well adapted to animal existence. If an animal be confined in a given quantity of it, its respiration becomes hurried and laborious before the whole of the oxygen is consumed, and it dies even though so much oxygen is still present, that another animal of the same species, introduced into the residual air, will live. Hence the adaptation to animal life of an atmosphere such as ours is, in which oxygen is diluted with another air, which appears to be nearly negative in its effects.

Oxygen has a tendency to combination, more extensive perhaps than any other chemical agent has. It is necessary to support combustion, and during that process it combines with the combustible body. The products are compounds of oxygen, and are numerous and important agents in chemistry. The acids are of this kind, and their activity is principally dependent on their oxygen, which they yield readily to other bodies, and which, by the dense state in which it exists, is often capable of exerting powerful affinities. All the metals are capable of combining with this principle. And it exists in an immense number of natural substances. It is unquestionably more abundant in nature, and more extensively dif-

fused than any simple body: its affinities are more numerous and more energetic; the development of its agencies formed the principal part of what has been named the modern theory of chemistry, and still affords the most important relations of the science.

CHAP. II.

OF NITROGEN GAS.

This elastic fluid remains after the removal of oxygen from atmospheric air, by the processes which have been described. It is most easily procured by burning phosphorus in atmospheric air, or exposing this air to the liquor, formed by boiling sulphur and lime with water: in either case the oxygen gas is abstracted, and the residual nitrogen gas is agitated with water to render it pure. Nitrogen is also disengaged from animal substances, acted on by diluted nitric acid. It has been known by various appellations, as Corrupted Air, Mephitic Air, Phlogisticated Air. It received the name of Azote or Azotic Gas, from being, in opposition to oxygen, incapable of sustaining animal life by respiration. The more correct denomination of Nitrogen is given to it, from being the base of an order of compounds which have been long known by the name of Nitrous.

Nitrogen gas is permanently elastic, invisible, insipid, and inodorous. It is lighter than atmospheric air, its specific gravity being to that of the latter as 966 to 1000.

This gas, possessing no very striking property, is principally characterized by certain negative qualities in its pure form, and by the nature of the compounds it forms. Thus it is incapable of supporting combustion. It is equally incapable of supporting animal life by respiration. It is not inflammable; for although it combines with oxygen, a process generally attended with the phenomena of combustion, nitrogen presents the anomaly of exhibiting none of the appearances of burning during this combination; it neither sensibly evolves heat nor light. Lastly, nitrogen gas is not perceptibly absorbed by water; it suffers no apparent diminution of volume when exposed to it. If, however, the water has been previously freed from all air by boiling, and the nitrogen gas be exposed to it for some hours, a very small quantity, 1.47 cubic inch, is absorbed by 100 cubic inches of the water.

Nitrogen exhibits more distinctive characters in the combinations into which it enters. It unites with oxygen in different proportions, and forms compounds possessed of very peculiar chemical properties. It unites too with hydrogen. And it is a chief ingredient in the products of the animal system, and appears to give their most distinguishing chemical characters.

Opinions have often varied with regard to the nature of nitrogen, and certain facts were observed which rendered the investigation of this difficult. Priestley stated many

experiments in which nitrogen gas appeared to be procured from water by peculiar processes. Thus, in distilling water from an earthen retort, or in passing it through an earthen tube at a red heat, an elastic fluid was always obtained, consisting chiefly of nitrogen. In the freezing of water, a portion of elastic fluid is disengaged, which Priestley found also to be nitrogen; and the production of this appeared to him to be unlimited. A given portion of water, which had been previously freed as much as possible from any air it might hold dissolved, being made to freeze in a tube, gave out air; and when this was removed, and the water melted without exposing it to the atmosphere, still, on freezing it, there was the disengagement of nitrogen gas. Girtanner gave an extensive series of experiments, affording similar results with regard to the production of nitrogen in converting water into vapour. He concluded from them, that nitrogen is, like water, a compound of oxygen and hydrogen, containing a smaller proportion of oxygen than water does; atmospheric air, therefore, he supposed to be a compound of oxygen and hydrogen; and the nitrogen gas obtained from it by the usual methods he supposed to be formed by a portion of the oxygen being abstracted, and the remaining quantity entering into combination with the hydrogen. Priestley had drawn different conclusions. Water he regarded as probably a simple body, and the basis of all elastic fluids, appearing under the form of nitrogen, hydrogen and others, by modifications produced on it by the operation of more subtle principles which we are not able to ascertain by weight.

These hypotheses were generally regarded as extravagant, and nitrogen gas was in the system of Modern Chemistry held to be a simple substance. The late discoveries, however, by the application of galvanism, have appeared to establish facts with regard to it which preclude this supposition. Ammonia is a compound of nitrogen with another elastic fluid, hydrogen; and when this compound is submitted to the action of potassium, the base of potash, aided by heat, an olive-coloured substance is obtained, the ammonia disappears, and a portion of hydrogen is evolved. The solid substance, Mr Davy inferred, from its formation, and from the results of its analysis, is a compound of the potassium with the nitrogen of the ammonia, and a little oxygen derived, either from moisture, or perhaps existing as an element of ammonia. When decomposed by heat, it gives out nitrogen with a portion of hydrogen, and a little ammonia; but the most singular fact is, that in this decomposition less nitrogen is obtained than what ought to be given out. Since, therefore, nitrogen is not evolved in the first experiment, when the ammonia is decomposed by the action of potassium, and since the quantity of it given out in the decomposition of the substance formed by that action, is not equal to what ought to be evolved from the quantity known to exist in the composition of ammonia, there is an evident loss of it; and this loss of nitrogen, Mr Davy farther finds, is accompanied with a production both of oxygen and nitrogen.

From these singular results, if no source of fallacy can be supposed present, it follows, that nitrogen has some peculiar relation both to hydrogen and oxygen. The most

obvious suppositions are, that it may be an oxide of hydrogen; or that both it and hydrogen may be compounds of one elementary matter, the base of ammonia. But we have no facts from which the question can be decided; Mr Davy's subsequent investigations have indeed rather thrown doubt on the former conclusions, as they point out some circumstances whence the loss of nitrogen and production of hydrogen might be in part accounted for, without supposing the nitrogen to be decomposed. Yet even these are not so unequivocal as to be altogether decisive, and the opposite view, as Mr Davy remarks, may still be defended.

The idea of the composition of nitrogen derives no support from the original observations from which it was inferred, the production of it in passing water through ignited earthen tubes, or in the freezing of water; for, with regard to the former, it has been shewn to arise from the admission of atmospheric air from the porosity of the tube; and, with regard to the latter, Mr Davy has found, that when care is taken to exclude the admission of atmospheric air, the production of aërial matter is very limited, and what does appear is probably atmospheric air, and merely the small portion of it held by water in a state of solution. The nature of nitrogen, therefore, remains at present wholly in obscurity.

CHAP. III.

OF ATMOSPHERIC AIR.

For the discovery of the composition of atmospheric air, chemistry is indebted to Scheele. The following is the experiment from which he inferred it: Having put into a bottle, capable of containing 24 ounce measures, four ounces of a liquor prepared by boiling a solution of potash on sulphur, and having closed the bottle accurately, and inverted it in water, he allowed it to remain in this situation for two weeks. At the end of that time, he opened the bottle under water, when a portion of water immediately rushed in, shewing that part of the air included with the liquor had been absorbed, or lost its elastic form: the quantity which had disappeared amounted to six parts nearly of the original twenty. The remaining air was changed in its qualities, was lighter than atmospheric air, and incapable of supporting combustion.

Scheele had previously discovered the existence and properties of oxygen gas, and by this discovery he was enabled to explain the nature of the changes which the atmospheric air had undergone. Since it was diminished in volume, it was obvious that a portion of elastic fluid had been abstracted from it; and since it was also changed in its qualities, and in particular was no longer capable of supporting combustion, it might be inferred, that it had

not been a portion of the entire air that had been absorbed, but a principle which gave it that property. Scheele accordingly concluded, that oxygen gas had been abstracted from it, the entire air being a compound of this with the residual gas, which is nitrogen. He found, what was conformable to this, that oxygen gas is absorbed by the solution of sulphur and potash by which the diminution in the volume of atmospheric air had been produced. And he farther confirmed his conclusions synthetically, by adding oxygen gas to the residual nitrogen when an air similar to atmospheric air was produced. He found, that similar changes are produced in atmospheric air by other substances which are capable of abstracting its oxygen.

Lavoisier soon after advanced the same opinion with regard to the composition of atmospheric air, from experiments in which its oxygen was abstracted by burning inflammable bodies or calcining metals in it. From some of the compounds formed in these processes, particularly in the calcination of quicksilver, he obtained the oxygen which had disappeared, and adding it to the residual nitrogen gas, reproduced atmospheric air. The composition of this air, therefore, is demonstrated, both by analysis and synthesis.

The process by which the proportion of oxygen in atmospheric air is determined, has been named Eudiometry, from an opinion which at one time was entertained, that the salubrious power of the air with regard to animal life depends on oxygen, and that therefore by this process we might be able to ascertain this,—an opinion for which there is no foundation. Different eudiometrical methods

are employed, such as the action of the liquor prepared from sulphur and potash, or sulphur and lime boiled in water, the slow combustion of phosphorus, the detonation of the air with hydrogen gas, and the action of nitric oxide gas,—applications to be noticed under the history of these substances.

The proportions of oxygen and nitrogen in the atmosphere have been variously estimated, from the diversities arising from different eudiometrical processes. The average result from those experiments that can be regarded as most accurate, is 21.5 of oxygen gas to 78.5 of nitrogen gas by measure, or 22.5 to 77.5 by weight.

It has been supposed, that the composition of atmospheric air varies at different parts of the earth's surface, and also at different heights. The reverse of this, however, has been sufficiently established, and, by more recent experiments, made with every precaution, it has been shewn, that air, in the upper regions of the atmosphere, is the same in composition with air at the level of the sea, and that there is an equal uniformity in composition in the air of distant countries. It is also uniform, according to De Marti's experiments, in every state of the atmosphere with regard to temperature, pressure, humidity, the season of the year, or the hour of the day or night. What appears rather more singular, the same experiments prove what Priestley had indeed before established, that the air of places the most offensive and unhealthy, is of the same sensible chemical composition as that of situations the most salubrious; the air of crowded cities, or of manufactories, being not less pure than that of the coun-

try; the deleterious agency, therefore, of such air, depending not on any difference in composition, but on the presence probably of more subtle effluvia, unfavourable to health.

In the composition of atmospheric air, there is a striking singularity, which requires to be pointed out. Its constituent gases are of different specific gravities, and therefore, were they not retained in union by a mutual attraction, it might be concluded that they must separate; the heavier, that is, the oxygen, collecting towards the surface of the earth, the lighter receding from it, and occupying the upper region,—a separation which, it appears from the preceding facts, does not take place. Yet, although they remain united, there are none of the usual indications of chemical union, no modification of properties, and even no change of density. What, then, is the nature of that constitution by which they are preserved in a state of equal and uniform diffusion?

To solve this problem, a very ingenious hypothesis has been advanced by Mr Dalton, founded on the assumption, that the particles of mixed gases neither attract nor repel, but are perfectly indifferent with regard to each other. Did they attract, Mr Dalton conceives, they must enter into intimate combination, which would be marked by a change of properties. Did they repel each other, they must separate, and be arranged according to their specific gravities. Either supposition, therefore, he concludes, is excluded by the known constitution of the atmosphere; and there remains only the hypothesis, that the particles of the elastic fluids composing it neither attract nor repel,

nor are indeed at all affected by their proximity. On this hypothesis, each gas diffuses itself from the repulsion between its own particles, and there rest, upon the surface of the earth, so many columns, as it were, of these gases, each supporting itself by its own elasticity, intimately blended with the others, but altogether independent of each other. And as the diffusion is complete, we discover, in any given portion of the mass, these gases in the same relative proportion.

Another hypothesis may be proposed on this subject, resting perhaps on a principle more probable *à priori*, and equally adapted to explain the constitution of atmospheric air. The most correct views of chemical affinity lead to the principle, that all bodies have mutual attractions, and that these are prevented from operating, so as to establish intimate combination only by the exertion of external forces. In the action of a liquid on a solid, cohesion operates, counteracting the mutual attraction, and, if sufficiently powerful, preventing solution. In the action of an aërial substance on a solid, the cohesion of the one, and the elasticity of the other, are the obstacles to the effective exertion of the attraction exerted between them. And in the case of two aëriform fluids presented to each other, the same elasticity in each is the cause counteracting that affinity which would unite their particles. But in all these cases, it is not to be supposed that the affinity is not exerted: it no doubt operates with a certain force, the circumstances which act against it only being so powerful as to prevent intimate combination. The particles of oxygen and nitrogen gases are capable, under

certain circumstances, of exerting a strong attraction, and entering into intimate combination. Under the circumstances in which they are presented to each other in the atmosphere, this attraction is not exerted so as to overcome the elasticity of each, and establish this combination. But still it exists, and may so far operate as to counteract the slight difference in their specific gravity, and retain them in slight union. This accounts satisfactorily for the phenomena, and, in particular, reconciles the two facts, which appear incompatible, the uniformity of the composition of atmospheric air, while it has no properties different from those of its constituent parts. The principle, too, in the abstract, is more probable than that of the opposite hypothesis. The particles of any individual gas repel each other: why therefore should the particles of mixed gases not exert a similar repulsion? It is scarcely possible to conceive any cause for this, but the exertion of a mutual attraction not sufficiently powerful to overcome their elasticity, and bring them into intimate combination, but exerted at least with such force, as to counteract their repulsion, so as to prevent their separation.

Besides the oxygen and nitrogen which principally compose the air of the atmosphere, there always exists in it a sensible quantity of a compound elastic fluid, Carbonic Acid Gas. This is easily discovered, by exposing to the atmosphere, substances which have an attraction to this gas, as lime water, or an alkaline solution; they are soon found to have imbibed a portion of it. The proportion of this gas to the other gases composing the atmosphere is so small, that it is not easy to estimate it with

accuracy. It has been supposed to amount to a hundredth part. Mr Dalton has inferred, from experiment, that it does not exceed a thousandth by weight. As this gas is produced in respiration, and in other processes at the surface of the earth, the portion of it contained in the atmosphere has been supposed to be derived from these sources. This is not improbable; at the same time, from the reciprocal attraction which gases exert, it is uniformly diffused; and it appears also to be present always in nearly the same proportion, and at the greatest heights at which the air has been examined.

Aqueous vapour is another constituent part of the atmosphere; in quantity, however, very variable, and obviously derived from the evaporation of water at the surface,—an operation dependent on temperature and other causes, and therefore not uniform. The temperature is the great cause by which the quantity is varied, and hence the proportion of watery vapour in the atmosphere is much dependent on climate and season. In the torrid zone, Mr Dalton remarks, its quantity is such as to exert a pressure on the surface of the earth equal to from 0.6 to an inch of mercury: in our climate it is seldom equal to a pressure of 0.6, and in winter is sometimes so low as 0.1. While it preserves completely the elastic form, the air through which it is diffused is perfectly transparent. When condensing, it communicates a degree of opacity, and, according to the extent and rapidity of the condensation, gives rise to the appearances of clouds, dew, mist, and rain.

A subject of chemical inquiry is, by what operation is water elevated in vapour in the atmosphere? and, what is strictly connected with this, in what state does the aqueous vapour exist? Water, being capable of passing into vapour from the action of heat alone, it has been supposed that its elevation in the atmosphere is entirely the result of temperature; the vapour formed existing, according to one view, in a state merely of mechanical diffusion, or independent of any action of the permanent gases upon it, or, according to a different hypothesis, being combined with these gases by a weak attraction. According to a different theory, the transition into vapour is owing to the chemical affinity exerted to water by atmospheric air, and of course it is retained by that air in a state of solution or weak combination.

This last theory, proposed by Halley, and afterwards illustrated by Le Roy, Hamilton and Franklin, is probably the just one. A mutual affinity exists between water and the gases composing the atmosphere, for it absorbs them in sensible quantity; the same affinity must operate in enabling these gases to dissolve a portion of water, and this is promoted, like all similar combinations, by a high temperature, by agitation, and of course also by the dryness of the atmosphere. The opposite views rest on an assumption extremely doubtful, that water, independent of any chemical action of the air upon it, can pass into vapour at natural temperatures. The proof which has been usually given of this is, that water, placed *in vacuo*, passes into vapour at such temperatures. But the proof, from the manner in which the experiment has been performed,

is altogether inconclusive. A little water is placed in the jar of the air-pump, and the air is exhausted, or it is introduced into the barometer, and of course into the more perfect Torricellian vacuum. But in either case the pressure of the atmosphere is withdrawn, along with its chemical agency; and although a portion of water may, under these circumstances, pass into vapour, this is no proof that the same thing will happen under the usual atmospheric pressure. The experiment to be conclusive must be performed under a pressure equivalent to that of the atmosphere, that is, equal to a column of mercury $29\frac{1}{2}$ inches in height. But the result is then subversive of the hypothesis; for water, under that pressure *in vacuo*, does not sensibly evaporate.

It is probable, therefore, that the spontaneous evaporation of water, exposed to the atmosphere, depends principally on the attraction exerted to it by the elastic fluids which form atmospheric air, and the aqueous vapour existing in it may be regarded as in the same state of slight union with the other gases composing it, as they are with each other. The only difference is, that they, being so far distant from the point at which they assume the aëriform state, are not affected by natural changes of temperature, while these changes must effect the combination so far as it relates to the aqueous vapour.

Another chemical question of considerable interest, but still involved in difficulty, relates to the causes by which water is precipitated from the atmosphere, or the theory of rain. It is obvious, that it may be occasioned by reduction of temperature, but it is not easy always to trace this

cause, and especially to account for the deposition being so sudden and copious. Hutton advanced the hypothesis, that the solvent power of air, with regard to water, is increased by temperature in a higher ratio than the increase of temperature itself; and hence, if two portions of air, at different temperatures, are mingled, as they may be in the atmosphere by winds, the whole quantity, if each has been previously saturated with humidity, will be incapable of retaining in solution all the water which the separate portions held dissolved: a quantity therefore will be rapidly separated, and its particles, uniting and meeting with resistance in their descent, will coalesce so as to form rain. The principle of this hypothesis, however, is not established, and it is even perhaps more probable, *à priori*, from theory, that the solvent power should proceed in a decreasing ratio with regard to temperature, the increase of temperature augmenting the elasticity, which is an obstacle to the combination. Electricity has sometimes been supposed to be concerned both in the spontaneous evaporation of water, and in its deposition from the atmosphere, but the facts with regard to this are not well ascertained.

The atmosphere, then, so far as its constituent parts can be ascertained by chemical analysis, consists of oxygen, nitrogen, carbonic acid, and aqueous vapour; the three first are in constant, the last in variable proportions; but taking the mean, the following may be given as the relative quantities of these principles:

Nitrogen gas,	77.5	by measure,	75.55	by weight.
Oxygen gas,	21.	———	23.32	———
Aqueous vapour,	1.42	———	1.03	———
Carbonic acid gas,	.08	———	.10	———

The properties of atmospheric air are simply those of its constituent gases, weakened by their mutual dilution. It is invisible, insipid, inodorous, compressible and permanently elastic. Its specific gravity is .0012279,—the medium, as nearly as can be estimated, between the specific gravities of oxygen and nitrogen gases, in the proportions in which they are mixed in the atmosphere.

Atmospheric air supports combustion, a power dependent on its oxygen. From the operation of the same principle, it sustains animal life in respiration. The action of the nitrogen is negative in both processes; it serves therefore merely to weaken the action of the oxygen.

Water absorbs atmospheric air, though in sparing quantity. The absorption, too, appears to be unequal with regard to its constituent parts, more of the oxygen being absorbed than of the nitrogen. By agitation of a small portion of air with a large quantity of water, the whole of its oxygen may even be abstracted, while the greater part of the nitrogen remains unabsorbed. Hence all water exposed to the atmosphere holds air, chiefly oxygen, dissolved, and it is difficult to expel this air from it entirely.

Atmospheric air is, from its chemical powers, an important agent in many chemical and natural processes. It equalizes temperature over the globe, and distributes water. It sustains life in respiration, and is necessary in the process of vegetation. And by its chemical action it slowly effects changes in the greater number of substances which are exposed to it.

An interesting subject, but one extremely obscure, re-

lates to the natural processes by which the purity and uniform composition of the atmosphere are preserved. By respiration, and many other chemical changes going on at the surface of the earth, there is a constant consumption of its oxygen, and, by many of these processes, there is also a production of carbonic acid gas, by both of which the composition of the air must be altered, and its purity considered in relation to animal life impaired. Yet we do not find that any sensible deterioration takes place; and indeed we have proof, from its adaptation to the processes of nature, that its composition must have always been the same. By what causes, then, is this uniformity of composition preserved? At one time it was imagined, that the vegetable kingdom performed this important function; growing plants absorbing, it was supposed, carbonic acid gas by their leaves, and exhaling oxygen gas. The two tribes of animated beings thus stood opposed to each other in their relations to the atmosphere, and presented an admirable view of adjustment in the economy of nature. There is, however, much reason to doubt of the facts on which this opinion rests, and, from more recent investigations, it appears even, that except when under the direct action of the rays of the sun, vegetables, like animals, consume oxygen, and form carbonic acid. There must therefore be other processes by which the changes in the atmosphere are regulated, and its purity restored;—processes probably depending on the relations which exist between oxygen, hydrogen, and nitrogen, and which the progress of the science may soon unfold.

CHAP. IV.

OF THE CHEMICAL AGENCY OF OXYGEN IN ITS PURE FORM, AND AS IT EXISTS IN ATMOSPHERIC AIR, AND OF ITS GENERAL CHEMICAL RELATIONS.

The attractive power of oxygen towards other bodies is more extensive than that of any other chemical agent, and the history of its combinations forms perhaps the most important part of chemical science,—an importance which the progress of discovery is only more fully unfolding. The agencies of this element admit of some general observations; and as they are exerted by it both in its pure form, and as it exists in atmospheric air, I consider these observations as best placed after the history of the atmosphere. They form the subject of the present chapter.

The most general phenomenon attending the combinations of oxygen, is the evolution of heat and light. This constitutes the operation of Combustion or Burning, the theory of which is first to be explained.

The phenomena of combustion, and the distinction of bodies into combustible or inflammable, and incombustible or uninflammable, are sufficiently familiar. The latter, when exposed to heat, have their temperature raised proportional

to the degree of heat applied; but when this is withdrawn, the temperature falls, and they return to their former state. Combustible bodies, on the contrary, when sufficiently heated, begin of themselves to emit heat: this is also accompanied with an evolution of light; and while these changes proceed, the body appears to be consumed, or at least it is converted into matter, which is no longer inflammable. It is this emission of heat and light, and apparent waste of substance, or change of properties, which constitute the process of Combustion.

Becher first endeavoured to explain these phenomena on chemical principles. Fire he considered as the effect of a peculiar principle, what he named Inflammable Earth, in a state of motion: this principle he supposed to exist in inflammable bodies, and when brought into this state, to exhibit the phenomena of burning. Stahl, without adopting the whole of this hypothesis, supposed that inflammables contain a common principle, the matter of heat and light, on which their inflammability depends; that the disengagement of this gives rise to the sensible phenomena of combustion, and that to its evolution the loss of inflammability is owing. He farther established, in conformity to these views, an important fact, that inflammability may be restored to the uninflammable product, by heating it with another inflammable substance,—a change which he ascribed to the transfer of the inflammable principle, or phlogiston, as he named it, from the one to the other.

This hypothesis appearing to afford a satisfactory explanation of the phenomena, was soon universally received, and, for a considerable period, no doubt was enter-

tained of its truth. In framing it, however, Stahl had not attended to the influence of the air in combustion, which, even before his time, had been demonstrated, and the nature of it in some degree ascertained, by the experiments of Mayow and Boyle. It was therefore defective in not accounting for the necessity of the presence of the air to the support of that process. It had farther been ascertained, that some bodies, instead of losing, gain weight in burning,—a fact inexplicable on the supposition that combustion consists merely in the disengagement of a principle from the burning body.

Various attempts were made to solve these difficulties, but with little success; and the discoveries which were soon after made of the chemical agencies of the elastic fluids, proved still more clearly the deficiency of the original doctrine. It was observed, that combustion proceeds more rapidly in oxygen gas than in atmospheric air; and it was farther shewn, that when it is carried on in atmospheric air, the volume and weight of the air are diminished, and the residual air is incapable of supporting that process,—changes which were farther proved to be owing to the consumption of oxygen. These facts led to different views. While the greater number of chemists laboured to reconcile them with the system of Stahl, two French chemists, Bayen and Lavoisier, considered them as leading to the subversion of the hypothesis. Bayen had observed, that from the calces of metals, as they were named, a large quantity of elastic fluid is given out on exposing them to heat with charcoal, or even with regard to some of them to heat alone, the metal being at the same

time reduced to the metallic form; whence he concluded, that the metal owes its calcined state, not, as the system of Stahl supposed, to the loss of phlogiston, but to its combination with this air. Lavoisier had at the same period traced still farther the agency of the air in combustion. He demonstrated, what in part indeed had been shewn by former chemists, though it had never been much attended to, that its volume is diminished during this process, the diminution ceasing when it proceeds to a certain extent; that the substance in burning increases in weight, and that from the product of the combustion, an elastic fluid may be obtained. The views suggested to him by these experiments, he gradually extended and strengthened by new researches. He at length established the simple principle, that combustion is merely the combination of oxygen with combustible bodies. And availing himself of the discovery of Black, of the large quantity of latent caloric peculiar to the aëriform state, he farther inferred, that the heat produced in burning is not derived from the combustible matter, but from the oxygen gas. With these conclusions were combined others, forming a system, in which the chemical relations of oxygen were developed.

The theory of Lavoisier rests on the following general facts: 1*st*, The presence of oxygen is indispensable to combustion: a combustible body being incapable of being kindled *in vacuo*, or in any air which cannot afford to it oxygen; or, if kindled, it is immediately extinguished in any of these situations: if, on the contrary, it be placed in pure oxygen gas, its combustion is more vivid than in atmospheric air. 2*dly*, The oxygen present is always con-

sumed, as is proved by the diminution of volume and abstraction of oxygen which attend combustion in atmospheric air: hence, too, a burning body, when confined in a certain quantity of air, burns only for a limited time, that is, until the oxygen present is consumed; while, in the same quantity of oxygen gas, it continues to burn much longer; the diminution of volume too is in this case greater, and were the oxygen gas pure, the whole of it might be spent in the combustion. *3dly*, In every case of combustion the combustible body increases in weight, an increase equal to the weight of the oxygen which disappears: this increase of weight indeed is not always apparent; on the contrary, it often appears that the weight is much diminished, or even that the body is entirely consumed; but this is owing to the product being one existing in the aëriform state, and therefore not evident to the senses: if obtained, however, and weighed, it is found to exceed the weight of the combustible body; and in every case of this kind, as well as where the product is a concrete substance, and of course more easily weighed with accuracy, the increase of weight is found exactly equal to the weight of the oxygen gas, which, during the combustion, had combined with the combustible body. *Lastly*, the oxygen which has disappeared during the process of combustion, can always be recovered from the substance formed by the process: it cannot always indeed be obtained in a pure form, for the affinity by which it is retained combined with the combustible body, is in general too powerful to be overcome by the mere application of heat; but it can always be procured by exposing the substance formed by the combustion to the action of another inflammable body, having a

stronger attraction to oxygen; the oxygen is tranferred from the former to the latter, and the substance which we know to be formed from that substance combined with oxygen is obtained; the quantity of this new product indicating the quantity of oxygen transferred, and this always corresponding with the quantity which had originally been consumed in the combustion. All these facts have been ascertained by experiments of great accuracy, and they establish the conclusion, that combustion consists in the combination of oxygen with combustible bodies: These bodies are substances having an attraction to oxygen: And the products of combustion are compounds of them with this principle.

This combination, like other cases of chemical action, is influenced by temperature: in general, heat requires to be applied to cause it to commence, the evolution of caloric from the combination itself being then sufficient to enable it to proceed. The heat operates by diminishing the cohesion of the combustible body which opposes the combination, and the degree of it will be regulated by the force of that cohesion, and the strength of the affinity between the oxygen and the combustible matter.

From the principle thus established, it remains to explain the phenomena which attend combustion,—the evolution of caloric, and of light.

With regard to the origin of the heat in burning, the popular notion appears at first view incontrovertible,—that it is derived from the burning body. It is more or less hot; no other agent appears to be concerned; and it appears nearly a self-evident conclusion, that the body, the

temperature of which is thus elevated, is the source of the caloric by which the elevation is produced. It is accordingly the conclusion which was received in the earlier hypotheses of Becher and Stahl.

The discovery of the influence of the air in combustion, at once invalidates the apparent strictness of the reasoning whence this conclusion was drawn; for, when it is discovered that combustion is not merely an affection of the combustible body, but is the result of its combination with a portion of the air around, it is obvious, that the heat may, with as much probability, *à priori*, be supposed to be derived from the one as from the other. Whether it proceed from the combustible matter, or from the oxygen gas, it must be evolved at the surface where the combination proceeds, that is, at the surface of the burning body: it is apparent to the senses, while the gas being invisible escapes observation; but still the caloric given out by the gas, and communicated to the substance in the act of combustion, may be the cause of its elevation of temperature.

When it was farther ascertained, as was done by the discovery of Black, that aëriform substances contain a large quantity of caloric peculiar to their aëriform state, it became even the more probable opinion, that the caloric evolved in combustion is derived from the oxygen gas, which in that process generally passes into a more dense, and often indeed into a concrete form. This accordingly appears to have been the first modification of this opinion that was proposed, the heat produced being supposed to be the latent caloric peculiar to the oxygen in its aërial form.

Another view of the subject, or perhaps rather a different mode of expressing it, was likewise proposed by Lavoisier. He regarded caloric as existing in bodies, and especially in those in the aëriform state, in a state of chemical combination, and supposed it to be disengaged in combustion from the oxygen gas, in consequence of the superior affinity of the combustible body to oxygen.

Crawford gave the explanation under a form less hypothetical, and more directly inferred from experiment. The general fact had been demonstrated, that different bodies at the same temperature contain different quantities of caloric,—a fact expressed by saying, that they have different capacities for heat. Irvine had farther shewn, that the capacity for heat is often changed by chemical combination. It occurred to Crawford, that this might happen during combustion, and, if it did, might give rise to the evolution of heat which attends the process; for, if the capacity be diminished, in other words if the capacity of the compound resulting from any combination be less than the mean of the capacities of its constituent parts, a portion of caloric must be rendered sensible, or produce an elevation of temperature. This led to an extensive experimental investigation, whence were established the general facts, that the capacity of oxygen gas for caloric is uncommonly great, that the capacities of combustible bodies are comparatively small, and that the capacities of the substances formed by combustion, though superior to those of combustible bodies themselves, are inferior to the mean of these and of oxygen gas. Hence an elevation of temperature must attend the combination, and the caloric

producing this must be derived from the oxygen gas, not from the combustible matter. In different bodies, the difference in the proportion between the capacities before and after combustion are different, and hence the quantities of caloric evolved are extremely various.

It is not difficult to determine which of these explanations is to be preferred. Crawford's involves no hypothesis; and if the experiments by which the capacities are determined be correct, or even be approximations to accuracy, it is simply what every philosophical theory ought to be, the expression of general facts. Nor is there any reason to call in question the general accuracy of the experiments, though, from the difficulty of the investigation, they may be involved in some errors, affecting not the principle, but merely the estimation of the quantities of caloric evolved.

The origin of the light in combustion is of more difficult explanation; at least we can have still less certainty of the justness of any opinion with regard to it. Lavoisier had supposed it to be derived from the oxygen gas, but without any conclusive evidence; for it is obvious, that the admission of the fact, that the caloric is evolved from this gas, is no proof that the light has the same source; at least without the assumption sufficiently improbable, that these two principles are the same.

We have perhaps no very decisive evidence, that the light is derived from the combustible body; still there are some facts which appear to render this rather the more probable opinion. Thus, light is often evolved, when

oxygen is transferred from one inflammable to another, and as the oxygen in its first combination has parted with its light, if it contained any, the light evolved in the second combination must be supposed to be derived from the inflammable body. Another fact, still more conclusive, is, that an evolution of light attends the combination of inflammable substances with each other, of which we have a striking example in the combination of sulphur with metals. This proves that light is a principle existing in these bodies, and as we have no similar proof of its existence in oxygen gas, it follows as the more probable conclusion, that the light evolved in the combustion of these substances is that which they are thus proved to contain. At the same time, it is to be remarked, that with regard to principles so subtle, our conclusions must in the present state of chemistry be somewhat uncertain; and the production of intense light by galvanism, without our being able distinctly to assign its origin, proves sufficiently that we are imperfectly acquainted with the chemical relations of this power.

Very different quantities of light are given out by different combustible bodies in burning; in general, the illumination is greatest from those which are in the state of vapour while burning; at the same time, this is not strictly necessary, some substances which remain fixed, as phosphorus or iron, giving very intense light. The constitution of the light emitted with regard to the different coloured rays, is also different in different bodies, some in burning giving white, others differently coloured light. This appears to be very much connected with the tem-

perature which accompanies the combustion. Those which burn with a low heat, as sulphur or ardent spirit, in general emit the blue or purple rays most copiously; those which burning produce a greater elevation of temperature, as charcoal, give the red rays; and where the temperature is high, and the combustion rapid, all the rays are emitted so as to constitute white light.

Besides the simple case of the combination of oxygen in the elastic form with bodies, which constitutes combustion, there are others rather more complicated, in which, after having been combined with one body, it is transferred from it to another.

Of this, the operation of Deflagration is an example. When an inflammable substance is mixed with nitre, on kindling the mixture, a very rapid combustion, attended with the disengagement of much heat and light, takes place, and this altogether independent of any action of the air. The theory of the operation is, that in nitre there exists a large quantity of oxygen in a concrete form, this salt consisting of nitric acid and potash, and this acid being composed of oxygen and nitrogen. These are not retained in union by a strong attraction; hence, when exposed to heat they separate, and, in deflagration, the oxygen being presented to the inflammable substance, combines with it rapidly, and causes it to burn. The nitrogen gas assumes the elastic form, mixed frequently with an aëriform product from the combustion. There is some difficulty in accounting for the high temperature produced by deflagration. Oxygen existing in the elastic form has a large capacity for caloric, and suffering a di-

minution of capacity in the combinations into which it enters, the temperature must be elevated. But existing in nitre in a concrete state, it is not to be presumed that its capacity will be equally great. In passing therefore into a new state of combination, there cannot be a diminution of capacity to the same extent, and hence there must be less caloric evolved. In some cases even of deflagration, the compound which the oxygen forms with the combustible body exists in the aëriform state, and reasoning from analogy, it must require more caloric to produce in it a given temperature than the nitre itself.

This difficulty perhaps cannot be entirely removed. It may be remarked, however, what so far lessens it, that the consumption of a given quantity of oxygen by deflagration, renders less caloric sensible than the consumption of the same quantity by combustion: thus, Lavoisier ascertained, that in the deflagration of charcoal with nitre, the heat evolved melted 29½ libs of ice, 1 lib. of oxygen being consumed; while in the consumption of the same quantity of oxygen in the common combustion of charcoal, the quantity evolved melted 37½ libs. It is also to be observed, that when oxygen combines with nitrogen, to form nitric acid, little caloric is set free; and again, when this acid combines with potash to form nitre, there is little disengagement of heat. We thus trace the large quantity of caloric in oxygen gas along with it into the solid salt, and hence may expect it to be evolved, when the oxygen is transferred to an inflammable substance. The only difficulty is, whether the large quantity of caloric, which would thus appear to be contained in ni-

tre, can be proved to exist in it from its known capacity, which according to this view ought to be great; and with regard to this, we have as yet no experiments that can be considered as decisive.

The origin of the light in deflagration, must be the same as that in combustion.

From the sudden and rapid extrication of aëriform matter, which attends deflagration, a high elastic power is exerted, especially as the elasticity of this is so much increased by the high temperature. This elastic power is of course greatest when, with the gaseous matter, from the decomposition of the acid of the nitre, there is an aëriform product from the combination of the oxygen with the inflammable. This happens in the deflagration of charcoal and of sulphur, and to this the expansive power of gun-powder, which consists of these ingredients with nitre, is owing. In some cases, the quantity of elastic product is so great, and the elasticity of it so much augmented by the caloric suddenly disengaged, that the mere resistance of the atmosphere gives rise to a loud noise. This forms what is named Detonation. It is not only produced by heat, but, with regard to some substances, by friction, or percussion.

The last general case of the combinations of oxygen to be noticed, is that where it is transferred from one body to another, without being accompanied by the phenomena of combustion. Thus the acids contain oxygen. In acting on an inflammable substance or a metal, they often yield this oxygen. Water, which is a compound of oxygen, sometimes affords it to other bodies; and the presence of an acid often favours this, or causes the water

to be more easily decomposed. In such cases, there is no great elevation of temperature, partly because the oxygen existing in these compounds has been deprived of the caloric peculiar to it in the aërial form, and partly as the substance evolved from the decomposition of the acid or the water, and which is usually gaseous, absorbs much of the caloric that would otherwise be rendered sensible. Neither is there in general any evolution of light: if evolved it is either not sensible from the slowness of the process, or else it passes into combination with the base with which the oxygen had been combined.

The combination of oxygen with a body, whatever may be the phenomena attending it, is named in general its Oxidation or Oxygenation, or, according to the nomenclature proposed by Mr Chenevix, Oxidizement or Oxygenizement. The result of it is, the formation of compounds which possess some common properties, and agree to a certain extent in the chemical agencies they exert. Hence they admit of some general observations.

Of these compounds some have a sour taste, are capable of reddening the vegetable colours, and of combining with the alkalis, so as to neutralize the alkaline properties. A substance possessed of these properties is named in chemical language an Acid. There are a number of Acids, and these in general, so far as they have been analyzed, contain oxygen. Hence this element is considered as the principle of acidity, from which indeed its name is derived.

Acidity, however, is not the invariable result of the combination of oxygen. The products of these combina-

tions are often destitute of any acid property. It is convenient to have a term to denote this class of compounds, and in the modern nomenclature they are denominated Oxides.

Oxides and Acids, then, are two orders of compounds, under which are arranged all those substances that result from the combination of oxygen with other bodies. Acids are distinguished by the possession of certain common properties just now enumerated. Oxides have scarcely any common qualities by which they are distinguished; the distinction being rather negative, or denoting that the compound has no acid power. The alkalis and earths are now to be regarded as oxides, and the most distinguishing property common to them, and likewise to all the metallic oxides, is that of neutralizing the properties of acids. But there are likewise oxides to which this property does not belong. The word oxidation or oxidizement is used, in strict propriety, to denote that combination of oxygen where the resulting compound is not an acid, but an oxide. Oxygenation or oxygenizement is a more general term, expressing every combination of oxygen.

Many substances are capable only of oxidizement. Thus the greater number of the metals are capable of combining with oxygen. These compounds are generally oxides; nor, with the exception of two or three metals, by any addition of oxygen, can they be made to acquire any acid property. Hydrogen unites with oxygen only in one proportion, and forms water, which is not acid.

There are other inflammable substances, again, which are capable of combining with oxygen, forming in one pro-

portion an oxide, and in another an acid. In general, the first degree of oxygenizement forms an oxide, and this by combining with a larger proportion of oxygen forms an acid. Thus nitrogen, united with nearly two parts of oxygen, forms a substance, which having no acid property, is an oxide of nitrogen, while, united with four parts of oxygen, it forms an acid compound. The case is the same with a number of other bodies. Again, there are some which appear to form acids even in the first stage of oxygenizement; at least their existence in the state of oxide is doubtful. But, in all those substances which, by combining with oxygen in different proportions, produce both oxides and acids, the oxide is invariably the product of the first stage of oxygenizement, and the acid results from the addition of a larger proportion of oxygen. In some cases, the same substance too is susceptible of different degrees of oxygenizement, so as to form two acids different in their properties from each other; the one, from the larger proportion of oxygen, being usually the most energetic in its action.

Mr Davy has lately advanced the proposition, that there is another principle productive likewise of acidity different from oxygen,—an opinion which will be considered under the general observations introductory to the history of acids.

BOOK II.

OF WATER AND ITS BASE.

If any ponderable substance can, from general reasoning with regard to its powers, be considered as an element, water may perhaps best claim this distinction. It is the substance which exists in largest quantity in nature, and we can trace its agency in almost all the transmutations to which matter is subject. Hence, in nearly every system, both of ancient and modern philosophy, the elementary nature of water has been admitted as a leading principle.

The more rigorous researches of Modern Chemistry have been supposed, however, to establish its composition. It was observed, that in the combustion of a peculiar species of inflammable elastic fluid, Hydrogen Gas as it is now named, water is the only sensible product; and that the quantity of it which appears is equal to the quantity of this inflammable gas, and of the oxygen gas which are consumed in the combustion. And again, when substances having a strong attraction to oxygen are made to operate on water, they are found to have received this principle; a portion of the water disappears, and hydrogen gas is produced. It appeared to follow from these facts, in conformity to the principles which regulate chemical in-

duction, that water is a compound of these two gases. This conclusion was accordingly received without reserve. Some doubts have lately been suggested with regard to it, but until these are supported on better evidence, water may be regarded as a compound, and hydrogen as its base.

CHAP. I.

OF HYDROGEN.

HYDROGEN exists when uncombined in the aërial form. Being disengaged in various common chemical processes, and from its property of inflammability being more easily recognised than the other elastic fluids, it was imperfectly known to the older chemists. Cavendish first clearly demonstrated its distinct existence and characteristic qualities, under the name of Inflammable Air. It has received the denomination of Hydrogen from being regarded as the base of water.

It is always obtained from water, subjected to the action of substances which attract oxygen. Thus, if watery vapour be passed over iron at a red heat, hydrogen gas is procured, and the iron becomes oxidated. If the resulting affinity of an acid be introduced, its production is more rapid, and takes place at a natural temperature. This is the process, therefore, that is generally followed. One part

of iron or zinc in fragments, is put into a bottle with a bent tube adapted to it, and two parts of sulphuric acid, diluted with five times its weight of water, are poured upon it; hydrogen gas is rapidly disengaged. The agency of the acid in promoting the decomposition is somewhat obscure, but, so far as any explanation can be given, it may be classed as an example of what Berthollet names Resulting Affinity; the acid, the metal, and the oxygen of the water, exerting mutual forces of attraction, which prevail over the single attraction of the oxygen to the hydrogen: hence the three former combine, while the last being separated from its combination with the oxygen, assumes the elastic form.

Hydrogen gas is the lightest of all the elastic fluids, and the lightest substance therefore whose gravity we can ascertain. In its usual state, when collected over water, it is about 10 times lighter than atmospheric air. When freed as much as possible from the water it holds dissolved, it is nearly 13 times lighter, or the specific gravity of water being 1000, that of pure hydrogen is 84. It is from this levity that it is employed in the construction of balloons. When free from water it is inodorous, but when humid it has a slight smell.

Inflammability is the property which, next to its great rarity, eminently distinguishes hydrogen. It kindles on the approach of an ignited body when in contact with the air: if previously mixed with twice its volume of atmospheric air, it explodes when kindled; with oxygen gas its explosion is still more violent. Water is the only sensible product of its combustion.

From this inflammability hydrogen gas has been ap-

plied to the purpose of eudiometry, a given volume of it being introduced into the tube, Fig. 22. with a measured quantity of the air submitted to trial, and inflamed by the electric spark. The diminution of volume indicates the quantity of oxygen that had been contained in the air, 100 measures of oxygen combining with rather less than 200 measures of hydrogen. Thus, 60 measures of hydrogen gas exploded with 100 of atmospheric, leave a residual gas equal to 100 measures, the 21 of oxygen in this portion of air having combined with 39 of hydrogen. Though a eudiometrical method of sufficient delicacy from the great reduction of volume, it is rather troublesome in the execution, and more simple methods are therefore generally preferred.

Hydrogen gas proves fatal to animal life when respired, apparently, however, not by any positively deleterious power, but merely by excluding oxygen: hence it can be breathed for a few inspirations; and when diluted with a portion of atmospheric air, can be breathed longer with safety. It does not, like some of the other elastic fluids, prove noxious to vegetable life; some plants even absorb it; and there are observations which appear to prove, that it can, to a certain extent, supply the place of light in supporting vegetation.

Hydrogen gas is not sensibly absorbed by water, at least unless the water has been previously freed from the atmospheric air it holds dissolved; 100 cubic inches of it then take up, according to Henry's experiments, 1.5 of the gas; by applying strong pressure, the water may be made to absorb one-third of its volume.

Hydrogen enters into chemical combinations with other substances, principally with those that are inflammable, as sulphur, phosphorus and carbon; it also dissolves some of the metals. With oxygen it forms water, with nitrogen ammonia; and it is an abundant ingredient in the vegetable and animal products.

It is disengaged by some natural processes, though not pure. Thus, holding carbon dissolved, it rises sometimes from stagnant water in which vegetable matter is diffused; and in a similar state of composition it is collected in mines, forming what has been named Fire Damp. It has been supposed, that from its levity it may be accumulated in the upper regions of the atmosphere, and that some of the phenomena of meteorology may be connected with its action.

The recent discoveries in chemistry have suggested some interesting speculations with regard to the nature of hydrogen,—a singular fact having been established, which leads to the conclusion, that its base or gravitating matter is of a metallic nature. The substance named Ammonia is a compound of hydrogen with nitrogen. When this is placed in contact with quicksilver, negatively electrified in the galvanic current, the quicksilver increases rapidly in volume, acquires consistence, and becomes at length a soft solid. These are changes strictly analogous to what it would suffer from the addition of metallic matter, and they can scarcely be supposed to arise from any other cause. They lead to the conclusion, therefore, that the ammonia, in the decomposition it suffers in the galvanic circuit, has yielded metallic matter to the quicksilver; this

must be derived either from the nitrogen or the hydrogen, which are the elements of the ammonia. Hydrogen being inflammable, may be supposed, with more probability, to be allied to metals, and the results therefore afford some ground for the conclusion, either that its gravitating matter is metallic, in other words that hydrogen is a metal in the gaseous form, or that it is a metal in some state of combination, perhaps in an oxidated form. Or, from the ultimate relation which appears to exist between hydrogen and nitrogen, both may be compounds of the same metallic base.

Mr Davy has remarked, that even a different view, extending still farther the relations of hydrogen, may be presented; that it may be, as was formerly maintained in the discussion of the antiphlogistic theory, the common principle of inflammables and of metals, forming them, when combined with unknown bases, and thus acting in opposition to oxygen. This receives some support from the apparent relations of those principles to the different electrical states. "Oxygen is the only body which can be supposed to be elementary, attracted by the positive surface in the electrical circuit; and all compound bodies, the nature of which is known, that are attracted by this surface, contain a considerable proportion of oxygen. Hydrogen is the only matter attracted by the negative surface, which can be considered as acting the opposite part to oxygen: may not then the different inflammable bodies, supposed to be simple, contain this as a common element?" But to these speculations, as Mr Davy has justly added, not much importance can be attached.

"The age of chemistry is not yet sufficiently mature for such discussions; the more subtle powers of matter are but just beginning to be considered; and all general views concerning them must as yet rest upon feeble and imperfect foundations."

CHAP. II.

OF WATER.

The composition of water has been inferred both from analysis and synthesis. When hydrogen gas is burnt, an operation in which of course oxygen is combined with it, water is the only sensible product; and when water is acted on by substances capable of attracting oxygen, these are oxidated, water disappears, and hydrogen gas is evolved. From these facts, the conclusion was drawn nearly at the same period by Cavendish and Watt, that water is a compound of hydrogen and oxygen; and the experiment, of forming water by burning hydrogen gas, was executed by the former philosopher on a considerable scale. It has since been often repeated, and with the utmost attention as to the proportions and the accuracy of the results.

This was necessary, not only from the importance of the question in its relations to chemical theory, but also as

some circumstances were found connected with the experiment, which required to be elucidated. In particular, it was observed, that an acid is frequently formed alongst with the water; and some were disposed to conclude, that this is the real product, and that the water is only adventitious, being the moisture deposited, which had been held dissolved by the gases. The repetition of the experiment, however, discovered the origin of this acid. It was found to be generally the nitric: this acid is a compound of oxygen and nitrogen, and had therefore been formed from nitrogen, which had been mixed with the gases, and from which indeed it is difficult to procure them entirely free. Sometimes the acid appeared to be the carbonic, and this had obviously been derived from a small portion of carbon held dissolved by the hydrogen, derived from the materials from which it had been obtained. When these sources of fallacy are guarded against, the water formed in the combustion is perfectly pure, and the weight of it amounts exactly to the weight of the hydrogen and oxygen gases consumed. This has been established by repeated experiments, made on a large scale, and with the greatest care.

The composition of water has also been established by analytic experiments. When transmitted over iron at a red heat, the iron is oxidated, and hydrogen gas is disengaged. And it has farther been proved, that the quantity of hydrogen, added to the increase of weight which the iron gains, corresponds with the quantity of water which disappears.

From these experiments, synthetic and analytic, the

proportions of the two gases which unite to form water have been determined. Excluding fractional parts, which, from the nature of the experiment, cannot be of any importance, they may be fixed at 15 of hydrogen by weight, and 85 of oxygen.

The action of electricity affords a mode of resolving water into its constituent gases, and of combining these again so as to reproduce it. When an interrupted electrical discharge, from a coated jar, is transmitted by wires, placed at a short distance, through a column of water, there is a production of aëriform fluid; and when from repeated discharges this has accumulated in sufficient quantity to be examined, it is found to consist of oxygen and hydrogen gases: hence, when the electric spark is taken in it, it immediately disappears with inflammation; the two gases being combined, and water again formed. The experiment, as a proof of the composition of water, is so far satisfactory, as the results are obtained without the intervention of any other ponderable matter.

Lastly, the action of electricity, in the form of galvanism, has afforded similar results, connected also however with peculiar phenomena, which require to be stated more particularly, as it is from them that doubts have been suggested, whether the theory with regard to the composition of water is just.

If in a quantity of water in a glass tube a wire connected with the positive side of a galvanic battery, and another wire from the negative side be inserted, employing metals which are not susceptible of oxidation, as gold or platina, and bringing the extremities of the wires to the

distance of about half an inch from each other, a stream of gas immediately arises from each, and this continues while the galvanic action is kept up, until, by the accumulation of elastic fluid, the water is depressed beneath the extremity of the upper wire. When this aërial fluid is examined, it is found to consist of oxygen and hydrogen, in the proportions which form water, and by transmitting the galvanic spark through it, it is again converted into water.

In this experiment is presented a phenomenon which appears at first view singular. If the evolution of elastic fluid arise from the decomposition of water, it might be expected that the elements must be evolved together, and that of course a stream of oxygen and of hydrogen gases shall arise from each wire. On making the experiment, however, so that the gas from the wires shall be obtained separate, as is easily done by inserting each in a separate tube, either placed in the same vessel of water, as represented Fig. 25. or even connected only by a humid conductor, or by the interposition of certain liquids, it is found, that the gas from the one wire, that connected with the positive side of the galvanic battery, is oxygen, that from the other or negative side is hydrogen, and each is perfectly pure, if care has been taken to free the water from the atmospheric air it holds dissolved. The elements of the water are evolved therefore at separate, and even at distant points; and the question that obviously presents itself is, what becomes of the oxygen at the wire where the hydrogen is evolved, and what becomes of the hydrogen where the oxygen is given out?

To solve this question, various hypotheses were proposed. It was supposed that water, in common with other compounds, is capable of combining with an excess of either of its ingredients, and that in this experiment it may remain with such an excess at each wire, with an excess of hydrogen at the wire where oxygen is evolved, and with an excess of oxygen at the wire where hydrogen is disengaged,—an hypothesis liable to the obvious objection, that when the portions of water are in separate vessels, connected only by a humid conductor, this must have a limit, and that the properties of the water, from such changes of composition, must soon suffer important changes. By other chemists, it was imagined, that the principles of the decomposed water are conveyed by the galvanic influence to these distant points. How this was accomplished, was never, however, very well explained; and the improbable hypothesis was even advanced, that it might be by the direct combination of the principle of galvanism either with oxygen or hydrogen. Mr Davy at length shewed, that this is merely a case of the general law by which the decompositions from galvanic influence are produced; that certain substances are, from their peculiar relations to electricity, attracted to the positive, and repelled from the negative pole of a galvanic series, while others are attracted to the negative, and repelled from the positive pole; oxygen and acids belonging to the former class, hydrogen, and in general inflammable substances, as well as alkalis and earths, belonging to the latter. When water, therefore, is submitted to the action of galvanism, the oxygen of a portion of it is, in conformity to

this law, attracted to the positive side, and the hydrogen is repelled: the reverse of this happens at the negative side, the hydrogen is attracted, and the oxygen repelled; the decomposition of the water is therefore the result, each of its elements is brought to the wire in connection with that side of the galvanic series to which it is attracted, and as it cannot enter the wire, it there assumes the elastic form. The evidence on which this law rests, has been already stated, and it affords a sufficient explanation of this phenomenon.

Some chemists, however, have proposed a theoretical view of this subject altogether different. It has been remarked, that water may not be a compound, but a simple body assuming the forms of oxygen and of hydrogen according to its electrical states. When rendered positively electrical, it will form hydrogen gas; when in the opposite or negative state, it will constitute oxygen; and when brought within the sphere of action in these forms, the two electrical states will be subverted, the equilibrium established, and water will be reproduced.

It is difficult to prove the impossibility of an hypothesis of this nature, but it forms perhaps a sufficient objection to it, that it has nothing peculiar for its support. Were water the only substance suffering such changes when submitted to galvanic action, this would afford some grounds for such a conclusion; but all compound substances suffer changes equally important; they appear under the form of new substances, or are converted into what we regard as their constituent principles. To consider these principles as the compound in different electrical states, would be an

extension of the theory extravagant and absurd, yet there is no reason why it should be limited to water, since there is nothing peculiar in its apparent production or decomposition. Its conversion into oxygen and hydrogen, by the action of galvanism, is exactly similar to the conversion of sulphate of potash into sulphuric acid and potash by the same action: the conclusion, that the water is a compound of these principles, rests precisely on the same grounds as the conclusion that the compound salt consists of the acid and the potash, and both rest on evidence as direct as can be adduced in support of any chemical fact *.

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* Ritter, by whom this theory of water, being a simple substance appearing under the forms of oxygen and hydrogen, according to its electrical states, was maintained, has stated, that when a wire attached to the positive side of a galvanic battery is placed in water in a tube, and a wire from the negative side is placed in another portion of water in another tube, and when these are connected, not by placing them in a vessel of water, but in separate vessels connected by a metallic wire, the usual phenomena are produced, and the oxygen is evolved at one wire, the hydrogen at the other. Now, although it may be supposed, that particles of oxygen and hydrogen may be conveyed to distant points by powerful attracting or repelling forces through water, it can scarcely be conceived, that they shall be capable of being conveyed thro' the wire of metal, which in this experiment forms the medium of connection between the two portions of water; and hence the result, Ritter concludes, establishes the conclusion, that the communication merely of positive and negative electricity to water (the metallic wire in this case completing the circuit) causes it to assume these forms. Were the fact as it is stated, the conclusion would perhaps follow. I have found, however, on making the experiment, that it is a mere deception. The connecting

It was at one time supposed, that in the decomposition of water by galvanism, there is a formation of new products: a portion of acid frequently was observed to be formed at the positive wire, and of alkali at the negative wire. The origin of these, however, has been sufficiently traced. They are in general derived from the small portion of saline matter which water holds dissolved, and from which it is not even perfectly freed by one distillation, the acid of which is attracted to the one wire, the base to the other; and as these attractive powers are so strong, the most minute quantities are rendered sensible. From the same circumstance, even the containing vessel is sometimes acted on; and the atmospheric air, held dissolved by water, has some influence, its nitrogen,

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wire becomes a galvanic one, and its two extremities becoming electrical, by what electricians have denominated position or induction, are in states of electricity the reverse of the galvanic wires in the tubes; and hence oxygen and hydrogen are evolved at their extremities, corresponding with the hydrogen and oxygen evolved at the others; the extremity of the connecting wire, for example, in the tube in which the *positive* galvanic wire is inserted, being *negative*, and giving out hydrogen, corresponding to the oxygen which appears at that wire, and its other extremity in the tube in which the *negative* wire is inserted being *positive*, and therefore giving off oxygen, corresponding to the hydrogen which appears at that wire. The effect, I have farther found, is exactly the same in the decomposition of a compound salt, acid being collected at the extremity of the positive galvanic wire, and alkali at the extremity of the negative galvanic wire in the different tubes, but the corresponding portions of alkali and acid appearing at the same time at the extremities of the connecting wire.

by combining with the nascent oxygen at the positive pole, forming nitric acid, and combining in like manner with the nascent hydrogen at the negative pole, and forming ammonia. But when these sources of fallacy are avoided, the water, Mr Davy has shewn, remains pure to the end of the experiment, and is resolved into oxygen and hydrogen alone.

Water, as a chemical agent, has qualities extremely peculiar. It affords the example of an inflammable base saturated with oxygen, forming a product which has no acidity. Besides this, though its affinities are extremely numerous, they are seldom energetic; and hence in general it combines with bodies, without materially changing their qualities, and by communicating fluidity to solids, without modifying much their chemical relations, favours their mutual actions.

It is tasteless, colourless, and inodorous. It passes to the solid state at 32° of Fahrenheit, and in doing so crystallizes, spiculæ shooting out at a certain angle, and of a prismatic form: by the continuance of the congelation, the vacuities are filled up, but the mass remains transparent, and is hard and brittle. In congealing, there is, as has been already stated, an enlargement of volume, and this expansion even takes place previous to the congelation, during the reduction of temperature, for six or eight degrees, the greatest density of water being about 40°. In the act of freezing, too, the greater part of the air which the water holds loosely dissolved is expelled.

Water passes into vapour when exposed to the atmosphere at any natural temperature, and even ice evapo-

rates, as is proved by its losing weight when suspended in the air. The transition into vapour is promoted by heat; at 212°, under a medium atmospheric pressure, water boils. Its vapour at this temperature is permanent, transparent, and invisible; when condensing, it becomes, from the approximation of the particles, opaque. It occupies 1800 times the space which it fills when in the state of water, and has a specific gravity to that of atmospheric air at the same temperature as 10 to 14. It exerts a great degree of elastic power, and its elasticity increases in a high ratio by elevation of temperature.

Water absorbs the aërial fluids, but in quantities very different, according to the force of attraction which it exerts towards them. Of some of the acid gases, it absorbs many times its own volume; of others the quantity is so inconsiderable as not to be very perceptible, unless ascertained by an apparatus adapted to shew the result. The quantities absorbed are greater as the temperature is low, down to freezing, when the cohesion of the solid, weakening the affinity, the aërial matter is expelled. They are also augmented by pressure, and, according to a very simple law stated by Dr Henry, as the result of his researches on this subject, "Water takes up in all cases, under equal circumstances of temperature, the same volume of condensed gas, as of gas under ordinary pressure." To whatever degree of density, therefore, the elastic fluid is brought by pressure, the same volume of it is still absorbed; and hence, by increasing pressure, a large quantity of the solid or gravitating matter of the gas may be forced into the water. It is singular, that water thus impreg-

nated by pressure with large quantities of the gases, which, under the mere pressure of the atmosphere it absorbs sparingly, does not suffer much change in its qualities.

This absorption of gases by water, so far at least as regards those which require pressure to cause their absorption in any sensible quantity, has been supposed by Mr Dalton to be a mere mechanical effect, the gas being forced as it were into the interstices of the water by the pressure applied. It is rather to be regarded, however, as arising primarily from the affinity exerted by the water to the particles of the aëriform fluid. This is counteracted by the elasticity of the gas, and not being strong it cannot operate with much effect. Pressure counteracts this elasticity, hence lessens the resistance opposed to the combination, and, operating like reduction of temperature, causes a larger quantity to be absorbed. We accordingly find, that in those cases where the exertion of an affinity by the water to the gravitating particles of the gas is undoubted, as in the example of muriatic acid gas, pressure is equally effectual in promoting the absorption: and also what is in conformity to this view, that even in those gases the absorption of which is inconsiderable, the quantities absorbed are different under the same pressure,—a difference which can only be ascribed to the different forces of affinity exerted to them by the water.

There are some important facts with regard to the relations of water to the aërial fluids in their absorption. Thus, from the affinities it exerts to all of them, however weak, if it be agitated with a mixture of two or more gases, portions of both will always be absorbed, the same as

if they were presented to it separately in their proper density; the quantity therefore being greatest of that which separately is most largely absorbed by water. Or, if water has been previously impregnated with one gas, on agitating it with another, a portion of the latter will be absorbed, and a portion of the former displaced. Hence, as water usually contains a portion of atmospheric air, in exposing any gas to an extensive surface of it, and still more in agitating any gas with it, while a quantity of this is absorbed, a portion of the air the water holds dissolved will be separated, and added to the residual gas, whence frequently sources of error have arisen in chemical experiment; oxygen gas, for example, if kept in a jar surrounded with water exposed to the air, will soon have an intermixture of atmospheric air; and indeed all gases long exposed in this manner have a similar intermixture from the water yielding its air.

Water which has been exposed to the atmosphere always contains portions of both of its constituent gases; but the oxygen appears to be absorbed in preference to the nitrogen, and in larger quantity. Hence by agitating atmospheric air with a large portion of water, or passing it repeatedly through a column of water, the greater part of its oxygen is abstracted. The presence of oxygen loosely combined in water, is usually shewn by the test of sulphate of iron; the oxide of iron which is the base of this salt, attracting this portion of loose oxygen, whence becoming insoluble, it is precipitated, and forms a yellow sediment: this precipitation seems also, however, to be in part owing to the decomposition of the salt by the affinity of the wa-

ter to its acid, aided by its quantity. The portion of air held dissolved by water is expelled with difficulty. It is in part removed by removing the atmospheric pressure by the air-pump, by strong boiling, and by freezing, but part of it is still retained. It is rather singular too that the nitrogen appears to be retained with greatest force. If, through water freed as much as possible from air by boiling, and by the air-pump, an electrical discharge be transmitted, a small portion of nitrogen is disengaged, along with the oxygen and hydrogen evolved from the decomposition of water, as Dr Pearson found in his experiments. And in freezing water which had been previously freed as much as possible from air by boiling, the air disengaged is, according to the experiments of Priestley, nitrogen, especially when the freezing of the same portion of water has been repeatedly performed. Ritter, on the contrary, has inferred from some experiments, that the air disengaged in the freezing of water is oxygen, evolved from decomposition, and that ice has therefore an excess of hydrogen. Mr Davy has more lately found, that this air is atmospheric air, and that the production of it does not take place in the unlimited manner which had been represented by Priestley, but ceases after the freezing has been repeated three or four times. Water melted from snow with the exclusion of the atmosphere, appears to be nearly free from air. Rain water, and especially dew, have, on the contrary, been supposed to be saturated with air. Spring water, besides the atmospheric air it holds dissolved, contains a portion of carbonic acid.

Water is contained in all the elastic fluids, derived ei-

ther from the materials from which they have been extricated, or that through which they have been transmitted. It exists in them in the state of vapour, probably weakly combined, and is capable of being condensed, in part at least, by cold, and of being abstracted by substances exerting an attraction to it, as by sulphuric acid or lime. But even when abstracted as much as possible by the action of these substances, it has been supposed that a portion is retained by a stronger force; and there are facts which appear to prove, that in some gases at least, the quantity of this is considerable, and is essential even to their existence in the aëriform state. This is a question at present of much interest, but not easily determined.

A singular fact, from which this conclusion with regard to the existence of combined water in aërial fluids has been drawn, is, that in compounds in which these gases exist in a dry state, the gas cannot be disengaged by heat unless water be supplied. This is the case with the native carbonate of barytes or of lime; and from the former, even the carbonic acid is very imperfectly disengaged by an acid, unless it be diluted with water. From both facts it has been inferred, that water is essential to the constitution of carbonic acid gas,—an inference which may be just to a certain extent, though it is also possible that the operation of the water may be not altogether on the gas, but on the base with which it is combined, favouring its disengagement by the attraction it exerts to that base.

Another fact in favour of the same conclusion is the disengagement of hydrogen from certain gases, when they

are submitted to the action of the electric spark, after they have been rendered as dry as possible. In some of these experiments, indeed, those where the carburetted hydrogen gases were operated on, it now appears that the fact had not been accurately observed, the phenomena whence the evolution of hydrogen had been inferred being owing to the decomposition of the gas itself; but there are others free from this ambiguity, muriatic acid gas, for example, affording about $\frac{1}{35}$ of its volume of hydrogen gas, on being submitted to the action of the electric spark, after it has been exposed to muriate of lime to abstract its water.

The facts more recently established, with regard to the relation of muriatic acid to water, appear to prove still more clearly the necessity of water to its existence in the gaseous form. Thus Gay Lussac and Davy found, that this acid could not be disengaged from its combinations by a dry acid with the aid of heat, from muriate of lime for example, by phosphoric or boracic acid, while if water were added, it was disengaged in large quantity. The gas itself too, rendered as dry as possible, on being submitted to the action of potassium, afforded hydrogen in such quantity, that Mr Davy inferred, first, that it must contain at least one-tenth of its weight of water, and afterwards that the quantity must amount even to one-third of its weight. These latter facts may indeed admit of a different explanation on the new theory which Mr Davy has given of the constitution of muriatic acid; but that theory can scarcely be regarded as established; and the facts are

on the whole favourable to the conclusion, that in gases, and particularly in those the gravitating matter of which has a strong attraction to water, a considerable portion of this fluid exists, and is necessary to their transition to this state. The still more singular fact appears even to be established, that it is necessary to the development of their acid powers. This, however, will form a subject of consideration under the history of muriatic acid.

Water is the general solvent of saline substances, and in those of them which crystallize, it is always retained, forming a part of the substance of the crystal. It is capable of dissolving the earths, some of them in considerable quantity, particularly barytes and strontites; the others more sparingly. Even those earths and stones which it cannot dissolve, it wears away and reduces to a state of extreme division, partly by attrition, and partly by its chemical powers. Hence it acts even on glass, especially when aided by a high temperature,—a fact which at one time gave rise to the opinion that it is convertible into earth, a portion of earth being always left when it is distilled from glass vessels.

Water, though incapable of combining with the metals, exerts a chemical action upon them, affording to several of them oxygen at the temperature of ignition; and at a natural temperature, aided by atmospheric air, oxidating or corroding others. At a high temperature it is decomposed by charcoal and sulphur, which receive from it oxygen.

Water is a solvent of many other substances. Few of the animal or vegetable products are insoluble in it, and all

of them are affected by it as a chemical agent, receiving from it oxygen, or the re-action of their constituent principles being promoted by the fluidity it communicates, so as to give rise to spontaneous decomposition.

From the extensive solvent power of water, it is scarcely ever met with pure in nature. Every kind of spring or river water is impregnated with saline and earthy bodies of different kinds. Spring water contains, according to Bergman, carbonate of lime, muriate of lime, and muriate of soda; river water contains carbonate of lime, muriate of soda, and each of these also sometimes a little alkali. Well-water, besides these, contains always a portion of sulphate of lime, the presence of which is the cause of the quality in waters termed *Hardness*. Rain or snow water is freer from these foreign substances, but is not perfectly pure, as it affords a trace of muriate of soda and muriate of lime. Water is freed from these substances by distillation; and for any chemical process in which accuracy is requisite, distilled water must be used.

BOOK III.

OF ALKALIS AND THEIR BASES.

THREE substances possessed of certain common properties have been long classed together by the chemists, under the name of Alkalis. They are soluble in water; their taste is acrid; and when applied to animal matter, they erode or dissolve it; they change the blue and purple colours of vegetables to a green, the yellow they change to a brown; they combine with oils and fats, forming soaps; and they unite with the substances which belong to another class, the acids, neutralizing their characteristic properties, so that in the compound which is formed, when the due proportion is observed, the presence of the acid or of the alkali cannot, from any remaining property of either of them, be recognised. The three alkalis are named Ammonia, Soda, and Potash, (or what, for similarity of termination, would be preferable, Potassa.) The first existing when uncombined in the aërial form, and being even when combined with water easily volatilized, has been named Volatile Alkali; the other two, though they are volatilized at a red heat, yet still having comparitive fixity, are denominated Fixed Alkalis.

The most important and characteristic property of the alkalis is that displayed in their relations to the acids,

their combining with them, and forming compounds in which the peculiar acid powers are neutralized. But the same property is possessed by another order of chemical agents, the Earths; and several of these approach even more closely to the alkalis, being soluble in water, acrid and caustic, combining with oils, and changing the vegetable colours to a green. In the leading property common to both, the analogy is even still farther extended, for the compounds of the metals with oxygen, the Metallic Oxides as they are named, are equally capable of combining with the acids, and of neutralizing the acid powers. Thus, the whole are connected into one series; and though the alkalis, earths, and metallic oxides may be distinguished as subordinate orders, by some peculiar characters, they are still in their most important chemical relations strictly connected, and the transition is nearly uninterrupted, from the substance placed at the commencement of the one division, through those belonging to the others.

This analogy has been rendered perfect by the splendid modern discovery, that the alkalis and earths are compounds of a basis of a metallic nature with oxygen; that under this point of view, therefore, they are actually metallic oxides. The earths resembling the more common metallic oxides in many of their properties, had frequently been supposed to be metallic. The same supposition, however, had scarcely ever been extended to the alkalis, partly from the circumstance, that in their properties they are more remote from the oxides of the metals, and partly from the composition of ammonia having been dis-

covered, and having apparently no relation to metallic matter, its elements being hydrogen and nitrogen.

At length, Mr Davy led by the knowledge of the law which regulates the chemical decompositions produced by galvanism,—that oxygen is attracted to the one galvanic pole, inflammable and metallic matter to the other, with a force proportioned to the strength of the galvanic battery, and that, therefore, compounds of these, acted on by galvanism, are decomposed and their elements separated, submitted potash and soda to the action of a powerful galvanic battery. Their decomposition was effected; their bases, substances before altogether unknown, but of a very peculiar nature, may be regarded as metallic, and these bases are combined with oxygen. Mr Davy farther submitted the earths to the same powerful instrument of analysis; and though their decomposition has been rather less perfect, it has been sufficiently so to demonstrate that they also consist of metallic bases in an oxidated state. Ammonia alone remained insulated, until the Swedish Chemists, Berzelius and Pontin, made the interesting discovery, that it, too, when placed in the galvanic circuit, under peculiar arrangements, affords from its decomposition metallic matter. And thus the analogy has been extended through the whole substances belonging to the two orders, and from them to the oxides of the metals, proving that all are of similar chemical constitution.

These conclusions have not, however, been implicitly received. Gay Lussac and Thenard have explained the results on a different theory, that the new metallic substances are compounds of the alkalis and earths with hy-

drogen, and that it is therefore the communication of this element, not the abstraction of oxygen, which takes place in their production.

Though the alkalis, earths, and metallic oxides have been connected by these discoveries, there still remain, perhaps, sufficient reasons to arrange them as distinct orders; and in the present state of chemistry, it is even necessary that this arrangement should be adhered to. The bases of the alkalis and the earths, though they may be regarded as metallic, are very different from the common metals, both in their physical and chemical properties; and except in the leading character of combining with the acids, the alkalis are very different in their qualities from the metallic oxides, and are much more active in their chemical relations. The earths approach nearer to the metallic oxides, and form the series intermediate between them and the alkalis.

Several of the earths, particularly barytes and strontites, approach so nearly to the alkalis in their properties, that it has been proposed to transfer them to this class. They are still, however, on the whole, more strictly connected with the other earths: if the entire series is to be subdivided into two orders, it could not be done with more propriety, than in conformity to those already established; and the alkalis may be regarded as associated and distinguished by their much greater solubility in water, and affinity for it; by their solubility in alkohol; by their greater fusibility and volatility, and in general by their greater activity as chemical agents.

CHAP. I.

OF AMMONIA AND ITS BASE.

This alkali, obtained by indirect processes, was known to the older chemists only in its combination with water, forming the liquid which, from its volatility compared with the other alkalis, was denominated Volatile Alkali. Dr Priestley first shewed, that a permanently elastic fluid can be procured from it by a moderate heat, and that this is the alkali in its pure form.

In the progress of pneumatic chemistry, several facts were observed, proving the composition of ammonia. Priestley found, that on taking the electric spark in it, or on transmitting it through an ignited earthen tube, the volume was much enlarged, and its properties were entirely changed; it was no longer absorbed by water, and was highly inflammable. By heating certain metallic oxides in the ammoniacal gas, he farther found, that they are reduced to the metallic state; a little water appeared to be produced, and the residual gas was nitrogen. Scheele, too, observed the decomposition of ammonia, and the production of nitrogen, particularly in the detonation of fulminating gold, a substance composed of ammonia and oxide of gold.

Berthollet, reviewing and comparing these experiments,

was led by them to institute others, in which ammonia was decomposed; and, from the whole, he inferred that it is a compound of hydrogen and nitrogen gas. From the products of its decomposition by the electric spark, he concluded, that 100 parts of it contain by weight 80.7 of the nitrogen with 19.3 of hydrogen. With this the results of the analytic experiments made by Mr Davy at a later period, almost agree; the proportions he assigns being 80 and 20. Both Dr Henry and Mr Davy find, that when 100 measures of ammonia are decomposed by the electric spark, 74 measures of hydrogen and 26 of nitrogen are obtained, which correspond to the above proportions.

The composition of ammonia is not easily established by synthesis, the elasticity of the two gases being an obstacle to the exertion of the mutual affinity of their gravitating matter, so that when mixed together they cannot be combined, even by the agency of the electric spark. It had been observed, however, that in some cases of chemical action, ammonia is evidently formed, or is evolved, though it does not pre-exist in the materials. This production of it was known to take place in the action of nitric acid on tin; and the theory of its production, as well as the principle on which it depends, were ascertained by Austin. Tin being a metal having a great avidity to oxygen, it decomposes when acted on by nitric acid, both the acid itself and the water the acid contains attracting the oxygen of both. The nitrogen of the one and the hydrogen of the other are evolved: and being presented to each other in the moment of their evolution, and before they have become elastic, (in their *nascent state*, as it has been

named), their mutual affinity is exerted with effect, and they combine. Dr Austin farther found, that it was sufficient to present hydrogen in its nascent state to nitrogen gas to form ammonia, this result being obtained when iron-filings moistened with water are confined in a tube with nitrogen gas over quicksilver. The reverse experiment, however, that of presenting nascent nitrogen to hydrogen gas, was not successful, probably from the great rarity of hydrogen in its gaseous form.

The discovery of the existence of oxygen, as a constituent principle of the other two alkalis, potash and soda, obviously suggested the suspicion, that it probably also exists as an element in the composition of ammonia, and if the experiments on the analysis of ammonia be examined, it will appear that they do not preclude the possibility of this; for when it is resolved into hydrogen and nitrogen gases, a small portion of oxygen might be mingled with these, and not be detected from the manner in which the experiments were made; or by combining with a portion of the hydrogen, it might be disguised in the state of water. On the discovery, therefore, of the existence of oxygen in the composition of the fixed alkalis, it became an object of importance to determine whether it does not also exist in the composition of ammonia.

It appeared to be established by Mr Davy's experiments that it does. On heating charcoal in ammoniacal gas, rendered as dry as possible, carbonic acid (a product formed by the combination of charcoal with oxygen) was formed. By transmitting ammoniacal gas repeatedly over iron-wire in a platina tube at a red heat, the pre-

sence of oxygen was rendered apparent, both by the oxidation of the iron, and the deposition of water. And, lastly, in resolving ammonia into hydrogen and nitrogen gases, by the agency of the electric spark, and estimating the quantities of these by weight from their volumes, there was found a deficit of nearly $\frac{1}{11}$ of the ammonia employed, probably from the disappearance of a portion of oxygen, combining partly with the platina wires employed in the experiment, and partly with hydrogen forming water. From these experiments Mr Davy inferred, that the proportion of oxygen in the composition of ammonia may be equal to seven or eight parts in the hundred, or may even be larger.

The experiments of other chemists have not, however, confirmed these results. Dr Henry, submitting ammonia to analysis by the action of electricity, has, when the due precautions have been observed, been unable to obtain any indications of oxygen; it is resolved into hydrogen and nitrogen alone. The same conclusion has been drawn by Berthollet from his experiments. And, more lately, Mr Davy, repeating his experiments, has not obtained results favourable to the conclusion, that oxygen is evolved in the decomposition of ammonia, but rather establishing the reverse, that the products are hydrogen and nitrogen. In either of these, however, oxygen may be an element, as has been already stated; and on the theory that it is the principle productive of alkalinity, this supposition obviates the anomaly, which ammonia would otherwise present.

The analogy in chemical constitution between ammonia and the other alkalis has been under another point of

view, that which relates to its base, confirmed by the interesting discovery by Berzelius and Pontin, noticed under the history of hydrogen, that metallic matter is obtained from it by the action of galvanism. This matter cannot be procured by itself: it is necessary to introduce the operation of another substance which may combine with it, and this is done by placing quicksilver in the galvanic circuit with a solution of ammonia, or with an ammoniacal salt, carbonate or muriate of ammonia. On completing the circuit, by connecting the positive and negative wires of the galvanic battery with the ammonia and the quicksilver, the latter soon undergoes changes indicating the communication to it of metallic matter. It increases in volume, becomes less mobile, and this continuing, it is at length enlarged to four or five times its original volume, and becomes a soft solid. This change is evidently analogous to amalgamation; and that the metallic matter producing it is derived from the ammonia, is apparent, not only from the circumstances of the experiment itself, but farther, from the fact, that when the amalgam is exposed to the air or dropt into water, ammonia is reproduced. These experiments were confirmed by Mr Davy: they are indeed easily performed, requiring no powerful battery: and Mr Davy farther found, that quicksilver suffers a similar change when ammonia in contact with it is subjected to the powerful de-oxidating influence of the metallic bases of either of the other alkalis.

This metallic matter must be regarded as the base of ammonia, and as such it has been named Ammonium. Whether it is derived from the hydrogen or nitrogen into

which ammonia is resolvable, or from both, or whether these gases are different forms or combinations of it, remains at present unknown; but the discovery sufficiently confirms the analogy between this and the other alkalis.

Ammonia is always procured by indirect processes. Its ultimate source is usually from the decomposition of animal matter, of which its constituent principles are elements, and which, in the new combinations taking place in that decomposition, unite so as to form it. It is thus obtained abundantly in the distillation of bones and other animal substances. Procured in this way, however, it is always impure, and the chemist therefore usually avails himself of a salt, containing it prepared on a large scale for different purposes in the arts, the muriate of ammonia, or sal-ammoniac of commerce, from which it is easily obtained pure. This salt consists of muriatic acid, combined with ammonia. On mixing it with two parts of slaked lime, the pungent smell of ammonia is immediately apparent; and on applying heat to the mixture in a retort, there is an abundant production of elastic fluid, consisting of the ammonia in this form, the lime combining with the muriatic acid of the compound salt, and the ammonia being disengaged. The ammoniacal gas is received over quicksilver, as it is instantly absorbed by water.

Ammonia, in the state of gas, has an odour extremely pungent, and is so acrid as to inflame the skin. It is one of the rarest of the elastic fluids, its specific gravity being to that of atmospheric air as 600 to 1000.—100 cubic weigh 18 grains. It is permanently elastic at natural temperatures, but when exposed to a cold —56° of Fahren-

heit, it is condensed into the liquid state,—a condensation facilitated probably by the operation of the water which it may hold dissolved. The gas extinguishes combustion; it is itself slightly inflammable, the flame of a taper partially introduced into it being enlarged, and when it is previously mingled with atmospheric air it burns with a slight lambent flame, and when kindled in mixture with oxygen gas burns more strongly. When transmitted through an ignited tube, or submitted to the action of the electric spark, it is decomposed.

Ammoniacal gas is largely and rapidly absorbed by water; the water, under a mean atmospheric pressure and temperature, taking up rather more than one-third its weight of the gas. Ice immediately liquefies in it, at the same time condenses it, and this is accompanied by the production of cold. Its solution in water is of inferior specific gravity to pure water, being, when concentrated, not more than 9054. The gas is expelled from it by an elevation of temperature; by intense cold the solution is congealed without the ammonia being separated: the congelation takes place at —40°: and at —58° it loses all smell.

It is under the form of the watery solution that ammonia is usually employed as a chemical agent. The solution is prepared by connecting a retort of green glass with the mixture of muriate of lime and ammonia in the proportions already stated, and with about twice their weight of water, with the bottles of Woolfe's apparatus containing water. Heat is applied to the retort by the medium of a sand-bath: the lime combines with the muriatic acid, the ammonia is expelled, and is condensed partly by the water

that distils over from the retort, and partly by the water in the bottles of the apparatus through which it is transmitted. On a large scale, the distillation is carried on from an iron-still containing the muriate of ammonia and lime dry, to which the fire is directly applied, the still being connected with a spiral tin tube placed in a refrigeratory, and with the extremity of which a series of globular receivers is likewise connected. When properly prepared it is colourless, and has the pungency of the ammonia unaccompanied with any fetor.

Ammonia has been supposed to be inferior to the other two alkalis in alkaline power, as they decompose the compounds it forms with the acids. This, however, is probably owing to its volatility; and as a given weight of it neutralizes larger quantities of the acids than the same weight of the other alkalis do, it follows, from Berthollet's views of the strength of chemical affinity, that it is even superior in power. From the inferior concentration, however, of its solution, it acts less strongly on a number of substances; it combines rather less intimately with the oils, and it does not dissolve the earths.

CHAP. II.

OF POTASH AND ITS BASE.

This alkali has long been employed in a state of greater or less purity as a chemical agent, and has been distinguished by various appellations. Being usually procured from the combustion of vegetables, it received the name of Vegetable Alkali. As it is the base of the impure alkaline salt, the potash of commerce, it has been named Potash. The term Potassa has been received as the Latin appellation, and would be preferable even in our language, as similar in termination to the names of the other alkalis, and as different from the term applied in commerce to a substance containing only the alkali in an impure form: but that of Potash appears to be established by general use.

Potash had sometimes been suspected to be a compound substance, but these conjectures rested only on remote analogies, and nothing was truly known with regard to its composition previous to Mr Davy's discovery of it. Guided by the principles which he had established with regard to the decompositions which galvanism produces, he submitted it to the action of this power in sufficient intensity, and obtained its base,—a substance before altogether unknown, possessed of very singular properties, and which has led to the discovery of others equally peculiar.

The decomposition of potash by galvanism is most easily effected by placing a small piece of it slightly moistened, in a platina cup, in connection with one extremity of a galvanic battery. On establishing the communication with the other side by a wire of platina, an effervescence is excited at the surface of the potash at the positive side, owing to the disengagement of elastic fluid, accompanied with the liquefaction of the potash; while at the surface in communication with the negative side, globules appear having metallic lustre, and in mobility similar to quicksilver. The elastic fluid disengaged, Mr Davy found, is oxygen gas; the metallic globules are the base with which the oxygen had been combined.

This analysis of potash Mr Davy confirmed by synthesis. On exposing the metallic-like matter to atmospheric air, its lustre is diminished, a white crust soon forms upon it, which is potash, and this is accompanied with an absorption of oxygen. On heating it in oxygen gas it entered into vivid combustion; solid potash was likewise produced, and a portion of the oxygen consumed. Or, lastly, on dropping it into water, an immediate disengagement of hydrogen takes place, the metallic matter disappears, and a solution of potash is obtained. From these experiments, both analytic and synthetic, the conclusion appears necessarily to follow, that potash is a compound of this metallic matter and oxygen, since it is resolved into them, and is re-produced when they combine. The proportions have been estimated by Mr Davy to be, at a medium, 85 of base, and 15 of oxygen.

A confirmation of this discovery, extremely important,

as excluding any suspicion that might have been entertained that galvanic action is essential to these changes, was soon after the publication of Mr Davy's experiment made by the French chemists, Gay Lussac and Thenard, potash having been decomposed by them by the action of iron,—an experiment which has been often repeated with success. Clean iron-filings are put into an iron tube, bent so that the filings shall lie in the curvature towards the middle of the tube, and be raised to the necessary heat by being placed in a small furnace. To one extremity of the tube is adapted, by grinding, a smaller one having a stopper inserted at its open extremity, and containing a quantity of pure potash; when the iron-filings are raised to a white heat, this potash is liquefied by applying to it the heat required, and it is allowed to run through a small aperture on the filings. It is then decomposed, the iron attracts its oxygen, and the metallic matter, which is its base, is sublimed to the other extremity of the tube, which is kept cold, so that it shall be condensed. A little hydrogen gas is disengaged during the process, apparently derived from the water contained in the potash, and is allowed to escape by a tube of safety connected with the tube. The metallic matter adheres in brilliant plates to the sides of the extremity of the large tube; it is similar to that obtained from the decomposition of the alkali by galvanism, but is a little heavier, probably from a slight alloy of iron. Potash has also been decomposed by charcoal.

To the substance obtained in these experiments, the base of potash, Mr Davy has given the name of POTASSIUM. The following are its principal properties.

It appears in the form of globules, having metallic lustre and opacity at the temperature of 60, very similar in appearance to those of quicksilver, but rather less mobile. At 70° the mobility and fluidity are greater, and at 100 it is completely liquid, so that the globules run easily together. At 50 it becomes solid, is similar in appearance to silver, and is malleable; at 32 it is hard and brittle. Though it resembles the metals, however, in opacity, lustre, and other properties, it differs from them remarkably in density: in this property it is inferior even to water or alcohol; when liquid it does not sink in naphtha, the specific gravity of which is .77: in its solid state it is rather heavier, but still, even at 40, it floats in this liquid; its specific gravity, therefore, is probably not more than 6, water being 10.

Potassium, though so remarkably affected by heat, is not very volatile; it requires a temperature approaching to ignition to volatilize it. At temperatures inferior to this it combines with oxygen slowly, and without any sensible combustion; but, when heated to the point of volatilization, it burns vividly with intense heat and light. It appears to combine with different proportions of oxygen; for, when slowly heated in a quantity of oxygen not sufficient to saturate it, the oxygen is absorbed, and a substance is formed of a greyish colour, consisting partly of potash, and partly of potassium in a low degree of oxidation. This, when heated in the air, or moistened with water, is converted entirely into potash.

From its avidity to oxygen, potassium decomposes water with rapidity, producing explosion with flame, and being converted by oxygenation into potash. Placed on ice

it burns with a bright flame melting the ice. It attracts oxygen with similar rapidity from the mineral acids, and burns; and so susceptible is it of oxidation, that it is difficult to preserve it unchanged.

It unites with inflammable substances. When heated in hydrogen gas, it diminishes in volume: and the gas, on being mingled with atmospheric air, explodes with the production of alkaline fumes. It unites with phosphorus; and if the air has been excluded, the compound has the appearance of the metallic phosphurets. When heated with sulphur, under the vapour of naphtha, they combine rapidly with the evolution of heat and light, and form a substance of a grey colour, with the lustre and appearance of artificial sulphuret of iron.

It also combines with the metals, and forms compounds having metallic properties which absorb oxygen from the air and decompose water, potash being formed, and the metal separated unchanged. Its action on quicksilver is singular. They instantly combine with the evolution of more or less heat: the potassium in a minute quantity adds to the consistence of the quicksilver, and diminishes its mobility: when the quantity is about $\frac{1}{70}$ of the weight of the quicksilver, the amalgam is soft and malleable: in a quantity a little larger it renders it solid, and nearly similar to silver in colour. When it amounts to about $\frac{1}{30}$ of the weight of the quicksilver, the alloy is hard and brittle. The fluid amalgam dissolves all the metals, even those with which quicksilver alone does not combine. Compounds of the metals with potassium are likewise formed by heating an excess of it with the metallic oxides, one portion of it

abstracting oxygen and forming potash, the other uniting with the reduced metal. From this action it acts on glass, reducing the oxides of iron and lead which it contains, and forming potash, which dissolves the glass.

Though this substance has not the property which has been regarded as most characteristic of the metals, that of great density, it can scarcely but be regarded as metallic, as it has the peculiar physical qualities belonging to the class, opacity, lustre, and malleability: and in its chemical relations it displays properties similar to those of other metals,—combining with oxygen, uniting with inflammables, and with the metals themselves, forming compounds which retain the general metallic qualities.

Gay Lussac and Thenard, in conformity to the theory they have advanced with regard to the metallization of the alkalis, consider potassium as a compound of potash and hydrogen, the latter element being afforded in its formation by the water which the alkali contains. The opinion does not rest on any conclusive argument, and the discussion of it merely as a possible hypothesis, would, in the present state of the inquiry, be premature.

Potash, of which this substance is the base, is usually procured from the combustion of land vegetables, the process being carried on in those countries which abound in wood; the ashes remaining after the combustion being lixiviated, the liquor affords, on evaporation, saline matter, which, when exposed to heat, forms a solid white mass. This consists of various salts, principally of potash, combined with carbonic acid, partly also of potash combined with sulphuric and muriatic acids, together with

siliceous earth, oxides of iron and manganese, and occasionally other impurities. It has not been well determined, whether the alkali is produced by the combustion, or whether it pre-exists in the vegetable matter, and is merely evolved. It is obtained in different quantities from different vegetables: the harder woods afford more than those that are spongy, shrubs more than trees, herbaceous plants a quantity still larger, and even different parts of the same plant give different proportions of it, the leaves, from a given weight, yielding more than the branches, and the branches more than the trunk.

Potash is sometimes procured from other sources, and in a state rather more pure, as from the decomposition by heat of the salt named Tartar, or from the deflagration of nitre with charcoal, this alkali being the base of these salts.

Potash, as obtained by all these processes, is combined with carbonic acid. To abstract this, the saline matter, the Sub-Carbonate of Potash as it is named, is mixed with twice its weight of recently slaked lime, and as much water as is necessary to give the consistence of a thin paste: this is put into a glass funnel, the tube of which is obstructed with a piece of linen; the mass of lime soon subsides, so that the liquid portion filtrates through it very slowly, and water is occasionally added, as the filtration proceeds, until a quantity of liquid has passed through ten times the weight of the sub-carbonate of potash employed. The lime in this process attracts the carbonic acid, and, from the large quantity employed, and the slowness with which the water holding the alkali dissolved passes through

it, the abstraction is more complete than could be obtained by any other arrangement.

Still, though the potash is thus obtained in a state of solution nearly pure, it is not perfectly so; a little carbonic acid remains combined with it, and there may be present too small portions of sulphate and muriate of potash, originally derived from the potash of commerce, as well as a little siliceous earth. To obtain it in a state of purity, different methods have been proposed; that which is generally followed is one proposed by Berthollet. Potash is soluble in alkohol, but is insoluble when combined with carbonic or sulphuric acid. The alkaline solution, therefore, obtained by slow filtration from the mixture of subcarbonate of potash and lime, is evaporated until it become of a thick consistence, and there is then added to it an equal weight of alkohol. A quantity of undissolved matter subsides, a dark-coloured liquid floats above this, which is principally water holding dissolved potash combined with carbonic acid; a lighter coloured liquor is above this; it is drawn off, and is partially evaporated in a silver bason. On standing, it separates into two liquids of different specific gravities, the heavier being a solution of the alkali with carbonic acid, the lighter a solution of the pure alkali. The latter is poured off, and is evaporated, so that on cooling it shall either deposite crystals, or pass into an irregular crystallized mass; a small portion of residual liquor being poured off, the potash is thus obtained in a solid form.

Potash thus prepared is, if the evaporation has been carried to dryness, a substance solid, hard, and brittle, of

a white colour. If evaporated to a less extent, it crystallizes in forms which are modified by the degree of evaporation: it is thus obtained in thin plates, in slender needles, or in tetrahedral pyramids, single or double, these containing different portions of water of crystallization. They produce cold in dissolving in water, while the solid potash produces heat. Even in the driest form to which it is reduced by evaporation, and after it has been kept in fusion, the potash retains a considerable quantity of water combined with it; 100 parts containing, according to Berthollet's estimate, 14 of water. Mr Davy has observed, that the product formed by the combustion of potassium in dry oxygen gas is, from the absence of water, much less fusible than the common potash: it is the alkali in its pure form, and requires about 19 *per cent.* of water to convert it into a substance analogous to the common potash, which, even when it has been heated to redness, is a hydrate of potash.

In all these forms the alkali has a strong attraction to an additional portion of water: it imbibes it rapidly from the atmosphere, so that its surface becomes humid, and dissolves in less than its own weight of water, forming a solution dense and somewhat viscid. It is very fusible, melting at a heat of 360°; this fusibility is owing in part, however, to the water it contains. At a red heat it is volatilized. So great is its causticity, that it quickly erodes animal matter; and its alkaline powers are so energetic, that the most minute quantity of it changes the blue and purple colours of vegetables to a green.

Potash has the distinguishing alkaline property, that of combining with acids, and neutralizing the acid powers, though, as a larger quantity of it is necessary to saturate a given weight of acid than is required of ammonia or soda, it is probably inferior to them in real alkaline power.

It unites too with oils and fats, forming soaps, which, though concrete, are soft or gelatinous.

With some of the earths it combines by fusion, and others it dissolves even in the state of its watery solution.

It has little energy of action on the metals, but combines with some of their oxides. It unites too with sulphur and phosphorus, rendering them to a certain extent soluble in water, and enabling them to decompose it by attracting oxygen.

From the numerous and powerful chemical actions which it exerts, it is applied to many purposes of utility in the arts, and as it is the alkali most easily procured, it is the one most extensively used. It is thus employed in bleaching, dyeing, soap-making, the manufacture of glass and others. In medicine, it is employed as an antacid, a lithontriptic, and an escharotic.

Besides being produced in the vegetable, it is found, though not in large quantity, in the mineral kingdom, either as a saline combination, or as an ingredient in some earthy fossils. It also exists in several of the animal fluids and solids.

CHAP. III.

OF SODA.

Soda being found more extensively diffused in the mineral kingdom than either of the other alkalis, has been denominated Mineral Alkali. The term Soda is that usually applied to it, and is unexceptionable.

On the discovery of the composition of potash, Mr Davy submitted soda to the same methods of analysis, and discovered, that it is a compound of a base apparently metallic with oxygen. It required for its decomposition rather a greater degree of galvanic power than potash did; but when this was applied in sufficient intensity, the phenomena were similar; an effervescence was produced at the positive side, which was found to arise from the disengagement of oxygen gas; and at the surface in contact with the negative wire, globules were produced, having metallic lustre, these being the base of the alkali; the decomposition being effected from the powerful attractions and repulsions exerted at the different galvanic surfaces. This base, exposed to the air, absorbed oxygen, and reproduced soda; the same result took place more speedily, and with the phenomena of combustion, when it was heated in oxygen gas, thus confirming the analysis by synthesis. The quantity of oxygen in soda, Mr Davy

found reason to conclude, is rather larger than in potash, its proportion, taking the mean of various experiments, being 21.5, with 78.5 of base. To this base Mr Davy gave the name of Sodium. The following are its principal properties:

It is white and opaque, with metallic lustre, having the general appearance of silver; it is very malleable, and is so soft, that with a slight force it can be extended in thin leaves, a softness which it retains even when cooled to 32°. Though lighter than water, its density is considerably greater than that of potassium: Mr Davy estimates its specific gravity at .9348. It requires a higher heat to melt it than potassium does: at 120 it begins to lose its cohesion; at 180 it is perfectly fused: it is also less volatile, as it remains fixed even at ignition.

When exposed to the atmosphere it is oxidated, soda being formed on its surface, which deliquesces slowly. When heated nearly to ignition, the combination is attended with combustion; the small globules of it, as they are produced in the experiment of the decomposition of the alkali, are easily inflamed by the electric spark, and when sodium is heated in oxygen gas, it burns with a vivid white light, emitting bright sparks.

From its strong attraction to oxygen, it decomposes water rapidly, soda being formed by its oxygenation, and hydrogen disengaged; and if the water is in small quantity, the heat produced is such as to inflame the sodium. It is inflamed too by nitric acid, and is rapidly oxidated by the other acids. Like potassium, it appears to be susceptible of different degrees of oxygenation; soda, when

only partially de-oxidated, forming a substance of a dark grey colour, and a similar substance being produced when sodium is fused with a portion of soda, which, when exposed to the air, or moistened, attracts oxygen, so as to pass to the perfect alkaline state.

Sodium does not appear to be dissolved by hydrogen, probably from its inferior volatility. It combines with sulphur and phosphorus, the combination being attended with the evolution of much heat and light, and the compounds being similar in external properties to those formed by potassium with the same inflammables.

It unites too with the metals, forming compounds which retain the general metallic properties. When combined with quicksilver in so small a proportion as $\frac{1}{400}$, it renders it fixed, forming a solid which has the appearance of silver. All these compounds are decomposed by exposure to air or water, the sodium by absorption of oxygen being converted into soda.

It is evident, that sodium approaches still more closely in its properties than potassium does to the common metals, as it is more dense and malleable, and less fusible and volatile; and it must be regarded as a metallic substance.

Soda is usually obtained from the combustion of marine vegetables, of which different species afford it in different quantities and states of purity. The various kinds of fuci or sea-weed, afford in this country the impure alkaline product, known by the name of Kelp; on the shores of the Mediterranean, the salsola, salicornia, and others, afford the purer barilla. Even, it, however, contains much fo-

reign matter: the soda contained in it is combined with carbonic acid, and with this are associated muriate and sulphate of soda, charcoal, lime, magnesia, and siliceous and argillaceous earths. The origin of the soda afforded by the process is not altogether determined, but it is most probable that it is ultimately derived from the muriate of soda with which these plants are from their situation supplied; as when they are transplanted to an inland situation, it is established by the experiments of Du Hamel and Cadet, that the quantity they afford diminishes progressively, and after some years they afford only potash. Vauquelin's experiments prove, that in the salsola soda, carbonate as well as muriate of soda exists previous to the combustion.

It is usually from barilla that soda is procured. The barilla in powder being lixiviated with boiling water, the solution on evaporation affords crystals of the salt formed by soda, combined with carbonic acid. To obtain from this the pure soda, it is dissolved in twice its weight of water, to which is added as much lime newly slaked as gives a thick consistence: this being poured into a glass funnel, in the neck of which a piece of linen is put, water is added as the filtration proceeds slowly, until the quantity of solution is equal to five or six times the weight of the subcarbonate that had been employed. The lime abstracts the carbonic acid, its affinity to it being aided by the large quantity of it used, and the slowness with which the solution passes through it. Still the soda has a small quantity of carbonic acid combined with it: to obtain it altogether pure, therefore, it requires to be submitted to the ac-

tion of alkohol, in the manner described under the history of potash.

Soda thus obtained is in the state of a solid white mass, which is crystallized with difficulty; its crystals are prisms, but are not regular: even in its driest state, it contains, like potash, a portion of combined water, to which it owes in part its fusibility. It is acrid and caustic, abundantly soluble in water, and is fused and volatilized by heat. It changes the vegetable colours to a green, and combines with the acids, neutralizing the acid properties: with oils it forms soap; with siliceous earth it unites by fusion and forms glass: it combines too with sulphur and phosphorus, rendering them soluble in water, and enabling them to decompose it.

So close is the resemblance in properties between potash and soda, that the distinctions between them in properties require rather minute attention to discover them. Soda appears to have a less strong attraction to water; in their combinations they can be at once distinguished, the salts formed by the one united with the acids, having qualities altogether different from those of the other. Both are applied to the same purposes.

BOOK IV.

OF EARTHS AND THEIR BASES.

The earthy aggregates which occur in nature are usually heterogeneous or compound; but by analysing them, chemists have arrived at the knowledge of a few substances, in general insipid, of no lustre or transparency, having a loose texture, insoluble in water, uninflammable, very difficultly fusible, and of moderate specific gravity. These resisting farther analysis, they regarded as simple substances, distinguishing them still by the name of Earths, and thus affixing to this term a signification different from that which it has in popular or even in mineralogical language. Four substances of this kind were known to the older chemists, silex, argil, magnesia, and lime: other two were afterwards made known, barytes and strontites, and more lately three, zircon, glucine, and ittria, have been added to the number.

The important discovery has also been made, that they are not simple substances but compounds, their bases being somewhat similar to those of the alkalis, and these bases being united with oxygen. From the similarity of the earths in chemical properties to the metallic oxides, it had often been conjectured that they are of a metallic nature, and their reduction had frequently been attempted, and at

one time had even been supposed to have been accomplished. This, however, was a mistaken result, and nothing was truly known with regard to their composition, until Mr Davy, after his discovery of the chemical constitution of the alkalis, submitted the earths in a similar manner to the action of galvanism. Though results were obtained indicating their composition, these were much less perfect than those obtained with regard to the alkalis, owing partly perhaps to the strength of affinity between their principles, but principally to their being less perfect electrical conductors. By obviating this by submitting them to the galvanic action in mixture with potash, or with metallic oxides, results more distinct were obtained: and a method employed by Berzelius and Pontin proved still more successful,—placing them in the galvanic circuit with quicksilver. They thus obtained the metallic bases of barytes and lime in combination with the mercury. Mr Davy, by the same method, decomposed strontites and magnesia, and by distilling the quicksilver, obtained their bases. By submitting silex, argil, zircon, or glucine, to the action of the galvanic battery in fusion with potash or soda, or in contact with iron, or by fusing those earths with potassiam and iron, appearances were obtained indicating their decomposition, and the production of bases of a metallic nature: and there can remain little doubt, that all the earths are compounds, and of similar constitution.

The bases of the earths obtained in these experiments approach still more nearly than the bases of the alkalis to the common metals, and the earths themselves have a stricter resemblance than the alkalis to metallic oxides.

Yet there are also grounds, as has been already stated, for retaining their distinction as a natural order, forming the link which connects the alkalis with the metals.

Of the characters assigned to the earths, none can be regarded as of itself altogether distinctive. They are usually said to be insipid; but there are three of them, barytes, strontites, and lime, which have a strong taste: they have also been considered as insoluble in water; and the greater number of them are not sensibly soluble, but still these three earths are dissolved in a certain proportion. Infusibility is a character less equivocal, as there is none of them but what requires at least a very intense heat for its fusion. They are altogether uninflammable, a property obviously arising from their being substances saturated with oxygen. In common with metallic oxides, they are destitute of metallic lustre and opacity.

The earths combine with the acids and neutralize the acid properties; these combinations, in the laws they observe, and the compounds to which they give rise, being similar to those which the alkalis form with the acids. There is an exception to this in one earth, silex, which, in the humid way, scarcely unites with any acid but the fluoric, and which does not produce the state of neutralization. It is the substance, therefore, which is at once most remote from the alkalis, and from the metallic oxides.

One property has been assigned as distinctive of the earthy from the metallic salts, that the solutions of the former are not precipitated by prussiate of potash. This is not, however, without exceptions, the earth named ittria, and also, as Klaproth has affirmed, zircon, giving

precipitates with this test. In general, the earthy salts are not much altered by infusion of galls, a re-agent which so sensibly affects metallic salts: neither are they coloured. Ittria affords also, however, an exception to this, some of its salts having a red colour, and being precipitated by infusion of galls; and from these circumstances it ought perhaps to be transferred to the class of metals, though it has not been actually reduced to the metallic state. None of these characters, indeed, is very distinctive.

Several of the earths combine with sulphur and phosphorus, and like the alkalis render these inflammables soluble in water, and capable of decomposing it. The same earths unite with sulphuretted hydrogen.

The earths and alkalis combine. By fusion with either of the fixed alkalis, they form glasses, and the alkali digested with water on several earths, dissolves a portion of them.

The earths combine with the metallic oxides by fusion, forming coloured glasses, and they even exert mutual affinities in the humid way, producing in their mixture moistened with water a degree of induration.

Lastly, the earths exert affinities to each other. Several of them combine by fusion, forming glasses more or less transparent. And when boiled together in water, it frequently happens, that an earth insoluble by itself is dissolved by the affinity exerted to it by another earth, which is itself of sparing solubility. Their mutual affinities exerted in the humid way is well displayed by another fact, that if solutions of two earths in the same solvent be mixed together, in different cases, they combine, the

power of the solvent is overcome, and they form an insoluble precipitate. And in all these combinations, the earths modify materially the properties of each other.

Of the different earths, barytes, strontites and lime have properties considerably analogous to those of the alkalis. They are to a certain extent soluble in water; their solution has an acrid taste, and changes the vegetable blue and purple colours to a green. They have hence been named Alkaline Earths, and, as has been already remarked, it has even been proposed to transfer them from the class of Earths to that of Alkalis. They are still on the whole, however, more strictly connected with the other earths; and they may be placed at the head of the order, forming the transition from the alkalis.

CHAP. I.

OF BARYTES AND ITS BASE.

This earth was discovered by the Swedish Chemists, Scheele and Gahn. It received the name of Terra Ponderosa, from the great specific gravity of some of its combinations, a name changed by Kirwan to that of Barytes. It occurs in nature combined with sulphuric acid and carbonic acid.

This earth had always been more peculiarly supposed to be of a metallic nature, partly from the great weight of

its native combinations, and partly from some of its saline compounds proving poisonous to animals. But this remained a mere conjecture, until the discovery of its composition by the application of galvanism. Mr Davy on placing it slightly moistened alone, or mixed with potash, in the galvanic circuit, obtained appearances of decomposition, and the evolution of metallic matter. Following the method discovered by Berzelius and Pontin, of placing the barytes in contact with quicksilver, in communication with the negative side of the galvanic battery, the analysis was more completely effected; the quicksilver had its fluidity diminished, and on exposing it to the air, it became covered with a film of barytes. And the experiment was still more successful in substituting oxide of quicksilver. He thus obtained an amalgam, from which the quicksilver was separated by distillation, leaving the metallic base of the barytes, a substance which Mr Davy named BARIUM, and which, as obtained by this experiment, he found possessed of the following properties.

It is solid, of a white colour, with metallic lustre, having a resemblance to silver. It melts at a heat inferior to ignition, but is not volatilized even when heated to redness. Exposed to the air, it tarnishes rapidly, and falls into a white powder, which is barytes, oxygen being absorbed. Dropt into water, it immediately decomposes it, evolving hydrogen, and being converted into barytes. It sinks not only in water, but in sulphuric acid, and Mr Davy supposes it to be four or five times heavier than water. It is flattened by pressure strongly applied. Mr Davy was unable to ascertain the proportion of oxygen with which

it is combined in the composition of the earth; but the facts were ascertained that it absorbs oxygen, gains weight by this absorption, and that barytes in its driest state is the product of this operation; whence it follows, that this earth is a compound of this metallic matter and oxygen.

Barytes is procured either from the native carbonate or sulphate. From the former it is obtained, as Dr Hope first shewed, by urging it with the powerful heat of a forge fire in a black lead crucible, the carbonic acid being expelled; and by dissolving the residual matter in water, the barytes may be crystallized. The sulphate may be decomposed by exposing it to a red heat for two hours in a covered crucible, mixed with one-third its weight of charcoal. By adding water to the residual matter, a compound of barytes with sulphur and sulphuretted hydrogen is dissolved; from this the barytes may be precipitated in the state of carbonate, by the addition of carbonate of potash; or by adding nitric acid, nitrate of barytes is formed, and can be obtained crystallized; and either the carbonate or nitrate thus procured can be decomposed by exposure to a sufficient heat, and the pure earth obtained.

As afforded by these processes, barytes is in the state of a grey, solid mass; its taste is extremely harsh and caustic. Exposed to the air it splits, falls to pieces, and is at length reduced to a white powder,—changes analogous to the slaking of lime, and arising like it from absorption of water.

Barytes, when combined with a portion of water, melts when raised to a red heat; when this is dissipated, it requires a more intense heat for its fusion. It appears, however, to be the most fusible of the earths.

It is soluble in water, and its solubility is greater than that of the other earths. When it has been obtained in a solid dry mass, on adding to this a larger quantity of water than is necessary to slake it, a portion of it dissolves, and afterwards forms a congeries of transparent needle-like crystals, which, according to Dr Hope, who observed this phenomenon, are flat six-sided prisms acuminated by four planes. He found them to be soluble in 17.5 of water, at the temperature of 60. The exsiccated barytes, according to Vauquelin, dissolves in 25 parts of cold water, and in twice its weight of boiling water, the latter solution forming crystals on cooling. The crystals of barytes lose their water on exposure to the air, and they suffer the same change from the application of heat. The watery solution has a strong acrid taste, and changes the vegetable blue colours to a green; a film forms on it when it is exposed to the air from absorption of carbonic acid.

Barytes combines with the acids; and as it decomposes a number of the salts which the alkalis form with the acids, it has been supposed to exert to them stronger attractions. These decompositions appear, however, rather to be owing to the exertion of the force of cohesion, from the insolubility of the compounds which it forms with these acids, than to superior strength of affinity: and in the power of neutralizing the acid properties, it is inferior

to the alkalis, and to the greater number of the other earths.

Barytes unites by fusion with the fixed alkalis, and likewise with several of the earths, though there are others of them with which it does not combine. It combines with several of them in the humid way, and communicates to them solubility, or otherwise modifies their properties. Thus it renders argil soluble in water, and silex it enables to combine with different acids.

Barytes combines with sulphur, either by fusion or by boiling them together in water, and by a resulting affinity enables the sulphur to decompose the water. It exerts a similar action on phosphorus. And it unites with some of the metallic oxides.

A chemical property which has been assigned to barytes, as distinctive of it, is that of its salts giving a precipitate with prussiate of potash, a property not belonging to the other earths, but characteristic of the metals. This precipitation, however, arises from the impurity of the prussiate, and in particular from its containing sulphuric acid. When pure, no immediate precipitation is produced by it in the barytic salt, though, after a few hours, if the solution is sufficiently concentrated, crystals of prussiate of barytes are formed.

This earth exerts considerable activity on the living system, and several of its saline combinations prove even poisonous.

CHAP. III.

OF STRONTITES.

The native carbonate of strontites, found at the mine of Strontian in Argyleshire, had been considered as a variety of carbonate of barytes, until Dr Hope shewed that the earth it contains is different from barytes and from any other. He at the same time pointed out its principal properties and chemical relations. Klaproth also and Pelletier afterwards demonstrated the existence of this as a distinct earth. It derives its name from the place where it was first found. It has besides been discovered native in different countries in the state of sulphate.

The decomposition of this earth has been effected by submitting it to the action of galvanism, in the same manner as barytes, and by a similar process its base has been obtained. To this base Mr Davy has given the name of Strontium. Its properties have been, however, only imperfectly examined. In lustre, colour, specific gravity, and other physical properties, it appeared to be similar to the metallic base of barytes; by exposure to the air it is converted into strontites, absorbing oxygen, and gaining weight in this conversion.

Strontites is obtained from either the native carbo-

nate or sulphate, by processes the same as those which have been described under the history of barytes. It is obtained crystallized, by dissolving the dry solid mass in boiling water, and allowing the solution to cool; crystals are formed an inch in length, the form of which is a thin quadrangular table, or compressed prism, sometimes bevelled at the extremities; they are transparent, but become white and opaque on exposure to the air, from losing their water of crystallization. The taste of this earth is less harsh than that of barytes, and it is not poisonous.

Crystallized strontites exposed to heat liquefies from the augmented solvent power of the water of crystallization; when this is expelled, the white powder which remains cannot be fused even by a very intense heat.

Strontites is soluble in water, the crystals requiring 50 parts at 60°; boiling water dissolves half its weight nearly. In its dry and uncrystallized state, it of course requires a much larger quantity, nearly 200 parts at 60°. The solution changes the vegetable colours to a green. This earth is likewise soluble in alkohol.

Strontites combines with the acids forming salts, of which some are soluble and crystallizable; others insoluble. The same superiority in strength of affinity has been ascribed to this earth as to barytes, from its decomposing the salts of the alkalis and other earths, but this arises from the same cause, the insolubility of the compounds it forms with the acids of the salts in which it occasions these decompositions. Its salts are in general decomposed by barytes. Dissolved in alkohol, they give

it the property of burning with a blood red flame, a property which has been assigned as one of those distinctive of this earth.

Strontites exerts no peculiar action on the alkalis, nor in general on the other earths, though with some of the latter it combines by fusion. It unites with sulphur; the compound is soluble in water, and at the same time decomposes it. On phosphorus its action is similar.

This earth resemble barytes in so many of its properties, that distinctive characters require to be pointed out, by which they may be discriminated. Strontites is less soluble in water; the forms of its crystals are different; its salts, particularly the nitrate and muriate, are considerably more soluble in water, and their solubility is augmented in a greater ratio by heat; they are decomposed by barytes; and they give a blood red colour to the flame of combustible bodies. Two re-agents distinguish them in their combinations. The watery solution of strontites is not like that of barytes precipitated by malic or gallic acid: and when the salts of strontites are decomposed by oxalic acid, the precipitate is not redissolved by an excess of acid, as that from the barytic salts is.

CHAP. III.

OF LIME.

This earth exists in great abundance in nature, usually in combination with acids. Its compound with carbonic acid forms the numerous varieties of marble, limestone, chalk and marl: with sulphuric acid it forms gypsum or plaster stone; and in these and other saline combinations it exists in the water of springs, in the water of the ocean, in vegetable and in animal matter.

Submitted to the action of galvanism in high intensity, lime gave indications of decomposition; and when the method described under the history of barytes was employed, Mr Davy obtained the amalgam of its base. This amalgam exposed to the air or to water, absorbed oxygen, lime being reproduced. In an experiment designed to obtain the base in an insulated state by distilling the quicksilver from it, the tube broke while warm, and at the moment that the air entered, the metal, which had the colour and lustre of silver, took fire, and burnt with an intense white light into quicklime. To this base Mr Davy gave the name of Calcium.

Lime is obtained with most facility from the native carbonate, from which, by a strong heat, the carbonic acid

may be expelled. This process is conducted on a large scale on the different varieties of limestone, for the purposes to which lime is applied. As it is not obtained altogether pure, the chemist, to have it in a state of purity, dissolves marble or chalk in diluted muriatic acid, leaving an excess of lime undissolved: any precipitate afforded by the addition of pure ammonia is separated; the solution is then decomposed by carbonate of potash or soda, and the carbonate of lime being washed with water and dried, is decomposed by heat.

Lime is white, moderately hard and brittle: exposed to the air it quickly absorbs water, which diminishes its cohesion, and causes it to fall down into a white powder extremely fine; this is the slaking of lime. It takes place rapidly from the affusion of water; the quantity absorbed is equal to one-fourth of the weight of the lime; and from its transition to a solid state in combining with the lime, a large quantity of caloric is evolved, producing considerable heat.

Lime is infusible; at least it does not melt in the intense heat excited by the concentration of the solar rays by the most powerful burning mirror, or that excited in the burning of combustible matter by oxygen gas.

It is soluble in water, the water at 60° dissolving about $\frac{1}{800}$th of its weight: at 212° it dissolves double that quantity, depositing the excess as it cools. The solution, Lime water as it is named, has a strong styptic taste, and changes the vegetable blue and purple colours to a green. Exposed to the air, a film forms on its surface from the absorption of carbonic acid, and the whole of the lime near-

ly is at length precipitated in the state of carbonate. The same absorption of carbonic acid takes place in dry lime, though much more slowly.

With the acids lime combines, neutralizing the acid properties. Its salts are in general decomposed by potash or soda, either of which precipitates the lime from their solutions; but not by ammonia, probably from the tendency which this alkali has to form a ternary compound with the acid and the lime.

Lime does not combine with the fixed alkalis by fusion, nor with barytes or strontites; but it unites either in the humid way, or by the application of heat, with magnesia, argil and silex.

It combines with sulphur and with phosphorus, rendering them soluble in water, and capable of decomposing it at a low temperature. It melts too, with several of the metallic oxides, forming coloured glasses; it even exerts affinities to several of them in the humid way, and in consequence of these affinities promotes the oxidation of the metals themselves by the action of air or water.

Of the different earths, lime is most extensively used. It is applied as a manure in agriculture; it forms the basis of mortar; and in practical chemistry, and many of the chemical arts, it admits of numerous applications from its chemical agencies.

CHAP. IV.

OF MAGNESIA.

This earth, in the state of carbonate, had been employed in medicine, and had been considered as analogous to carbonate of lime. Hoffman observed, that it formed with sulphuric acid a salt very different from that formed by lime with the same acid. And Dr Black discovering its principal properties, proved it to be essentially different from the other earths.

It is not much affected by galvanism, probably from the difficulty of rendering it a conductor of electricity. But when some of its saline compounds are submitted in the usual manner, in contact with quicksilver, to galvanic action, an amalgam is obtained, which contains the metallic base of magnesia, as this earth is formed on its surface by exposure to the air. From this amalgam, Mr Davy found it difficult to expel the whole of the quicksilver, the glass tube in which heat was applied to it being acted on. In one experiment a solid was obtained, having the white colour and the lustre of the metallic bases of the other earths, which sunk rapidly in water, producing magnesia, and was also covered with a crust of magnesia on exposure to the air. To this substance the name of Magnesium may be given.

Magnesia, under various states of saline combination, exists in nature in considerable quantity. It is found, in particular, in the water of the ocean, united with sulphuric and muriatic acids, and the same salts frequently exist in mineral springs. From either of them the magnesia may be procured by decomposing them, by adding to their boiling solution an alkaline carbonate; the carbonate of magnesia is precipitated, and being thoroughly washed and dried, the carbonic acid is expelled from the magnesia by a red heat.

Magnesia obtained by this process is in the form of a white light spongy powder, very soft to the touch, inodorous, and having a slightly bitter taste. It slightly changes the blue vegetable colours to a green.

It is infusible when exposed even to the most intense heat. If previously made into a paste with water, it suffers contraction when exposed to a sudden heat.

It is insoluble in water; when dry, it absorbs a portion of water, but does not form with it a ductile paste.

Magnesia combines with the acids: its salts are in general very soluble and crystallizable, and have a very bitter taste. They are decomposed by the fixed alkalis and by the alkaline earths, the magnesia being precipitated. Their decomposition by ammonia is partial, this alkali having a tendency to form with the magnesia and acid ternary compounds.

It exerts no reciprocal action with the alkalis, nor with the alkaline earths. It combines by fusion with lime, and in the humid way it exerts an affinity to argil, combining with it, and modifying its properties.

It combines, though very imperfectly, with sulphur. By sulphuretted hydrogen it is dissolved in small quantity. On the metals or metallic oxides it exerts no evident action.

Magnesia is scarcely applied to any use, except in medicine as an antacid. Some of the native combinations of it with other earths have been used in the manufacture of porcelain.

CHAP. V.

OF ARGIL.

This earth is the base of the different clays, whence the name of Argil has been given to it. Being likewise the base of the salt, known by the name of Alum, it has received the appellation of Alumina. The former is preferable, as less ambiguous. Though it exists in nature very nearly in a state of purity, forming the sapphire and some other gems, its state of aggregation in these forms of it disguises its chemical properties; and it is therefore as it is obtained by an artificial process that it is usually described.

The decomposition of this earth by galvanism has been very imperfectly effected. The usual methods proved unsuccessful, and Mr Davy obtained only imperfect indications by another method,—submitting the argil to galvanic

action in fusion with potash or soda. The metallic matter obtained consisted principally of potassium or sodium; but with this was evidently combined a small portion of the base of the argil, for when this metallic matter was oxygenated by water, it produced not only the alkali, but a minute quantity of this earth.

The artificial process by which argillaceous earth is usually obtained, consists in dissolving common alum in water, and decomposing it by the addition of ammonia, this combining with the acid of the alum, and precipitating the argil which is its base. To this a little of the acid may however adhere; and to obtain the earth, therefore, in a state of perfect purity, the precipitate, after having been thoroughly washed, is redissolved in nitric acid, precipitated a second time by ammonia, and after being washed and dried, exposed to a red heat.

Argil, obtained by these processes, is in the state of a light white powder, spongy and soft. It is peculiarly distinguished by forming with water a paste, which, when kneaded, is tenacious and ductile; and it is from the presence of this earth that the natural clays derive their plastic quality. Though no sensible quantity of it is dissolved by water, it forms with it an imperfect combination, the loose precipitate of argil, from the decomposition of its saline compounds, being somewhat gelatinous; and if diffused in a large quantity of water, it retains a portion of it in subsiding, and even in drying, forming a kind of transparent brittle mass; while, if precipitated from a concentrated solution, without being diffused in water, it forms, when dried, a loose powder. The latter has been

named Spongy, the former Gelatinous Argil; it retains the water it has imbibed so strongly, that even exposure to a red heat does not entirely expel it.

The paste formed by kneading argil with water, contracts from the application of heat; the contraction, as has already been stated, in considering the application of this to pyrometry, continuing to proceed even at the most intense heats long after the whole of the water has been expelled. The clay at the same time acquires a great degree of hardness from its augmented aggregation. In the intense heat of the most powerful burning mirror, argil does not melt, but the fusion of it in minute quantities has been effected by the heat excited by a stream of oxygen gas directed on burning charcoal.

Argil combines with the acids, neutralizing the acid properties. Those of its salts which are soluble have a sweetish, and, at the same time, astringent taste. They are decomposed by the alkalis and alkaline earths.

Argil combines more readily than the other earths with the alkalis. When its salts are decomposed by potash or soda, an excess of either added redissolves the precipitate of argil, forming with the acid a ternary compound. They can dissolve argil alone; and they form with it by fusion a species of combination, in which the argil is rendered soluble in water.

Argil exerts affinities to the other earths, both in the humid way and by fusion. Barytes and strontites render it soluble in water. Lime forms with it an insoluble compound, but the argil in this combination renders the lime soluble to a certain extent in alkaline liquors. It also

unites in the humid way with silex, and, what is a singular effect, renders this earth soluble in acids. The combination of argil with silex by fusion, forms the basis of Pottery and Porcelain, at least these two earths form the essential ingredients, the argil communicating to the mixture that plastic quality, in consequence of which, the paste formed with water, when thoroughly kneaded, can be fashioned and turned on the lath, the silex preventing this from contracting too much in drying, and by the action exerted between it and the argil, rendering the mixture capable of that species of vitrification which forms Porcelain.

CHAP. VI.

OF SILEX.

This earth is one very extensively diffused; it forms the principal constituent part of a number of compound fossils; and those in which it predominates having usually a considerable hardness, and the silex itself being altogether insoluble in water, and in its usual state of aggregation not easily diffused, it remains when they have been disintegrated or decomposed: hence the sand of rivers and of the sea-shore is principally composed of it. Rock crystal, quartz, and flint, are fossils in which it exists almost perfectly pure, though in these its state of aggrega-

tion modifies its chemical properties, which are rather determined therefore from it in the state in which it is obtained by an artificial process.

The decomposition of silex has been very imperfectly attained. It is scarcely by itself affected by galvanic action, and when submitted to it in fusion with potash, the metallic matter obtained when exposed to the air, or dropt into water, gave indications of the regeneration of silex, so as merely to warrant the conclusion that it had been decomposed, but without affording more than imperfect results.

The process by which Silex is usually obtained, consists in fusing calcined flint with three or four times its weight of sub-carbonate of potash. The mass, when cold, is dissolved in water, and diluted sulphuric acid is added to the clear solution as long as any precipitation ensues; the precipitate is thoroughly washed with water, and dried.

Silex thus procured is in the form of a light white powder, insipid, and gritty to the touch; when mixed with water, it does not form an adhesive paste. It is extremely infusible, not melting in the intense heat excited by oxygen gas directed on burning charcoal. It melts, however, in the flame of hydrogen and oxygen gases mixed.

It is not dissolved in any appreciable quantity by water, yet there are facts which prove its solubility to a certain extent when this is not counteracted by its aggregation: if the solution of its compound with potash be decomposed by an acid, no precipitate appears, if the solution has been previously very largely diluted with water, though other-

wise it would be apparent; and it exists in solution in some mineral springs, in which no substance that can contribute to its solution can be detected.

This earth is scarcely soluble in the acids, nor does it form with any of them neutral compounds analogous to those formed by the other earths and salifiable bases, a character by which it is peculiarly distinguished. By fusion it combines with boracic and phosphoric acid, forming a species of glass; when in a state of extreme division, muriatic acid appears to dissolve a small quantity. Fluoric acid is its proper solvent, dissolving it either when the acid is gaseous, or when combined with water; though it is doubtful if the combination can be established so as to neutralize the acid.

This earth combines with the fixed alkalis. When boiled on it with water, a portion is dissolved, and by continuing the boiling, a gelatinous solution is obtained. By fusion, the combination is established perhaps more intimately, and the properties of the compound differ much according to the proportions.

When one part of flint or quartz is fused with three parts of sub-carbonate of potash, the carbonic acid is expelled, and the compound of silex and potash is partially soluble in water; with pure potash the combination is more perfect, and the compound more entirely soluble. The solution of silicated potash, or soda, becomes gelatinous when concentrated by evaporation. When kept for a number of years, crystals have been observed to be deposited from it, transparent and hard. It is decomposed by all the acids, the siliceous earth being precipitated.

With a smaller proportion of alkali the compound is less soluble, and a stronger heat is required for its vitrification: it may even be obtained altogether insoluble, transparent, and possessed of considerable hardness. Such a combination constitutes GLASS, the essential parts of which are siliceous earth, and potash or soda. The proportions are about two parts of the former, to from one to one and a half of the sub-carbonate of potash of commerce: they are intimately mixed, and the mixture is exposed to a heat sufficiently strong to expel the water and carbonic acid, and effect an imperfect combination. This is completed by afterwards applying a stronger heat, so as to produce perfect fusion, the impurities and unvitrified matter being drawn off. The glass thus formed is more transparent and colourless, as the materials have been pure. Oxide of lead is often added to communicate greater density and lustre; oxide of manganese to remove the green colour produced by iron; and by the addition of other metallic oxides in larger proportion, coloured glasses are formed.

Silex exerts affinities to the other earths, and combines with the greater number of them by fusion, forming glasses generally more or less opaque. These affinities too are frequently exerted in the humid way. Thus silex is precipitated from its solution in potash, by the attraction exerted to it by barytes, strontites, and lime.

CHAP VII.

OF ZIRCON.

The earth to which this name has been given, was discovered by Klaproth in a fossil, the Zircon or Jargon, brought as a gem from Ceylon, and it has since been discovered in the hyacinth. It is obtained from the zircon by fusing it after repeated calcinations with potash, dissolving in water, and adding to the solution muriatic acid, boiling it for a short time to precipitate more effectually the silex, with which the other earth is combined. The filtered liquor is decomposed by the addition of carbonate of soda; and the carbonate of zircon which is precipitated from it is dried, and the carbonic acid expelled by heat.

This earth, submitted to the action of galvanism in contact with potassium, affords metallic matter, which, when decomposed by water, afforded a minute portion of a powder, having all the characters of zircon.

Zircon, obtained by the above process, is a white powder, insipid, and rough. When exposed, imbedded in charcoal, to the violent heat of a forge, it undergoes a semi-vitrification; becomes so hard as to give fire with steel; has a brilliant vitreous fracture; and is of a grey colour. Its specific gravity is 4.3. When mixed with water, it imbibes it, and forms a semi-transparent jelly,

and it retains so much of this in drying, as to form a substance in appearance like gum.

It combines with the acids, and forms salts in general sparingly soluble. Those which are soluble have a sweetish astringent taste. Its affinities to the acids appear weak, as its salts are in general decomposed by a low heat, as well as by the alkalis, and all the other earths.

Zircon is insoluble in the liquid alkalis, but is dissolved by the alkaline carbonates. Its relations to the earths are scarcely known. It may be fused with silex and with argil, and a mixture of these three earths is more fusible than a mixture of two of them. It appears to combine too by fusion with some of the metallic oxides. On the inflammables it exerts no action.

CHAP. VIII.

OF GLUCINE.

This earth was discovered by Vauquelin, forming a constituent part of the beryl and of the emerald. Its name of Glucine is derived from the property it has of forming salts having a sweet taste. The process by which he obtained it from the beryl, was to fuse one part of it with three parts of potash; the mass, after cooling, was diffused in water, and dissolved in muriatic acid: the solution is evaporated to dryness, and, on again dissolving in water,

the silex present remains undissolved. The solution is decomposed by sub-carbonate of potash: the precipitate is digested with a solution of pure potash; the greater part of it, consisting of argil, with a portion of glucine, is dissolved; but there remains a portion undissolved, which is the glucine, sometimes coloured by oxide of iron.

Mr Davy, in attempting the decomposition of Glucine, obtained results similar to those from zircon, an amalgam being formed, when it had been placed in the galvanic circuit with mercury and potassium which decomposed water, and which reproduced glucine, when the alkali in the liquid was neutralized by an acid.

Glucine obtained pure is white, soft to the touch, and adheres a little to the tongue: it is insipid; is infusible; insoluble in water, but forms with it a paste which is somewhat ductile; this paste is not hardened by heat, nor does it contract. Its specific gravity is 2.96.

Glucine combines readily with the acids; its salts are generally soluble, and have a sweet taste.

They are decomposed by the alkalis: the earth is even completely precipitated by ammonia, which distinguishes it from argil. It is soluble in the fixed alkalis, but not in ammonia; it is dissolved, however, in carbonate of ammonia, forming a triple salt,—a property characteristic of it, though possessed also by zircon. It decomposes the salts of argil. Its relations to the other earths are not known. With borax it melts into a glass.

CHAP. IX.

OF ITTRIA.

This earth was discovered by Gadolin, a Swedish chemist, in a fossil found at Ytterby in Sweden, since named Gadolinite, in which it is combined with silex and lime. It has since been discovered in some other fossils. In several of its properties it resembles glucine, but it differs entirely in others.

The process followed by Vauquelin to obtain the earth from the gadolinite, was to dissolve it with the assistance of heat in diluted nitric acid, pouring off the solution from the undissolved silex. The liquor is evaporated to dryness; the residuum being dissolved in water, the compound of nitric acid and ittria is obtained: ammonia is cautiously added; and after the separation of any oxide of iron in yellow flakes, a larger quantity is added, which precipitates the earth.

Ittria is thus obtained in the form of a white powder, insipid; it is heavier than any other earth, its specific gravity being 4.842. It is not fusible alone, but with borax it forms a white glass. It is not soluble in water, but it retains that fluid with considerable force.

Ittria combines with the acids; its salts have generally a sweetish taste. Several of them too are coloured,—a

property in which it differs from the other earths. They are decomposed by the alkalis, by lime, strontites, and barytes.

Ittria is not dissolved by the liquid alkalis; nor do they redissolve it when added in excess, after having precipitated it from its solutions, which distinguishes it from glucine. It is soluble in carbonate of ammonia, but it requires a quantity five or six times greater than glucine does. Prussiate of potash throws down from its solutions a granular precipitate, of a white or pearl-grey colour. It is precipitated in grey flocculi by the infusion of galls; but very slightly by pure gallic acid. It is not affected by sulphuretted hydrogen, or hydro-sulphuret of ammonia.

The great specific gravity of this earth, its forming coloured salts, and being precipitated by the alkaline prussiates and by tannin from its solutions, in some measure connect it with the metals, and it probably ought to be regarded as a metallic oxide. It is not reduced, however, to the metallic state by heating it with charcoal, but it runs with it into a kind of semi-fluid mass, which is heavier than the earth itself. It has not been submitted to the action of galvanism.

BOOK V.

OF ACIDS AND THEIR BASES.

Acids form an order of chemical agents, distinguished by very appropriate characters, and extremely important in their chemical relations, partly from the numerous and powerful affinities they directly exert, and partly from the changes they produce in bodies by the communication of oxygen. They are compounds of inflammable bases with oxygen; and in conformity to the arrangement I have adopted, the chemical history of these bases is to be connected with the history of the individual acids.

The following are the properties characteristic of the acids. They are all sour to the taste; they change the blue, purple and red colours of vegetables to a red; they in general have a considerable affinity to water, and combine readily with it; they dissolve the metals; and they combine with the alkalis and earths, forming compounds, in which, when the due proportion is observed, the properties of the acid and of the salifiable base with which it unites are mutually lost.

The last property, that of neutralizing the properties of alkalis, is the one most eminently characteristic of acids; and these two orders of chemical agents may be considered as in their chemical relations opposed to each other,

the one always weakening the powers of the other. In combining, the acidity is diminished in proportion to the power and the quantity of alkali added: the property of alkalinity is equally weakened in proportion to the quantity and power of the acid brought into combination; and in all these cases there is a certain proportion of acid and of alkali, in which, if the combination is established, the properties of neither are apparent, but are mutually neutralized. The compound formed at this proportion, is in chemical language named a Neutral Salt. It can always be obtained in a solid state, and generally crystallized.

It has usually been supposed, that an acid and alkali have a tendency to combine more peculiarly in this proportion in which mutual neutralization is produced: and when compounds are obtained insulated, with an excess either of acid or of alkali, it has been supposed that such compounds do not arise from the immediate combination of the acid and alkali, but are formed from an affinity exerted by the neutral salt to an excess of either of its ingredients. There are no just foundations, however, for such an hypothesis. The theory connected with the most just views of the operation of chemical affinity, and most directly inferred from the phenomena, is that an acid and an alkali are disposed to combine in every proportion, each weakening the properties of the other, in proportion to the quantity of it present; and that the separation of the compound takes place at that stage of the combination where the force of cohesion is exerted with greatest strength: this will generally coincide with the point of neutralization, because there the attractive power of the

respective elements is exerted with greatest force, and the condensation is therefore greatest; but where circumstances oppose this, or give rise to a greater tendency to cohesion at another stage of the combination, the compound may become insulated with an excess of either of its ingredients. The cause most commonly productive of this, is that of one of the elements having a greater tendency to pass to the solid form than the other, this prevailing so far as frequently to produce the separation of the compound with an excess of this ingredient. In all these cases, however, whether the compound is separated in the neutral state or not, the separation of it in that state, and of course the determination of the combination in the proportions at which this happens, is the result of the operation of external forces; and the immediate effect of the mutual affinity itself is to unite the acid and alkali in all proportions. This accordingly is the result, wherever no interruption of the progress of the combination takes place from the operation of these foreign powers.

The relations of the acids to the earths is perfectly similar; they produce by their combination mutual neutralization of properties, and form compounds analogous to the alkaline neutral salts; while the combination is also not limited to this, but may be established so as to form compounds with an excess either of acid or of earth.

The different acids differ greatly in their power of neutralizing the alkalis and earths, so that to produce the state of neutralization very different quantities are required; and conversely the alkalis and earths differ as much from each other in their power of neutralizing the acids. Ac-

cording to the view delivered by Berthollet, the energy of the respective affinities of the acids to the alkalis and earths is indicated by their relative powers of producing this neutralization, the different substances being compared in the same relative weights; as the affinities of the different alkalis and earths to the acids may also be judged of from their power of neutralizing them,—the less of any of these substances, whether acid, on the one hand, or alkali or earth on the other, which is required to neutralize a given quantity of another of the opposite order, the stronger being its attraction towards it. I have, at the end of the chapter on Chemical Attraction, given the tables of Kirwan and Richter, which present the results of the experiments that have been made on the relative quantities of the different acids, and the salifiable bases that are requisite to produce reciprocal neutralization.

The action of the acids on the metals is more complicated. An acid does not directly combine with a metal; the metal must always be oxidated. Hence, if it is not previously oxidated, the first action of the acid is to communicate oxygen, either a portion of the oxygen which it contains, or a portion of the oxygen of the water present, or sometimes of the atmospheric air; and with the oxide thus formed the acid combines. The relation of the oxide is then precisely the same as that of an alkali or earth to an acid; they produce mutual neutralization of properties in the necessary proportions, and the compounds formed are perfectly analogous to neutral salts. They are named Metallic Salts.

The Neutral Salts, whether alkaline, earthy, or me-

tallic, have certain properties as an order by which they are characterized, and a common nomenclature is applied to them, which it is necessary to explain, as the history of these compounds, at least those of them formed from the alkalis and earths, is connected with that of the respective acids.

In general they are soluble in water, though they differ much in the degree of solubility: where more than 1000 parts of water are required for the solution of a salt, as the quantity dissolved is not appreciable, unless by a very accurate experiment, such salts are regarded as insoluble. The solution of salts in water is augmented by increase of temperature, this weakening the force of cohesion, which counteracts the power of attraction exerted by the water to the salt, as has been already explained. And from the various forces of cohesion in different salts, the solvent power is very unequally increased by the same augmentation of temperature.

A salt may be recovered from its solution by evaporation of the whole, or even of part of the solvent. If the evaporation has not been carried too far, so that cohesion is forcibly and irregularly exerted, producing merely aggregation of the particles, the salt is procured in a crystallized form, that is, in small masses, transparent, and of regular geometric figures, denominated Crystals. Each salt takes on a figure peculiar to it, and hence the figures of the crystals serve to distinguish them, though these are also liable to be somewhat varied by circumstances. Some salts are crystallized with difficulty; while, with

regard to others, the crystallization is easily effected, and the figures are regular. By slow or spontaneous evaporation, more regular and larger crystals are formed, than when it has been hasty. The solution which remains after a salt has crystallized, contains, of course, a portion of the same salt, which by a second evaporation may be obtained in a crystallized form.

Crystallized salts always retain a portion of water, which is essential to the crystal, the transparency and cohesion being lost when it is abstracted. The quantity is very various, and is in some cases large, amounting to more than the weight of the real salt.

From their relations to water, neutral salts derive some of their distinctive properties. Some of them liquefy, from the application of a moderate heat, owing to the solvent power of their water of crystallization being augmented; and accordingly, when this is dissipated by a continuance of the heat, a dry mass remains. This is named the Watery Fusion of Salts, and takes place principally in those which contain a large quantity of water. Some, when heated quickly, decrepitate from the sudden conversion into vapour of the small quantity of water of crystallization they contain. The crystals of many salts lose their transparency from exposure to the air, are covered with a crust, and at length fall into powder. This, which is named Efflorescence, arises from the abstraction of their water of crystallization by the air. Other salts attract water from the air, so as to become humid, and at length liquid. This property, named Deliquescence, arises from the strong attraction of these salts to water.

It remains to explain the nomenclature of the acids and of the compound salts which they form.

Acids being regarded as compounds of oxygen with certain bases, the name of each is derived from the base of which it is formed. But as this base is often capable of combining with two proportions of oxygen, and of forming two acids different from each other, these must be distinguished, and this is done by a variation in the termination of the name, the syllable *ic* being the final one, when the acid is the one which contains the larger proportion of oxygen, and *ous* where it contains the smaller proportion. Thus sulphur, by combination with oxygen in two proportions, forms two acids; the term Sulphur is the radical whence their names are derived; the one, that with the less dose of oxygen, is the Sulphurous Acid; the other, the Sulphuric. We have thus also the Phosphorous and the Phosphoric, Nitrous and Nitric, &c.

Where the base gives rise to only one acid, the name terminates in *ic*, as in the example Carbonic Acid. The acids belonging to the vegetable and animal kingdoms have a compound base, from which the name cannot be derived; it is taken, therefore, from the substance from which they are formed or prepared, as the Citric, Malic, Prussic, &c.

The nomenclature of the salts, formed by the union of the acids with the alkalis, earths, and metallic oxides, is equally systematic. All the salts formed from one acid are considered as a genus, under which are placed as species the individual salts, formed by the union of that acid with these different bases. The generic name is de-

rived, therefore, from the name of the acid; the specific name from that of the base. When the name of the acid of which the salt is composed is that which terminates in *ic*, the final syllable of the name of the salt is *at*, or rather, as Mr Chenevix has remarked, *ate*; when, again, the name of the acid terminates in *ous*, that of the salt formed from it has the last syllable *ite*. Thus, all the salts formed from sulphuric acid, constitute a genus to which the name Sulphate is applied, and the species are designated by the addition of the name of the base, as the Sulphate of Soda, Sulphate of Potash, Sulphate of Lime, Sulphate of Iron. Those, again, formed by the sulphurous acid, are named Sulphites, as the Sulphite of Ammonia, &c. On the same principle, we have Nitrates and Nitrites, Phosphates and Phosphites, Muriates, Carbonates, &c.

Salts are sometimes formed with an excess of acid or of base; and to denote these a method was proposed by Dr Pearson, which has been adopted. The genus being formed from the acid, when there is an excess of acid in a salt, the epithet *super* is prefixed to the name, when a deficiency of acid, the epithet *sub*. We thus speak of the Super-sulphate of Potash, the Sub-carbonate of Soda, &c.

Where an acid is united with two bases, as is sometimes the case, the names of both bases enter into its name,—as the Sulphate of Argil and Potash, or the Tartrate of Potash and Soda.

Acids, as has been already stated, have in the modern system of chemistry been regarded as compounds of oxygen with certain bases, and this appeared to be established by a very ample induction, resting both on analytic and synthetic chemical investigations. Without invalidating it to a certain extent, its universality has lately been rendered doubtful, and the singular proposition appears to be supported by Mr Davy's researches, that there exists an acidifying principle different from oxygen, and even superior to it in energy of action. Oxy-muriatic acid, as it has been named, a substance hitherto regarded as a compound of oxygen and muriatic acid, Mr Davy has found reason to conclude, contains no oxygen, but is a simple substance. It belongs to the same class with oxygen, in a chemical arrangement; it displays the same relation to galvanic electricity, being attracted to the positive side of a galvanic arrangement, and being therefore itself negative; and on the hypothesis, adds Mr Davy, of the connection of chemical attraction with electrical powers, all its energies of combination correspond with those of a body supposed to be negative in a high degree. In combining with inflammable substances, it forms acid compounds: muriatic acid, for example, is a compound of it with hydrogen, and other acid products are formed by other combinations. The statement of the evidence on which these conclusions rest, belongs to the history of this substance, and of muriatic acid. It is sufficient to have given this brief view, as connected with the theory of acidity, and in considering the revolutions which chemical science at present undergoes, we can scarcely suppose that

this is the ultimate stage of the investigation. There is some improbability in the supposition of the existence of two acidifying principles, and discovery may in no long time unfold new relations amid these singular facts, and lead perhaps to a more simple theory.

If these conclusions, however, were established, they would lead perhaps to a different view of the theory of acidity. This in the present chemical system is supposed to be a property more peculiarly derived from oxygen. But it is possible that it may be a property derived rather from the bases which form acids, developed only by the combination of these bases with principles which communicate to them solubility and greater energy of chemical action, and appearing wherever the substances producing this effect are not such as neutralize acidity itself. Oxygen is the element that usually gives rise to this result; but, according to this view, it may arise from the action of others, from hydrogen for example; and the production of acidity in sulphuretted hydrogen, which has always been regarded as anomalous, may thus be accounted for. The acidifying operation of oxy-muriatic acid, if it is a simple substance, and exert such an operation, will fall to be explained from the same principle. And the singular fact, that the acid powers of oxymuriatic acid (supposing it to be a compound of muriatic acid and oxygen) are inferior to those of muriatic acid, is equally in conformity to this theory, while it is undoubtedly adverse to the hypothesis, that acidity is derived from oxygen.

CHAP. I.

OF NITRIC ACID, AND THE OTHER COMBINATIONS OF NITROGEN WITH OXYGEN.

Nitric Acid, long known to chemists in a state of greater or less purity, is a compound of oxygen and nitrogen; and the properties of nitrogen having been already considered, the history of the acid itself, and of the other compounds which nitrogen forms with oxygen, remains to be delivered under this chapter. With a smaller proportion of oxygen than what enters into the composition of nitric acid, a compound is formed, having no acid properties, denominated therefore Nitric Oxide. With a still smaller proportion, another compound of uniform composition is produced, named Nitrous Oxide. And when nitric acid has imbibed a portion of nitric oxide, it acquires some peculiar properties, and in this state has received the distinctive appellation of Nitrous Acid.

Sect. I.—*Of Nitric Acid.*

This acid being capable of being extracted without much difficulty from a salt in which it exists, common nitre, had been long known to the chemists, and in a diluted state had been used in the chemical arts, under the name of Aquafortis. Priestley observed its partial decomposition, and its reproduction from the union of nitric oxide the product of that decomposition, with oxygen. Cavendish discovered its ultimate composition, and proved that nitrogen is its base.

This was done by a very simple experiment,—taking the electric spark for a considerable time in atmospheric air, confined in a tube. The air suffered diminution of volume, an acid was produced, and this acid was found to be the nitric. If a portion of oxygen gas were added to the atmospheric air, and the electric spark continued sufficiently long, the disappearance of the whole was nearly complete, and a similar result was obtained, from submitting to experiment a mixture of oxygen and nitrogen gases. In all these cases, the electric spark establishes the combination of the gravitating matter of the two gases, and the principal peculiarity which attends this is the slowness with which it takes place, and its not being accompanied with any sensible extrication of heat or light.

The combination is effected in other modes, in which the gases are presented in their nascent state, as in pass-

ing the vapour of ammonia over black oxide of manganese raised to a red heat.

Analysis likewise establishes the composition of nitric acid. If it be passed through an ignited glass or earthen tube, it is resolved into oxygen and nitrogen gases; its saline compounds exposed to a red heat afford the same elements; and its oxygen can be abstracted by inflammable substances, its nitrogen being evolved either pure, or retaining a portion of oxygen combined with it, which by farther operations may be abstracted.

The proportions of its principles have been variously stated. Those assigned by Cavendish were 72.2 of oxygen, with 27.8 of nitrogen; and Mr Davy has stated them not far different from these, at 70.5 oxygen, and 29.5 of nitrogen.

This acid is always obtained from the decomposition of nitre, a salt in which it exists combined with potash, and the process usually followed is that by the medium of sulphuric acid. Two parts of nitre in coarse powder are put into a retort, and rather more than one part of sulphuric acid is poured upon it, the retort being placed in a sand bath, and connected with a large receiver. A moderate heat is applied to produce distillation, and towards the end is gradually raised. The sulphuric acid combines with the potash of the nitre, and disengages the nitric acid, this decomposition being effected partly from the greater volatility of the nitric than of the sulphuric acid, and partly from the affinity of the sulphuric acid, aided by the quantity in which it is employed, this quantity being greater than that required to saturate the potash of the

nitre, and the residual mass containing therefore a considerable excess of acid. The nitric acid, however, when disengaged, is also partially decomposed; losing a little of its oxygen, a portion of it passes to the state of nitric oxide, and this being absorbed by the acid which distils over, gives it a yellow colour more or less deep, or converts it into nitrous acid. This decomposition appears to arise in a great measure from the action of the high temperature, and hence it takes place principally towards the end of the distillation.

In consequence of it, an additional process is requisite to obtain nitric acid. The coloured acid is exposed to a gentle heat, applied by a water bath; the nitric oxide holding a portion of nitric acid combined with it is expelled, and it becomes at length nearly colourless; or, what succeeds more completely, the nitrous acid is distilled from a little black oxide of manganese, which imparting to it oxygen, converts it into nitric.

Nitric acid is colourless and transparent: it emits white vapours, having a peculiar odour. Its specific gravity is from 155 to 158. It has all the acid properties, tastes sour even when much diluted, reddens the vegetable colours, and neutralizes the properties of the alkalis and others. It contains in the strongest state in which it has been obtained a quantity of water; the precise proportion is not very easily estimated, but Kirwan has inferred that in the strongest acid that can be procured, that of the specific gravity of 1.5543, at 60°, the water is equal to 26, in 100 parts.

This acid freezes by cold, the facility of congelation va-

rying considerably, according to its state of concentration: if it is highly concentrated, or if, on the other hand, it is much diluted, it freezes with more difficulty than when of intermediate strength. It is volatilized by heat, and partially decomposed, and at the temperature of ignition, the decomposition is complete, and it is resolved into oxygen and nitrogen gases. A partial decomposition of it is also effected by light; oxygen is expelled, and it passes to the state of nitrous acid.

Nitric acid has a considerable affinity to water: it attracts it from the atmosphere, and it combines with it in every proportion. In consequence of this affinity, too, it acts with energy on ice and snow, liquefying them rapidly, and thus producing intense cold.

The affinity between the elements of this acid not being powerful, it is decomposed by a number of metallic and inflammable substances which attract its oxygen partially or completely; and in consequence of this facility with which it yields oxygen, it acts with much energy on these substances.

It combines with the alkalis, earths and metallic oxides, forming salts, denominated Nitrates. These are uniformly soluble in water and crystallizable; they have a cool penetrating taste; are decomposed at a high temperature, affording oxygen, and in consequence of this deflagrate, when heated with combustible bodies.

Nitrate of Potash is the salt well known by the name of Nitre, or Saltpetre. In warm climates it is, under certain circumstances, formed spontaneously at the surface of the soil; it is thus procured in India, whence

the nitre we use is imported. In some countries of Europe, the production of it is favoured by artificial arrangements. Vegetable and animal substances, with an intermixture of old plaster, mortar, or other forms of carbonate of lime, are put into ditches lined with clay, and covered with sheds to protect them from the rain, while the air is admitted. They are turned up occasionally, and at the end of a few months, when washed with water, afford nitrates of potash and lime. A quantity of wood ashes is added to the solution, the potash of which decomposes the nitrate of lime, and increases the product of nitrate of potash; this salt is obtained in crystals by evaporation, and is purified from a portion of muriate of soda and other saline matter which adheres to it, by repeated solutions and crystallizations.

As the nitre does not pre-exist in these materials, and as indeed a fresh quantity may be obtained by exposing them again under the same circumstances to the air, it is obvious that it is formed in the process. It has been ascertained, that to the mixture of animal and vegetable matter, the addition of carbonate of lime is necessary, and the admission of the atmospheric air is indispensable. The theory of the process probably is, that the nitrogen of the animal matter combines with the oxygen of the air, and perhaps with a portion of the oxygen of the vegetable matter, and forms the acid: the carbonate of lime may favour this combination by the resulting affinity exerted by the lime, and it will attract the acid as it is formed: the vegetable matter moderates the decomposition of the animal substances, and prevents their running into that pu-

trefaction by which the nitrogen is spent in the formation of ammonia; it may farther afford the potash, which is the base of the nitre, though it has also been supposed that a part of this is formed in the process. A certain degree of humidity favours the mutual actions whence these combinations arise, and diffuses more equally through the materials the nitrous salts.

Nitre crystallizes in six-sided prisms acuminated by six planes; its taste is cool; it is soluble in seven parts of water at 60°, a production of cold attending its solution, and in an equal weight of boiling water. It melts easily: if the heat be raised, a partial decomposition of the acid takes place, and oxygen gas is expelled; and at the temperature of full ignition, the decomposition is more complete, and oxygen and nitrogen gases are disengaged.

It is from this facility of decomposition by heat that nitre produces deflagration, as has been already explained, its oxygen being communicated to any inflammable body with which it is exposed even to a moderate heat, with such rapidity that the phenomena of combustion are produced. It is from this that it is the principal ingredient in the composition of gun-powder, which consists of 75 parts of it by weight with 16 of charcoal, and 9 of sulphur. These ingredients are reduced to a state of perfect intermixture by continued trituration, a small quantity of water being added to favour this; the paste into which the composition is at length brought, is granulated by pressing it through a sieve, and the grains, after they are dry, are rounded and glazed by friction from agitation. The deflagration of the gun-powder, when an ignited spark

falls on it, is of course owing to the rapid communication of the oxygen to the sulphur and the charcoal, the sulphur in particular being easily inflamed; and its great expansive force depends on the sudden extrication of the aërial products,—sulphureous acid and carbonic acid formed by the oxygenation of the sulphur and charcoal, and nitrogen from the decomposition of the acid, probably with watery vapour, the elasticity of these being increased by the caloric rendered sensible. Another detonating composition still more powerful than gun-powder, of which nitre is the principal ingredient, is that named *Pulvis Fulminans*. It consists of three parts of nitre, two of sub-carbonate of potash, and one of sulphur triturated together: when heated, it explodes with a very loud report. Its detonation appears to be owing to the formation of sulphuret of potash, which, re-acting on the water contained in the salts, disengages sulphuretted hydrogen, and this presented in its nascent state to the oxygen of the nitre, forms sulphurous acid and watery vapour in a state of high elasticity from the caloric disengaged.

Nitrate of Soda crystallizes in rhomboidal prisms. Its taste is cool and penetrating; it slightly attracts moisture from the air; it is soluble in three parts of water at the temperature of 60, and in an equal weight of boiling water; it is scarcely so fusible as the nitrate of potash, but is decomposed by heat in the same manner, and, like it, excites deflagration when heated with inflammable substances.

Nitrate of Ammonia crystallizes in slender prisms of four sides acuminated by four planes; or, if the solution

has been farther evaporated in indistinct crystals, which, when aggregated, form a compact mass, retaining less water of crystallization than the more regular crystals. Its taste is cool and bitter; it is deliquescent, and soluble in two parts of cold water, and half its weight of boiling water. Exposed to a moderate heat, it undergoes the watery fusion, and the water of crystallization is expelled; if the heat is increased, it is decomposed, and if raised to ignition, with a sudden detonation from the combination of the oxygen of the acid with the hydrogen of the ammonia. This happens at temperatures above 600: at temperatures below this, between 300 and 500, the decomposition proceeds more slowly; the products are nitrous oxide and watery vapour, and it is from this decomposition that nitrous oxide is obtained in its purest form.

Nitrate of Barytes is obtained by dissolving the native carbonate in diluted nitric acid: the solution, by evaporation, crystallizes in octaedrons, or in small brilliant plates: its taste is styptic and pungent: it is not much altered by exposure to the air: when crystallized, it is soluble in 10 or 12 parts of water at 60°, and in 3 or 4 parts of boiling water. It is decomposed by heat, its acid being converted into oxygen and nitrogen gases. It detonates, but feebly, with inflammable bodies.

Nitrate of Strontites is formed by pouring diluted nitric acid on the native carbonate. The solution, by evaporation, affords crystals, either hexaedral pyramids, or octaedrons. This salt is soluble in its own weight of water at 60°; and at 212° it dissolves in little more than half its weight. It is deliquescent in a humid atmos-

phere; in a dry atmosphere it effloresces. It is decomposed by heat, and it deflagrates feebly, when laid on burning fuel.

Nitrate of Lime is generally found in those situations in which nitrate of potash is formed. It is obtained pure by the direct combination of its principles. When the solution is evaporated to the consistence of a syrup, it affords slender prismatic crystals, deliquescent, and soluble in less than an equal weight of water at the temperature of 60, and in still less boiling water. They are also soluble in alkohol. Exposed to heat, they undergo the watery fusion, and are decomposed, the acid being expelled. By having been heated it becomes phosphorescent, and retains this property when cold. When thrown on burning fuel, it melts, and detonates slightly.

Nitrate of Magnesia has a taste bitter and acrid. Its crystallization exhibits a mass of small needle-like crystals: by spontaneous evaporation, it concretes in quadrangular prisms: it is deliquescent; is soluble in its own weight of water at 60°, and in half its weight of boiling water: it is also soluble in alkohol. By exposure to heat, it is decomposed: its acid being partly expelled, partly resolved into its constituent principles.

Nitrate of Argil.—The solution of argil in nitric acid becomes gelatinous on evaporation, and soft crystalline scales are formed. This has generally an excess of acid: its taste is sour and astringent: it is easily soluble in water, and deliquesces on exposure to the air. It is decomposed by heat. The nitrates formed from the remaining earths have been little examined, and are of no impor-

tance. The solution of ZIRCON in the acid affords a transparent resinous-like matter, not easily dried, having an astringent taste. That of GLUCINE cannot be crystallized, but by evaporation forms a gelatinous mass, which is very deliquescent. NITRATE OF ITTRIA assumes a gelatinous consistence by evaporation, and becomes brittle when this jelly cools. Its taste is sweet and astringent.

SECT. II.—*Of Nitrous Acid.*

THE name of Nitrous Acid is given to the yellow acid obtained by distillation in the usual process of decomposing nitre by sulphuric acid; and it has been remarked, that it owes its yellow colour to the presence of a portion of nitric oxide. When this is disengaged by applying a moderate heat, it becomes colourless, and if nitric oxide is transmitted through it in this state, it regains its colour, this being more or less deep, according to the quantity communicated.

Strictly speaking, therefore, there is no acid of determinate composition to which the name Nitrous can be properly applied. What is called such is nitric acid holding nitric oxide dissolved; and the quantity of this may be variable, and even indefinite, between the minimum and maximum. According to the quantity communicated, the colour is deeper. From a proportion not exceeding 1.2 of nitric oxide by weight in 100 parts, a pale yellow colour is communicated; this, as the quantity

is increased, passes through shades of bright yellow to dark orange, in which the proportion of nitric oxide amounts to about 5.5; beyond this an olive colour, and then a bright green, verging at length into blue, is obtained, and if the transmission of the nitric oxide gas be continued longer, it communicates its elasticity to the liquid acid, and the whole rises in very dense red suffocating vapours. The acid obtained by distillation from nitre and sulphuric acid is usually of a pale yellow colour: but if the heat has been raised very high towards the end of the process, it is of a deeper colour; and if any inflammable matter has been contained in the materials, it is of a dark orange red.

The colours which the acid assumes from this impregnation of nitric oxide, are likewise considerably dependent on its state with regard to dilution. If the dark orange-coloured acid be mixed with water, the different shades are produced, with a large quantity of water, blue, with more acid, olive, and bright green. These colours are not permanent; the oxygen loosely dissolved in the water, or imbibed from the atmosphere, oxygenating the nitric oxide, and bringing the whole to the state of nitric acid.

The nitric acid, by these combinations with nitric oxide, has its specific gravity diminished; a pale acid of 1.52, when converted into yellow acid, becoming nearly of the specific gravity of 1.51.

Nitrous acid in its relations to other chemical agents is similar to the nitric acid. It oxidizes in the same manner, and with the same phenomena, inflammable bodies and metals, and combines with the metallic oxides. These

combinations are indeed merely those of the nitric acid, as the nitrous oxide is disengaged during the process.

The compounds of nitrous acid with the alkalis or earths cannot be obtained by direct combination; for when it is added to any of these bases, the greater part of the nitric oxide is expelled. Some of them can however be obtained in an indirect mode, by a process pointed out by Scheele, that of exposing a nitrate, as that of potash, to such a heat as partially decomposes the nitric acid, and expels part of its oxygen. The remaining acid with a portion of nitric oxide exists in combination with the alkaline base, and these are probably to be regarded as triple compounds of these principles. They are named Nitrites. Berthollet observed that the nitrate of potash treated in this way became alkaline, so as to render green the syrup of violet, and that when an acid was poured upon it, effervescence happened, and nitrous acid vapour was disengaged. The others have not been examined very particularly, but the above characters appear to belong to all of them. On exposure to the atmosphere they absorb oxygen, and return to the state of nitrates.

As the chemical properties and agencies of the nitric and nitrous acids are so much alike, the latter is generally used in the arts, and indeed for most of the purposes to which the other might be applied, as it is more easily procured. The acid also, for the greater number of purposes for which it is used, must be diluted, and in this dilution it soon passes to the state of nitric. The *aquafortis* of commerce is a nitric acid diluted, and generally impure from the admixture of muriatic and sulphuric acids.

Sect. III.—*Of Nitric Oxide.*

During the action of diluted nitric acid on metals, a species of elastic fluid is disengaged, which was first observed by Hales, and afterwards examined by Priestley, who gave it the name of Nitrous Air, or Nitrous Gas, a name not sufficiently distinctive, as being equally applicable to another elastic fluid, and for which, therefore, that of Nitric Oxide Gas has been substituted. It is a compound of oxygen and nitrogen, containing a smaller proportion of oxygen than nitric acid. Its formation, therefore, in the above processes, is due to the metal abstracting a portion of the oxygen of the acid, the nitric oxide assuming the elastic form.

It is not always evolved pure, the abstraction of oxygen sometimes proceeding to a greater extent, and portions of nitrous oxide or nitrogen gas being evolved. It is obtained in the state of greatest purity in the action of diluted nitric acid on quicksilver or copper; one part of the concentrated acid being diluted with four or five parts of water, and poured on copper-filings in a retort; on applying a very moderate heat, the copper decomposes the acid by attracting oxygen, and nitric oxide gas is disengaged.

The relation of this elastic fluid to nitric acid is not only established by the nature of the process by which it is obtained, its composition is likewise established by its analysis. By taking the electric spark in it, it is converted in-

to nitrogen gas, and nitrous acid. When exposed to the action of substances exerting a strong attraction to oxygen, it is partially or entirely decomposed. Thus by the action of iron or zinc, of phosphorus, or charcoal, it is converted either into nitrogen gas, the whole of its oxygen being abstracted, or into nitrous oxide, part of it only being removed. From these analytic experiments, Mr Davy fixed the proportions of the principles of this compound at 56 of oxygen, and 44 of nitrogen by weight.

Nitric oxide is permanently elastic, colourless, and therefore invisible. It is rather heavier than atmospheric air, the proportion being nearly as 100 to 92. Its specific gravity is 0.00136. 100 cubic inches of it weigh 34.3 grains.

It proves extremely deleterious to animal life. Warm-blooded animals die almost immediately on a full inspiration of it, and the irritability of the heart is destroyed. Insects which live in several other noxious gases, are quickly killed by immersion in it, and fishes die in water impregnated with it. It proves even noxious to vegetable life, the leaves of a growing plant soon becoming withered in it, and the plant dying.

Exposed to distilled water, a portion of it is absorbed equal, when the water has been previously freed from air by boiling, to 11.8 cubic inches, by 100 of water. The gas is again expelled unchanged at a temperature of 212°. By common spring water, a larger quantity is absorbed, the nitric oxide being in part converted into nitric acid, by the oxygen which water holds loosely dissolved.

When the water is impregnated with certain metallic

salts, as with the green sulphate or green muriate of iron, it condenses a much larger portion of nitric oxide gas. This has been supposed owing to a decomposition of the gas, its oxygen being attracted by the metallic salt; and in confirmation of this, it has been observed, that a portion of nitrogen exists in the residual gas. Vauquelin and Humboldt concluded, that these changes are even more complicated, one portion of the nitric oxide, according to the view they gave, attracting oxygen from the water, so as to form nitric acid, and the nitrogen of another portion of it uniting with the hydrogen of the decomposed water and forming ammonia. Mr Davy, however, has found reason to conclude from his experiments, that the gas is merely absorbed: if the action of the atmospheric air be carefully excluded, he finds that the liquid has no sensible acidity, and the nitric oxide gas may be procured from it again unchanged, either by the removal of pressure by the air-pump, or by applying a very moderate heat. It is only if the air is admitted that nitric acid and ammonia are formed. The residuum of nitrogen observed, he supposes to be merely that which had been mixed with the nitric oxide, and foreign to it; and this therefore affords a mode of determining the purity of nitric oxide gas.

Nitric oxide gas has no acid properties. Its solution in water, freed from air, does not taste sour, nor does it redden the vegetable colours. Neither does this happen from the introduction of the gas itself, previously washed in water, to vegetable coloured infusions. The colour, however, is impaired.

Nitric oxide gas is capable of supporting combustion in

some substances only, and in them only at an elevated temperature. A lighted taper immersed in it is extinguished, as is sulphur introduced in a state of inflammation. Phosphorus may be fused in it without burning; but if introduced in a state of active combustion, it burns with great splendour. Pyrophorus burns in it at a low temperature. Charcoal suspended in it in a state of ignition, burns feebly.

With oxygen nitric oxide gas combines with great facility, and this forms its most important and characteristic property. They instantly combine, and a red coloured vapour is produced, which, if the experiment be made over water, is immediately absorbed, leaving, if the gases be pure, no residuum; and what is singular in so rapid a combination of oxygen, no sensible emission of light attends the combination, and so little caloric is rendered sensible, that the vessel scarcely becomes sensibly warm to the hand. The phenomena are similar when nitric oxide gas is presented to atmospheric air; the oxygen is condensed, and if the due proportions have been observed, the nitrogen of the atmospheric air remains pure.

From the application of this combination to eudiometrical experiments, it is an object of considerable importance to determine with precision the proportions in which these gases combine so as to produce mutual condensation. But this has been found very difficult; results extremely discordant have been given on different authorities, some fixing the quantity of oxygen condensed at 100, by 200 measures of nitric oxide gases; others finding that 250, or even 300 of the latter, are condensed by 100 of the former.

These differences arise from this circumstance, that oxygen and nitric oxide are capable of combining in different proportions, or rather, that although there is one proportion in which they are mutually saturated, the compound which results from this proportion is capable of absorbing variable proportions of nitric oxide, and these are materially determined by the circumstances under which the combination takes place. The presence of water, in particular, by condensing the product, has a very important influence. If it is entirely excluded, as by combining the two gases in an exhausted globe, there is scarcely any condensation; an elastic product of a red colour is formed, and this may admit variable quantities of oxygen or of nitric oxide into the combination. But if water be admitted to condense the elastic fluid, it does so during the progress of the combination itself, determines the proportions, therefore, in which this takes place, and renders these proportions different, as it is more or less freely admitted. The larger the surface of water is over which the mixture is made, the less oxygen enters into combination with the nitric oxide, probably from the circumstance, that when a narrow surface of water is exposed to the mixture the absorption is slow, and the progress of the combination continues towards saturation, while, when the surface is large, it is absorbed as it takes place, and before the proportion in which the nitric oxide is saturated is fully established. And, on the same principle, agitation, and even the order in which the gases are presented to each other, have an influence on the results.

This property of nitrous gas of combining with oxygen gas at natural temperatures, and forming a compound quickly absorbed by water, has been applied to the purpose of eudiometry, and it has some advantages. The combination takes place so rapidly, that the result is immediately obtained, and it requires no complicated apparatus. It was introduced by Dr Priestley, and since his time has been used in different forms. It has always, however, been found very difficult to employ it, so as to obtain accurate results, owing to its being so much influenced by circumstances, which determine the combination as above explained. Hence it was nearly relinquished. Mr Dalton, however, has lately given it a preference to any other, as more expeditious, and capable of being rendered equally correct. He has observed, that nitric oxide gas may be combined with oxygen gas, so as to form either nitric acid, or nitrous acid; 36 measures of it uniting with 21 to form the former, and 72 uniting with 21 to form the latter: the combination in either proportion is determined by the manner of making the experiment; and to give accuracy to the result as a eudiometrical process, it must be conducted in such a manner as to form nitric acid or nitrous acid wholly, and without a mixture of the other. The former he has found to be most easily and most accurately effected. "In order to this, a narrow tube is necessary; one that is just wide enough to let air pass water, without requiring the tube to be agitated, is best. Let little more nitrous gas than is sufficient to form nitric acid be admitted to the oxygenous gas; let

no agitation be used, and as soon as the diminution appears to be over for a moment, let the residuary gas be transferred to another tube, and it will remain without any further diminution of oxygen. Then $\frac{7}{19}$ths of the loss will be due to oxygen." In making the experiment, therefore, on atmospheric air, add 36 measures of nitric oxide gas to 100 of air; conduct the experiment as above directed; ascertain the diminution of volume, and having multiplied this by $\frac{7}{19}$, the product indicates the proportion of oxygen which the air had contained. "The tube which Mr Dalton uses is represented Fig. 20."

Another method of applying nitric oxide gas to eudiometry was introduced by Mr Davy, that of using solutions of sulphate or muriate of iron impregnated with it, these absorbing the oxygen of atmospheric air very quickly, and producing a diminution equal to 21 in 100 parts. An apparatus for employing these solutions in eudiometrical experiments has been invented by Mr Pepys, the liquid being put into an elastic gum bottle, which is connected by a glass tube, when the experiment is to be made, with a graduated tube containing the air; by pressing the bottle, the liquid is made to act on the air with a degree of compression, which favours the result. The method is however rather complicated for common use, at least when we have others equally accurate and more simple.

Sect. IV.—*Of Nitrous Oxide.*

This, the last of the compounds of oxygen and nitrogen, was discovered by Dr Priestley, who gave it the name of Dephlogisticated Nitrous Air. Mr Davy first obtained it in a state of purity, and to him we are indebted for our knowledge of its most singular properties. He gave it the more concise appellation of Nitrous Oxide.

It is obtained by various processes, in which nitric oxide or nitric acid is partially decomposed, as by exposing nitric oxide gas to the action of iron-filings moistened with water, of iron-filings and sulphur, or of the alkaline sulphurets; and it is also disengaged in a state of mixture with nitrogen and nitric oxide during the solutions of some of the metals in nitric acid. But the process by which it is obtained most easily and in greatest purity, is in the decomposition of nitrate of ammonia by heat. This salt, in the different states of crystallization in which it exists, is decomposed, so as to afford this product at different temperatures, intermediate between 320° and 500°. Above 600° the decomposition takes place with an explosion, and the evolution of other products, principally water, nitrous acid, nitric oxide, and nitrogen gas. But this can be guarded against, by the due regulation of the heat applied by a lamp to the salt in a tubulated retort, raising it quickly to the requisite temperature, taking care not to exceed 500°, and, in particular, not to raise it so high as to pro-

duce a luminous appearance in the retort. The nitrous oxide, with watery vapour, are disengaged; the latter condenses in the neck of the retort; the former is received over water, as not much of it is immediately absorbed; it is generally white, and a little opaque, from a small portion of the nitrate of ammonia being volatilized; but this is soon absorbed by the water, and it becomes transparent.

In this process the nitric acid and the ammonia of the salt both suffer decomposition; the hydrogen of the ammonia attracts a portion of the oxygen of the acid and forms water, and the remaining oxygen is just sufficient, when combined with the nitrogen of the acid and the nitrogen of the alkali, to form this compound, nitrous oxide. Accordingly water and nitrous oxide gas are the sole products, if the temperature has not been raised too high to cause the operation of other affinities. Estimating the proportions of the elements of this compound from its formation, Mr Davy states them at 62.4 of nitrogen, and 37.6 of oxygen; and from its analysis by detonation with hydrogen, or by burning charcoal in it, he finds them to be almost the same, 63 of the one element, and 37 of the other. With this the estimation of its composition by the Dutch Chemists agrees; the proportions they give being 62.5 nitrogen, and 37.5 oxygen.

Nitrous oxide is permanently elastic. Its specific gravity is to that of atmospheric air as 161 to 100. 100 cubic inches weigh 50.1 grains. Its taste is sweetish. Its odour is very faint.

This gas is absorbed by water; the water, at a mean

temperature, and under an atmospheric pressure, takes up about half its bulk; on boiling the solution, the gas is given out unchanged; the solution has a sweetish taste, and a slight odour, not disagreeable; neither it nor the gas changes the vegetable colours. It is likewise absorbed by alkohol and by ether, communicating a sweet taste; it is again expelled by heat, and in part by the addition of water.

Nitrous oxide gas suffers no diminution of volume, nor any change of properties, when mixed with oxygen, nitrogen, or hydrogen gas. At ignition, it detonates with hydrogen. It is decomposed at a high temperature, as by transmitting the electric spark through it, or passing it through an ignited earthen tube, and is converted into nitrous acid, and oxygen and nitrogen gases.

This gas is powerful in supporting combustion. A lighted taper burns in it with an enlarged and bright flame; phosphorus with a dazzling white light; sulphur with a vivid rose-coloured flame; and iron-wire with corruscations. A higher temperature, however, is required for these combustions, than for the burning of the same bodies in oxygen gas or atmospheric air. During the combustion, a portion of nitrous acid is produced along with the product of the oxygenizement of the combustible body.

The operation of this elastic fluid on the animal system, when it is received into the lungs, is scarcely analogous to that of any other physical agent. It had been believed to be, in common with the greater number of the gases, fatal to life. Mr Davy found that it could be breathed with safety, and in his farther experiments on it, discovered

the singular effects it produces. After a few inspirations of it have been made, it causes a sense of lightness and expansion in the chest, and a pleasurable sensation begins to extend over the whole body; this increases, and is accompanied with a desire to inhale the gas; respiration therefore becomes fuller, and is performed with more energy. Exhilaration is soon produced; and if the respiration is continued sufficiently long, a crowd of indistinct ideas, often in very singular combinations, pass through the mind; there is an irresistible propensity to laughter and to muscular exertion, and violent exertions are made with alacrity and ease. These effects, after the inspiration has ceased, continue for four or five minutes, or sometimes longer; they gradually subside, and what is not the least of these singularities, the state of the system returns to its usual standard, and from this high excitement no subsequent languor or exhaustion is felt. Its operation is not however uniform on different individuals: its effects occur in various combinations; they are, as may be easily supposed, more readily excited in some than in others; and where much susceptibility has existed, alarming or unpleasant symptoms have been produced. Warm-blooded animals confined in the gas, die in a few minutes, frequently with previous symptoms of excitement; and fishes die in water impregnated with it. The gas appears during its respiration to be absorbed by the blood: this fluid acquires a purple colour, and after death the muscles are found inirritable. No satisfactory hypothesis can be advanced with regard to its operation.

Nitrous oxide can be combined with the fixed alkalis, by an indirect process discovered by Mr Davy. It consists in exposing sulphite of potash or soda, mixed with pure potash or soda, to nitric oxide gas; the sulphite attracts oxygen from the nitric oxide, and converts it into nitrous oxide, which, as it is formed, combines with the alkali, and the compound is separated by solution and crystallization from the other saline matter. These compounds, to which Mr Davy gave the name of Nitroxides, are soluble, and have a sharp taste; they cause inflammable substances to burn or deflagrate when heat is applied, and afford nitrous oxide when decomposed by the acids, or by heat.

CHAP. II.

OF SULPHURIC ACID AND ITS BASE.

Sulphur is the base of sulphuric acid. When sulphur is combined with an inferior proportion of oxygen, it forms sulphurous acid. United with hydrogen in different proportions, it forms at least two compounds, sulphuretted hydrogen and super-sulphuretted hydrogen. It farther combines with the alkalis and earths. The chemical history of all these forms the subject of the present chapter.

Sect. I.—*Of Sulphur.*

This inflammable substance exists in the mineral kingdom, both in a state of combination and in a pure form. In the latter state, it is principally a volcanic production, though native sulphur likewise occurs, which cannot be supposed to have this origin. It exists, too, in small quantity in vegetable and animal products.

Volcanic sulphur affords the greater part of the sulphur of commerce. It is usually purified by sublimation, and the sulphur is thus obtained in the form of a light powder of a yellow colour. This is easily fused, and forms a solid mass, brittle, and displaying somewhat of a crystalline structure, and by slow cooling it may be obtained in needle-like crystals. By precipitating sulphur from its combination with an alkali by an acid, it is obtained nearly white, as it is also by dropping water on it when in fusion, or subliming it into a vessel filled with watery vapour; this whiteness has hence been ascribed to the combination of a small portion of water.

Sulphur melts at a temperature of 224°, and a phenomenon nearly peculiar to it is displayed in its fusion. If after it is fully melted, the heat be continued, or even raised, instead of flowing thinner, it becomes thick, and this thickening continues progressive, as the temperature rises even through a range of nearly 200 degrees, until it become quite viscid. The thickening, according to Dr Ir-

vine's experiments, commences at 226° of Fahrenheit, and continues to increase to 550, at which temperature the sulphur sublimes. It is quite independent of the action of the air, and does not therefore arise from oxygenation, and indeed depends on no permanent change, as by merely reducing the temperature, the liquidity is recovered, and the experiment may be repeated on the same sulphur a number of times. If poured when viscid into water, it remains for a time soft and tough, and it may be made to take the impression from a mould.

Sulphur rises in vapour, at a temperature not much higher than that at which it melts. If the air be admitted, it burns at a temperature of about 300, with a pale blue flame, and the production of pungent suffocating flames. If the heat be raised, its combustion is more vivid, as it is also in oxygen gas.

In its combustion, sulphur combines with two proportions of oxygen, forming two acids. The principal product is a gaseous acid, Sulphurous acid gas as it is named; but there is always formed with this a portion of a liquid acid not volatile, containing a larger proportion of oxygen, the sulphuric acid. The proportions of these are various, according to the circumstances of the combustion, the quantity of sulphuric acid being greater as oxygen is more freely supplied.

Sulphur combines with hydrogen, and this combination, too, appears to be established in different proportions. It unites with other inflammables, and with the greater number of the metals. It combines with the alkalis and alkaline earths, acquiring from their action so-

lubility in water, and the power of decomposing it. It also enters into combination with their metallic bases.

Sulphur had usually been regarded as a simple substance: but some facts have been more lately observed, whence it has been inferred that it contains hydrogen. Thus, the younger Berthollet found, that on passing sulphur in vapour through an ignited glass tube, traces of sulphuretted hydrogen are always obtained: and, in combining sulphur with metals by applying heat, there is an evolution of the same product: it is likewise obtained by passing the vapour of water over melted sulphur; and that in this case, it is not produced by the decomposition of the water, is proved by no portion of acid being formed. Mr Davy, in submitting sulphur to the action of galvanism, found sulphuretted hydrogen to be given out in considerable quantity; and in combining it with potassium by the application of heat, he likewise found that this product is evolved; he hence inferred, that sulphur contains hydrogen. And farther, finding reason to conclude, that oxygen exists in the composition of sulphuretted hydrogen, he supposes that this element must also be contained in sulphur. According to this view, sulphur is a compound of a base unknown, with small quantities of oxygen and hydrogen. This has scarcely been confirmed, however, by his subsequent experiments, and these results, so far at least as relates to the presence of oxygen, appear to admit of explanation on a supposition which the phenomena do not preclude, that sulphur may contain a small quantity of combined water.

Sect. II.—*Of Sulphuric Acid.*

Sulphuric acid used to be obtained by distillation from sulphate of iron, the Green Vitriol of the older chemists, whence the name of Vitriolic Acid, by which it was known. It is now always procured from the combustion of sulphur, the method having been discovered of conducting this combustion, so that the formation of sulphurous acid is in a great measure prevented, and the principal product is sulphuric acid. The process consists in adding a small quantity of nitre,—from one-eighth to one-tenth, the weight of the sulphur. They are intimately mixed in powder, and portions of the mixture are successively kindled, and kept burning in a leaden chamber, the bottom of which is covered with water to the depth of three or four inches. The sulphuric acid, and a portion of sulphurous acid that is formed, are absorbed by the water; and when the liquor is sufficiently acid, it is removed, and by boiling it in glass retorts, the sulphurous acid and the superfluous water are expelled, and it is brought to a state of concentration, having the specific gravity of 1.842. From the nature of this process, the acid is not perfectly pure. It contains a portion of sulphate of potash, derived from its action on the potash of the nitre, and perhaps also a minute quantity of sulphate of lead. These are in a great measure precipitated by di-

luting it with water, and are more completely separated by distilling it from a glass retort.

There is considerable difficulty in determining the proportions of oxygen and sulphur in sulphuric acid, principally from the difficulty of estimating the real product of acid free from water; and hence the results of different experiments have been extremely various. The proportion of sulphur has been stated so low as 42 in 100 parts, and so high as 72. The latest experiments are those of Chenevix and Thenard: the proportions assigned from the former are 61.5 of sulphur, and 38.5 of oxygen; from the latter 55.56, and 44.44, and even these are doubtful, as the estimate of the composition of sulphate of barytes on which they rest, appears, from subsequent experiments, to be incorrect. The acid, in any state of concentration in which it can be procured insulated, has a portion of water always combined with it. At its usual specific gravity of 1.842, this is calculated by Mr Kirwan to amount to 21 in 100 parts. The greatest state of concentration in which it has been obtained is that of the specific gravity of 1.846.

Sulphuric acid of this strength is somewhat viscid, and has an oily appearance. If pure, it is colourless and transparent; it is inodorous; its taste, when it is even largely diluted with water, is intensely sour, and in very minute quantity it reddens deeply the vegetable colours. In its concentrated state, it is highly corrosive.

Sulphuric acid is congealed by cold, and even crystallizes with regularity. The temperature at which this takes place is very different, according to its concentra-

tion. When of the specific gravity of 1.843, it congeals at —15, but if it is diluted with half its weight of water, it requires a cold of —36 to congeal it. There is a certain state of dilution most favourable to the congelation; this is when the acid is at the specific gravity intermediate between 1.786, and 1.775; at this it freezes at the temperature of melting snow; if either more diluted, or more concentrated than this, the congelation requires greater cold to produce it. These facts are singular, and one not less so is, that the acid remains congealed at a higher temperature than that necessary to cause its transition to the solid form. When sulphuric acid too is impregnated with a portion of sulphurous acid, it becomes concrete even at common natural temperatures.

Sulphuric acid boils at 590°. It is decomposed at a red heat, being resolved into oxygen and sulphurous acid.

It has a strong attraction to water, so that it imbibes it from exposure to the atmosphere. It combines directly with water in every proportion, the combination being attended with a considerable increase of temperature from diminution of capacity.

It forms no combination with oxygen or nitrogen: hydrogen decomposes it at a high temperature, by attracting its oxygen; it sustains a similar decomposition from the primary inflammables; any substance, for example, containing carbonaceous matter, acts on it even in the cold; the acid becomes black from the evolution of charcoal, and a little sulphurous acid is formed. If heat be applied, the action is much more rapid, and carbonic acid and

sulphurous acid gases are disengaged with effervescence; a portion of sulphur may likewise be obtained.

The metals abstract oxygen from sulphuric acid, in general partially, so as to disengage sulphurous acid, the oxide combining with a portion of the acid that remains undecomposed. When the acid is diluted with water, it enables, by a resulting affinity, those metals which have a strong attraction to water, to attract it from the water, and hence there is a disengagement of hydrogen gas.

Sulphuric acid combines with the alkalis, earths, and metallic oxides; producing, when the due proportions are observed, mutual neutralization of properties. Its salts are named Sulphates. A considerable force of affinity is exerted between their constituent principles, and this is not much counteracted by any tendency of the acid either to elasticity or to cohesion, and hence they are not very liable to decomposition by the action of substances exerting attractions either to their acid or base. They are decomposed in general by heat: the metallic sulphates are more susceptible of this decomposition than the others, the acid being either expelled, or, by partial decomposition, giving sulphurous and oxygen gases; the earthy at a higher temperature suffer a similar decomposition. The neutral alkaline sulphates are not decomposed, with the exception of sulphate of ammonia; but when crystallized with an excess of acid, part of that excess is by heat converted into the same products. They all suffer decomposition when heated with carbonaceous matter.

Sulphate of Potash is formed by adding diluted sulphuric acid to a dilute solution of potash, or of carbonate

of potash, until the acid and alkaline properties are neutralized. A cheaper process, generally followed in pharmacy, is to prepare it from the residual mass obtained in the distillation of nitric acid from nitre and sulphuric acid, adding to it, dissolved in water, a solution of carbonate of potash, to neutralize any excess of acid, and obtaining the sulphate by evaporation. The crystals of this salt are prismatic, small and grouped; it requires for its solution seventeen parts of water at the temperature of 60°, and not more than five parts at 212°. Its taste is bitter. It is decomposed, like the other sulphates, by exposure to heat with carbonaceous matter. Acted on by nitric or muriatic acid, it suffers partial decomposition from the abstraction of part of the base, the decomposing acid acting by its affinity and quantity, and producing that participation which happens when two acids act on one base. It can combine with an excess of acid, and even with this excess crystallizes, the crystals being considerably more soluble than those of the neutral sulphate; and by the repeated action of water this excess of acid is almost entirely abstracted.

Sulphate of Soda.—This is the salt known by the name of Glauber's Salt, from Glauber the chemist, by whom its properties were first noticed. He obtained it from the residuum of the distillation of muriatic acid, from muriate of soda and sulphuric acid, this consisting of the soda of the muriate of soda, with sulphuric acid in excess. It is dissolved in water; the excess of acid is neutralized by adding lime; the fluid is allowed to remain until it becomes clear; it is drawn off into shallow leaden

vessels, and on cooling affords the neutral sulphate in crystals. It is also obtained as a residuum in other processes, particularly in the preparation of sal-ammoniac from muriate of soda and sulphate of ammonia. It crystallizes in six-sided prisms, bevelled at the extremities. Its taste is strongly saline and bitter. It is effloresecent; the crystals in a dry atmosphere soon becoming white and opaque, and at length they fall into powder. It is soluble in less than three times its weight of water at 60°, and in less than its own weight at 212°. Exposed to heat it undergoes the watery fusion; the water of crystallization is soon dissipated, and by urging it with a strong red heat it may be melted. It suffers decompositions similar to those of sulphate of potash.

Sulphate of Ammonia crystallizes in six-sided prisms acuminated by six planes, the crystals being generally slender. It is soluble in about two parts of water at 60°, and in an equal weight of boiling water; is slightly efflorescent. Exposed to heat, it melts, and is decomposed, part of the ammonia being exhaled; at ignition its acid is decomposed.

Sulphate of Barytes is formed whenever barytes is presented to sulphuric acid, in whatever state of combination either may previously exist. It is precipitated in powder, which is not soluble in water in any appreciable quantity. It is melted by a strong heat. When heated with carbonaceous matter, its acid is decomposed, and sulphuret of barytes is formed. The determination of the proportions of its constituent parts is of considerable importance, as it has been usually employed as the mode of

obtaining sulphuric acid free from water, in the experiments made to determine the proportions of the principles of that acid. The results, however, have been very discordant; but the proportions fixed by Klaproth and Withering, of 67 of earth and 33 of acid, have been lately confirmed by its analysis by Mr Thomson. Besides this neutral salt, barytes can combine with an excess of sulphuric acid; it forms a liquid that congeals into a congeries of prisms; this is decomposed, and the neutral sulphate precipitated, on the affusion of water.

Sulphate of Strontites is in the form of a white powder, insipid, and so very sparingly soluble in water, as to require, according to Dr Hope's experiments, nearly 4000 parts for its solution. It combines with an excess of acid, and is rendered more soluble in water, and crystallizable.

Sulphate of Lime, long known to chemists under the names of Gypsum and Selenite, is one of the saline substances most abundant in nature. It forms entire beds, is diffused in almost every soil, and is contained in almost all river and spring water, giving rise, when the quantity is considerable, to the quality of these named hardness. It requires about 500 times its weight of water for its solution at a mean temperature. At that of 212 it is more soluble, and this latter solution, upon cooling slowly, deposites minute crystals. Exposed to heat it appears to effervesce or boil, owing to the expulsion of its water; it becomes opaque, and falls into a white powder. This, diffused in water, speedily consolidates from a species of irregular crystallization. When exposed to a more in-

tense heat, it vitrifies if any other earth is mixed with it. Heated on charcoal, or by the blowpipe, it is partially decomposed, part of the oxygen of its acid being abstracted. Its principal use is in statuary, and in the formation of plaster or stucco work.

Sulphate of Magnesia is found in sea-water, and in many mineral waters, and is usually extracted from the brine of sea-water, Bittern as it is named, this being boiled down until it afford the sulphate of magnesia, on cooling, in acicular crystals; or sulphate of iron is added, the sulphuric acid of which combines with the magnesia of the muriate of magnesia, and increases the quantity of sulphate. Obtained in this way, it exhibits a confused mass of needle-like crystals, which are deliquescent, but this is owing to the admixture of muriate of magnesia, as the pure sulphate is rather efflorescent. By slow evaporation of its solution, it crystallizes in quadrangular prisms acuminated by four planes. These crystals are soluble in little more than their own weight of water, at the temperature of 60°, and in three-fourths of their weight of boiling water. They undergo the watery fusion at a very moderate temperature, and the dry mass which remains is melted in a strong heat, but is not decomposed. The taste of this salt is very bitter, and the bitterness of sea-water and many mineral springs is owing in part to its presence.

Sulphate of Argil, formed by dissolving the earth in sulphuric acid, crystallizes when there is no excess of acid, in scales white and of a pearly lustre, which alter little by exposure to the air: its taste is astringent: it is very soluble

in water: when exposed to heat, its water of crystallization is dissipated, and, by a stronger heat, its acid is expelled. When there is an excess of acid, the compound crystallizes with more difficulty, as, on evaporation, it assumes a gelatinous consistence. Small brilliant crystals, however, are formed in it.

The salt known by the name of Alum is a ternary compound of argil, potash and sulphuric acid; sometimes even ammonia enters into the composition, and there is always an excess of sulphuric acid; its composition, as stated by Thenard, being 26 of acid, 12.5 of argil, 10 of potash, and 51.4 of water of crystallization, frequently with a little sulphate of iron, which is to be regarded as an impurity. It is often a natural product, occurring efflorescent in the layers of what has been named Alum Slate; and it is also formed by an artificial process, from what is named Alum Ore; this, which appears to be a variety of slate, being calcined, and afterwards exposed to the atmosphere in a humid state. The saline matter is extracted by lixiviation, and when a little potash has been added, alum is obtained by crystallization. The alum of commerce is in large masses, white and transparent. When regularly crystallized, the form of the crystals is an octaedron. It is soluble in 15 parts of cold, and in two parts of boiling water: its crystals are slightly efflorescent: its taste is sweetish and astringent. Its solution reddens the vegetable colours. When exposed to a moderate heat, it melts, from the water of crystallization which it contains dissolving the solid salt; this soon evaporates, and leaves a light white powder, named Burnt or Calcined Alum. By a strong heat,

the acid is partly expelled, partly decomposed, a quantity of oxygen being afforded by its decomposition. This salt is decomposed by the alkalis, and by barytes, lime, and magnesia, which attract the greater part of the acid, and precipitate the earth with a small quantity of acid combined with it. It is also decomposed when exposed to heat with carbonaceous matter.

A decomposition of this kind, in which a large proportion of carbonaceous matter is used, affords a very peculiar product, distinguished by burning spontaneously on exposure to the air. This substance, named Pyrophorus, is prepared by exposing to heat in an iron-pot, three parts of alum, with one part of flour: the mixture liquefies, and is to be stirred constantly till the whole becomes grey, and easily reducible to powder while hot. The coarse powder is put into a coated phial, so as nearly to fill it, and this, slightly stopped with clay, being surrounded with sand in a crucible, is exposed to a red heat, until a blue flame appears at the mouth of the phial: when this has continued ten minutes, the crucible is removed from the fire, and the phial, when sufficiently cold, is accurately stopt.

This substance inflames in atmospheric air, especially in a moist atmosphere. It burns brilliantly in oxygen gas, in nitrous gas, and oxymuriatic acid gas, and is inflamed by sulphuric and nitric acids. With regard to the theory of its combustibility, it has been proved, that in order to form it the alum must contain potash; the sulphuric acid is decomposed by the carbonaceous vegetable matter, and a portion of sulphur, which is its base, is supposed to combine with the potash, and form a sulphuret,

which is intimately diffused through the argillaceous earth. There likewise remains a quantity of charcoal in the same intimate mixture, and perfectly dry. When exposed to the air, moisture is absorbed by the sulphuret, by which the temperature is raised: the sulphur is enabled, by a disposing attraction exerted by the potash, to absorb oxygen: it is inflamed, and kindles the dry carbonaceous matter, the inflammation being facilitated by their extreme division, from their intimate mixture with the argillaceous earth, and the extensive surface they thus present to the air. Mr Davy has supposed, that a portion of the potash may even be decomposed by the joint action of the sulphur and charcoal, and potassium produced, to which the combustibility may be principally owing.

Alum is used in a variety of arts. It hardens tallow: it increases the adhesive power of the farinaceous pastes: it renders water clear, which is turbid from the admixture of earthy particles; and it is one of the most essential articles in the art of dyeing, fixing the colours, and often adding to their brilliancy. It is used in medicine as a powerful astringent.

The other sulphates have been little examined. Sulphate of Zircon is insipid and insoluble. Sulphate of Glucine is difficultly crystallizable; its taste is saccharine and astringent; it is very soluble in water, its solution assuming by concentration the consistence of a syrup. Sulphate of Ittria crystallizes in small brilliant grains, of a rhomboidal form, and of a colour inclining to amethyst red. Their taste is sweet and astringent.

The remaining combinations of sulphuric acid fall to be considered under the history of the substances to which they belong. The acid itself is of extensive use. It is one of the most important agents in chemical investigations, either by the affinities it exerts, or by the oxygen it communicates. In the arts it is much employed, as in bleaching; in some of the processes of dyeing; in metallurgic operations, and in the preparation of neutral salts.

Sect. III.—*Of Sulphurous Acid.*

Sulphurous acid is formed in the slow combustion of sulphur, but it is mixed with a little sulphuric acid, and to obtain it pure, the process followed is to decompose sulphuric acid by the action of substances which partially abstract its oxygen, and which do not form an aëriform product. The metals produce such a decomposition, and quicksilver or tin affords the purest product. One part of either is put into a retort, with two parts of sulphuric acid; heat is applied by a lamp; the metal attracts part of the oxygen of the acid, and the sulphurous acid gas is disengaged. Being absorbed by water, it is received over mercury.

The composition of sulphurous acid has been stated at 85 sulphur and 15 oxygen. Dr Thomson, from a series of experiments on the compounds of sulphur and oxygen, gives, as the proportions, sulphur 68, oxygen 32.

This acid exists in the state of gas; but it has been reduced to the liquid state by the application of intense cold,

and strong pressure. In its usual state its specific gravity is 0.00251, or it is more than twice as heavy as atmospheric air. It has a suffocating pungent odour, proves speedily fatal to life, and instantly extinguishes combustion.

It is easily absorbed by water, 100 grains of water taking up 8.2 grains, equal to 33 times its volume. The solution has a pungent disagreeable odour, and an acid taste. It reddens some of the vegetable colours, while there are others, however, the colour of which it destroys. From the application of a moderate heat, the greater part of the gas is expelled, though the liquor remains acid, from the presence of sulphuric acid. It is singular that it is not expelled by freezing; it remains combined with the ice, and renders it so heavy that it sinks in water.

The liquid sulphurous acid slowly absorbs oxygen from the atmosphere, and is converted into sulphuric acid. If they are mixed even in the gaseous state, if a small portion of water is introduced, they gradually combine. By passing a mixture of oxygen gas and sulphurous acid gas through a tube heated to redness, sulphuric acid is also formed. Hydrogen, at the temperature of ignition, attracts its oxygen. Charcoal, at the same temperature, produces in it a similar change, and sulphur is deposited. It is not decomposed by phosphorus, and it acts feebly on the metals.

This acid combines with facility with the alkalis, forming salts denominated Sulphites, which differ considerably from the salts formed by sulphuric acid. Their taste is sulphureous; they are decomposed by a high tempera-

ture, and by the greater number of the acids. The alkaline sulphites are more soluble than the sulphates in water, the earthy sulphites less so. All these salts are converted into sulphates by exposure to the atmospheric air, or by the action of any substance capable of affording them oxygen. They scarcely require individual notice.

Sulphite of Potash is obtained in crystals, white and transparent, of a rhomboidal figure, or in the form of small needles, soluble in an equal weight of water at a mean temperature, and in a less quantity of hot water.—Sulphite of Soda is white and transparent, soluble in four parts of water, more soluble in warm water; and the solution, on cooling, affords crystals of a prismatic form.—Sulphite of Ammonia requires less than its own weight of boiling water for its solution, and the solution crystallizes on cooling; its crystals, being six-sided prisms, white and transparent.—Sulphites of Barytes and Argil are insoluble; those of Lime and Magnesia soluble and crystallizable.

Sect. IV.—*Of Sulphuretted Hydrogen, and other Compounds of Sulphur and Hydrogen.*

Sulphur appears to combine with hydrogen in various proportions. The compound best known is an elastic fluid, which has received the name of Sulphuretted Hydrogen. There appears to be another with a larger proportion of sulphur, which may be named Super-sulphuretted Hydrogen, and there is even some reason to believe

that this latter combination may be established in different proportions.

1. Sulphuretted Hydrogen.—This compound is not easily formed by the direct combination of its constituent principles, but is obtained by indirect processes, in which the hydrogen is presented to the sulphur in a condensed or nascent state. That which affords it with most facility is the action of diluted muriatic acid on a sulphuret of iron, prepared by combining by fusion one part of sulphur with three parts of iron. The acid diluted with four parts of water acts on this compound, by a resulting affinity; it enables the iron of the sulphuret of iron to decompose the water, by attracting its oxygen; the hydrogen is disengaged, and being presented in its nascent state to the sulphur of the sulphuret, combines with it, and forms the sulphuretted hydrogen, which passes into the elastic form. It is also procured, but in less quantity, and with more difficulty, from the action of muriatic acid on the compounds which sulphur forms with alkaline bases.

The specific gravity of sulphuretted hydrogen gas is 1.36; compared with atmospheric air it is as 1142 to 1000. 100 cubic inches of it weigh 33 grains, or according to Mr Davy 35 grains. Its smell is extremely fetid and peculiar. It extinguishes combustion, and is incapable of supporting animal life. It is absorbed by water, the water taking up more than its volume, or 100 cubic inches absorbing, according to Mr Henry, 108, and acquiring from this impregnation the fetid smell of the gas, and a nauseous taste. It is colourless and transparent, but becomes turbid from exposure to the atmosphere.

In its elastic state, sulphuretted hydrogen does not combine with oxygen at low temperatures; but if placed over water, their mutual action is facilitated by its medium, the oxygen combines with the hydrogen, and a thin deposite of sulphur is formed. At the temperature of ignition the combination is more rapid. If the sulphuretted hydrogen gas be kindled in contact with the atmospheric air, it burns with a blue lambent flame. When previously mixed with one or two parts of atmospheric air, it does not detonate, and the combustion of its elements is not complete, part of the sulphur being deposited on the sides of the vessel. When mixed with an equal volume of oxygen gas, and kindled, it inflames with detonation, the products being watery vapour and sulphurous acid. It is decomposed by the action of some other gases, which afford to it oxygen, as by sulphurous acid, and nitric oxide gas, the oxygen combining principally with its hydrogen, and sulphur being deposited: oxy-muriatic acid gas likewise causes a precipitation of sulphur. From the results of these decompositions, Thenard inferred, that it is composed of 70.9 of sulphur, with 29.1 of hydrogen. Mr Davy has assigned as the proportions 2.27 of hydrogen, and 32.73 of sulphur.

Sulphuretted hydrogen exerts a peculiar action on the metals. It tarnishes them quickly, or communicates shades of yellow, brown or purple, with a diminution of metallic lustre. It deepens the colour of their oxides, and if added to metallic solutions, it produces a precipitate of the metallic oxide or of the metal in combination with the sulphur, generally of a dark shade.

Sulphuretted hydrogen combines with the alkalis and earths, and displays in these combinations, powers similar to those of an acid; it neutralizes the alkaline properties, and forms compounds capable of crystallizing, and having properties analogous to those of neutral salts. And not only has it these powers; it possesses the most distinctive character of an acid in an insulated state, that of reddening the vegetable colours, at least of the colour of litmus or radish.

If this substance, therefore, be a compound of sulphur and hydrogen, it forms an exception to the universality of the proposition, that oxygen is the principle of acidity, and affords an example of an acid containing no oxygen. To obviate this conclusion, it has been supposed that oxygen may exist in its composition, and it has been remarked, that its analysis never has been executed with that accuracy which precludes this supposition, the proportions of its elements always having been inferred from experiments, in which the proportion of sulphur only was determined, and the remaining matter having been supposed to be entirely hydrogen, though for any thing that the analysis establishes it might be partly oxygen. And in all the cases of its formation, there are obvious sources whence oxygen might be abundantly supplied. This view of the constitution of this compound appeared to be established by the results of the action of potassium on it, Mr Davy having found, that when this substance is heated in sulphuretted hydrogen, previously freed from moisture by the action of muriate of lime, it burns with a brilliant flame; the gas was

changed in its qualities, being resolved principally into hydrogen; the potassium had combined principally with the sulphur, and from the products obtained by the action of muriatic acid on this compound, Mr Davy inferred that it did not consist of the potassium combined with pure combustible matter, but contained oxygen.

He has since, however, found reason to call this conclusion in question, and of course there is no direct evidence of the existence of oxygen in sulphuretted hydrogen; for the evolution of heat and light, which accompanies the action of potassium on sulphuretted hydrogen, may arise merely from the intensity of chemical action. Still there is nothing to preclude the supposition, and on the theory, that oxygen alone is the principle of acidity, analogy would be in favour of it. Or, if the other view which I have already given of the theory of acidity, (page 384), that it is a property derived from combustible bases, developed only by substances which render these bases soluble and active, it may be admitted, as remarked under the statement of that theory, that hydrogen may have this effect as well as oxygen, and that, therefore, sulphuretted hydrogen may display acid powers, though no oxygen exists in its composition.

The compounds of sulphuretted hydrogen with the alkaline or earthy bases, are formed by transmitting it in its elastic form through water, in which they are dissolved or suspended, continuing the transmission until they are saturated. They are named Hydro-sulphurets. They are soluble in water, and crystallizable; their solutions are colourless, while the air is excluded, but when it is ad-

mitted, they become turbid from decomposition; the oxygen of the air combining with the hydrogen, a portion of sulphur is deposited, and another portion, if the exposure be continued sufficiently long, combines with oxygen, forming sulphuric acid. They are decomposed by the acids, sulphuretted hydrogen being disengaged; and they precipitate of a dark colour metallic solutions.

Hydro-sulphuret of Potash, obtained by the above process, is in prismatic crystals, white and transparent; its taste is bitter and alkaline; it is inodorous when dry, but becomes fetid, if moistened. It attracts humidity from the air, is soluble both in water and alkohol, and when acted on by acids, gives out a considerable quantity of sulphuretted hydrogen.—Hydro-sulphuret of Soda is also of a white colour, transparent, crystallized in tetraedral prisms, acuminated by four planes. Its taste is at first acrid and alkaline, soon becoming extremely bitter. It dissolves abundantly in water, and produces cold in dissolving: its solution is colourless, but gives a green tinge to paper: it has a smell of sulphuretted hydrogen. Acids produce with it a brisk effervescence, and render this odour very strong; but they do not render the liquid turbid. The nitrous and oxy-muriatic acids, however, produce a precipitate of sulphur.—Hydro-sulphuret of Ammonia. This compound is formed by the direct combination of its principles in their aërial form, a thin soft deposite being formed on the sides of the vessel, which exhales a penetrating vapour when exposed to the air. Another combination is obtained, by transmitting sulphuretted hydrogen through liquid ammonia, the liquid ac-

quiring a yellowish green colour, and fetid odour. Another combination long known to chemists, by the name of Fuming Liquor of Boyle, is prepared, by exposing to heat in a retort a mixture of sulphur, lime, and muriate of ammonia; a liquor distils over, of a yellow colour, which has a sharp fetid odour, and exhales white vapours. It varies considerably in the proportions of its constituent parts.

Hydro-sulphuret of Barytes is formed by transmitting sulphuretted hydrogen gas through water, in which barytes is suspended; it is abundantly soluble: and when barytes and sulphur are boiled together in water, the barytes renders soluble about one-fourth of its weight of sulphur, and a solution is formed of a yellowish red colour, which, when concentrated, deposites crystals of the form of hexaedral prisms. These according to Berthollet consist of hydro-sulphuret of barytes, without any excess of sulphur. They give out, when acted on by an acid, a large quantity of sulphuretted hydrogen. They are white, transparent, and of a silky lustre. A similar result is obtained from either of these processes with Strontites; and it is probable that the compound is of the same nature. Hydro-sulphuret of Lime can be formed by transmitting sulphuretted hydrogen gas through water in which lime is suspended. The compound is capable of crystallizing in prisms: it is soluble in water; the solution is without colour, but has a fetid smell. Sulphuretted hydrogen transmitted through water in which magnesia is suspended, dissolves a small quantity of it. Its relations to the other earths have not been examined.

II. Super-sulphuretted Hydrogen.—Besides the compound of sulphur and hydrogen, which forms sulphuretted hydrogen, they appear to combine in other proportions, so as to form different compounds. One of this kind is in particular formed by the action of alkaline sulphurets on water; it was observed by Scheele, and afterwards by Berthollet. It has been named more peculiarly Super-sulphuretted Hydrogen, and by some chemists Hydroguretted Sulphur.

If a large quantity of muriatic acid be added to a solution of an alkaline sulphuret; or if small quantities of the solution be poured into the acid, a little sulphuretted hydrogen gas is disengaged, part of the sulphur is precipitated, but a portion exists combined with the remaining sulphuretted hydrogen, forming a liquid which has the appearance of oil, of a yellow or reddish colour, and which soon subsides to the bottom of the vessel. This is what has been named Super-sulphuretted Hydrogen.

It has been little examined in its insulated state, and indeed it is not easily submitted to much chemical examination, as it is extremely susceptible of decomposition. Sulphuretted hydrogen escapes from it even at moderate temperatures, and it is also decomposed by the action of the air. In its action, however, on the alkaline and earthy bases, it forms combinations of some interest and importance.

These compounds are obtained by boiling an alkaline or earthy hydro-sulphuret with an additional proportion of sulphur. They are also formed merely by boiling sul-

phur with an earth or alkali in water, or by previously combining the sulphur with the earth or alkali by fusion, and then dissolving this in water. In either case, a decomposition of part of the water is produced; its oxygen is attracted by a portion of the sulphur and sulphuric acid formed, which is saturated by the requisite proportion of the alkaline or earthy base. The hydrogen of the decomposed water unites with the remaining sulphur, and with it and the rest of the base forms a ternary compound soluble in water; and as there is in the liquor a great excess of sulphur, the combination established is not that which constitutes sulphuretted hydrogen, but is super-sulphuretted hydrogen. It is probable even that, according to the relative proportions of the sulphur and alkali, the decomposition of the water may take place to a greater or less extent, and that these compounds may therefore vary in the proportions of their constituent principles. They are accordingly of different shades of colour, from reddish-yellow to a yellowish-green, and, what is a more direct proof of this, when they are decomposed by an acid, they afford variable quantities of sulphur by precipitation. The presence of the small portion of sulphate that is produced in their formation does not appear materially to modify their properties. They may be named, from the nature of their composition, Sulphuretted Hydro-sulphurets. The name of Hydroguretted Sulphur having been given to that compound of sulphur and hydrogen in which sulphur predominates, and this being the compound which they contain, they have been named Hydroguretted Sulphurets; but the name is so harsh that it can scarcely be adopted, and the

ether, without being liable to this objection, very well expresses their constitution, and the difference between them and the hydro-sulphurets.

These liquors are transparent, of a yellow colour more or less deep, and of different tints. Their smell is slightly fetid; they appear to be liable to spontaneous decomposition from the re-action of their elements; they are immediately decomposed by the addition of an acid, which neutralizes the base, precipitates the greater part of the sulphur, and disengages the hydrogen combined with a portion of sulphur in the state of sulphuretted hydrogen. Where the alkaline liquor has been largely impregnated with sulphur, the quantity of sulphuretted hydrogen disengaged is extremely small, so that there is no sensible effervescence. The precipitated sulphur is of a pale or white colour, either from its state of aggregation or combination with water. It contains, according to Berthollet, a portion of hydrogen.

The facility with which these compounds combine with oxygen forms their most important chemical property. If exposed, either to pure oxygen or to atmospheric air, the oxygen gas is absorbed, and the liquor continues to exert this action until nearly the whole of the sulphur it contains is converted into sulphuric acid, and it becomes, of course, a solution of the sulphate of the alkali or earth with which the sulphur had been combined. This facility of combination appears to be owing partly to the sulphur being in the liquid state, whence the resistance that is opposed by its cohesion in its usual form to its combination with oxygen does not operate; and partly to the alkaline or earthy

base, by a resulting affinity promoting the combination of the sulphur and oxygen.

From this power of absorbing oxygen gas, these liquors have been applied to the purpose of eudiometry, and they afford, on the whole, one of the best eudiometers. The liquor employed has been either the sulphuretted hydrosulphuret of potash or of lime; the latter being easily prepared in a high state of concentration, is preferred. It is obtained by boiling equal weights of lime and sulphur in 10 or 12 times their weight of water. When a tube containing atmospheric air is placed in a portion of this liquor, the oxygen of the contained air is gradually absorbed, and the liquor rises within; and if the tube has been graduated, the quantity of oxygen abstracted is indicated.

This method of operating, however, has the disadvantage of slowness; the liquor, from the smallness of the surface in contact with the air, absorbing the oxygen only very gradually, and a considerable time, too, being required to mark when the absorption has become complete. It is of importance, therefore, to accelerate the operation, and the apparatus which Dr Hope employs does so with every advantage. It consists (fig. 21.) of a small bottle designed to contain the sulphuretted solution; to the mouth of this is accurately adapted by grinding, a tube divided into 100 equal parts, and towards the bottom of the bottle is an orifice fitted with a stopper. The bottle being filled with the solution, and its orifice being covered with a flat plate of glass, it is placed under the surface of water, and the graduated tube containing the air subjected to trial, is inserted into it. The apparatus is removed

from the water, is inclined so as to allow part of the liquor to flow into the tube, and agitated strongly. It is replaced in the water, and the stopper at the under orifice withdrawn, when, from the absorption of the oxygen of the air, a quantity of water rushes in. The stopper is again introduced, the agitation renewed, and the operation is repeated until the absorption proceeds no farther. The amount of this may be determined by plunging the bottle with the tube adapted to it into water, removing the stopper of the under orifice, and taking care that the water without is at the same level as the liquor within, allowing it also to stand for a short time, that any slight rise of temperature from the application of the hand during the agitation may have ceased.

The diminution which atmospheric air suffers when subjected to this eudiometrical method, is between 21 and 22 in 100. Generally speaking, it is to be preferred to every other, as of easiest execution, and liable to fewest errors. The only fallacy to which it appears subject, is the absorption of a small quantity of nitrogen gas. If the liquor has been newly prepared by boiling, and if used without previous exposure to the air, it will, in common with any other watery liquid, absorb a portion of the atmospheric air undecomposed, or of its nitrogen as well as of its oxygen, and the substances with which it is impregnated perhaps even render the absorption of nitrogen rather greater than it would be by pure water. Accordingly, under these circumstances, it has been found that nitrogen is absorbed by these liquids; but this is easily obviated, by agitating the liquor, if it has been newly prepared, with at-

mospheric air before using it. It farther appears that when these liquors are kept for a considerable time in contact with the air, the condensed nitrogen combines with the hydrogen of the sulphuretted compound, and forms ammonia; a fresh portion of nitrogen is absorbed, and this continues to proceed, so that the diminution of volume is at length considerable; Scheele, for example, having found it to amount in atmospheric to 28 in 100 parts, undoubtedly from this cause. But, in performing the experiment in the above mode, this source of fallacy cannot operate.

The properties of the different compounds of this class with the alkalis and alkaline earths are so similar as to require no distinct enumeration. They are all liable to vary in their state of concentration from the relative quantistie of their ingredients; and there is also reason to believe, as has been already remarked, that the compound of sulphur and hydrogen which they contain, differs, from this cause, in the proportions of its constituent principles. Those of potash, soda, ammonia, barytes, strontites and lime, may be obtained highly concentrated; that with magnesia is less perfect, and contains much less sulphur dissolved.

Besides these compounds of sulphur and hydrogen, some other products have been obtained from the action of certain substances on sulphur which have been supposed to be formed of these elements. Lampadius had observed the production of a substance possessed of some singular qualities, in submitting to heat a mixture of native sulphu-

ret of iron with charcoal, coal, or bituminated wood; and the same, or a similar product, is obtained by exposing to heat a mixture of sulphur and charcoal, or passing sulphur in vapour over charcoal ignited in a tube. Lampadius, from its inflammability and volatility, named it Alkohol of Sulphur. It is liquid, colourless, or of a greenish tinge with transparency; it has a penetrating odour, is highly volatile, producing in its spontaneous evaporation a considerable degree of cold; it boils at 104, or, if the atmospheric pressure is removed, it assumes, at natural temperatures, the elastic form; it is heavier than water, its specific gravitybeing 1300; it is highly inflammable, burns with a blue flame and without smoke, and affords, by its combustion, sulphurous or sulphuric acid and a little water. It is soluble in water though sparingly, and is more abundantly soluble in alkohol. Lampadius supposed it to be a compound of sulphur and hydrogen. Clement and Desormes, on the contrary, who examined its production, consider it as a compound of charcoal and sulphur, and name it Carburetted Sulphur. The determination of this question with regard to the composition of this substance has occupied the attention of several chemists, and it does not yet appear to be altogether without doubt. Clement and Desormes observed that the charcoal disappeared in the process of its formation, if a sufficient quantity of sulphur were employed, and that in burning it gave a residuum of charcoal. The younger Berthollet, however, submitting it to examination, found that it deposites no charcoal in its combustion, and that in the products no indication of carbonic acid could be discovered; and when decomposed by oxy-

muriatic acid, there is also no trace of charcoal. Robiquet assisted by Vauquelin, obtained the same results. Hence it may be concluded, that it is a compound of sulphur and hydrogen, the hydrogen being derived, according to Berthollet, from both the sulphur and charcoal. Mr Davy has since remarked, that, from experiments made upon it, he finds it to differ considerably according to the kind of charcoal employed in its formation. If this has been imperfectly made, the product affords, by combustion, a carbonaceous residuum, while, if the charcoal had been well calcined, this could not be observed. It appears on the whole, therefore, that sulphur and hydrogen are its chief constituent principles.

In the process by which this product is obtained, other substances are formed, probably of analogous constitution, though varying in the proportions of their constituent principles. If little sulphur be employed the product is principally gaseous, has the odour of sulphuretted hydrogen, but differs from it in being less soluble in water. The liquid obtained is even of different degrees of density, according as the temperature, volatilizing more or less of the sulphur, regulates the proportions. And if there be a great excess of sulphur, a solid substance is obtained, which contains a smaller proportion of hydrogen. It has a laminated texture, a specific gravity a little inferior to that of sulphur, a fetid smell, and, when heated, gives out sulphuretted hydrogen. It is not impossible, too, but that oxygen may enter into the composition of some, or all of these products.

Sect. V.—*Of the Compounds of Sulphur with the Alkalis and Earths.*

Sulphur combines with the fixed alkalis, and with several of the earths, forming sulphurets, of which the chemical history remains to be given. These compounds are formed by exposing the alkali or earth, with the due proportion of sulphur, to a moderate heat in a covered crucible. They exist only in the solid form; for when dissolved in water new combinations are established from the decomposition of the water, as has been explained under the preceding section.

Sulphuret of Potash is formed by exposing to heat in a covered crucible, equal parts by weight of sulphur and dry concrete potash; the compound melts. When it has become concrete, it is firm and brittle, of a dark reddish-brown colour. A similar combination is obtained, by exposing to heat one part of sulphur with two parts of subcarbonate of potash, but it appears to be less intimate, part of the carbonic acid probably being retained: its colour is grey or green. Sulphuret of potash is inodorous while it remains dry; but when moistened or dissolved, acquires a fetid smell, from the production of sulphuretted hydrogen. It is fusible, and when exposed to a strong heat in close vessels, a portion of sulphur is sublimed from it. From suffering a chemical change when in a state of solution, it is scarcely possible to discover precisely its pe-

culiar agencies. One singular property belonging to it, is, that when fused with some of the metals, with gold for example, a combination is formed, which is soluble in water,—a fact observed by Stahl, and not yet fully elucidated.

Sulphuret of Soda is formed by the same process as sulphuret of potash, and has been described as similar in appearance.—Sulphuret of Ammonia does not exist, as there is no mode of bringing its elements to act on each other, without the production of sulphuretted hydrogen.—Sulphuret of Barytes is formed by exposing sulphur and barytes to a red heat in a covered crucible; the compound has a reddish-yellow colour.—Sulphuret of Strontites is formed by a similar process, as is also the Sulphuret of Lime; and in external appearance they are nearly the same.

Sulphur appears capable of combining with the bases of the alkalis and earths. Mr Davy found that it unites with potassium, when they are brought into contact in tubes filled with the vapour of naphtha; there is a rapid evolution of heat and light, and a grey substance in appearance like artificial sulphuret of iron is formed. This sulphuretted potassium easily inflames; it is also gradually oxygenated from exposure to the air, and converted into sulphate of potash. Sodium and sulphur combine with equal facility, intense heat and light being disengaged. The compound is of a deep grey colour. The phenomena displayed in these combinations are similar to those

which attend the combinations of sulphur with the metals; and the compounds have properties similar to the metallic sulphurets.

CHAP. III.

OF CARBONIC ACID, ITS BASE, AND THEIR COMBINATIONS.

In the combustion of charcoal an acid is produced which exists in the aërial form. Charcoal being a heterogeneous substance, or containing with its inflammable matter small portions of saline and earthy substances, the term Carbon was introduced to denote its pure base, and the acid formed in its combustion was hence named Carbonic Acid. Carbon, in this sense, therefore, denoted merely the inflammable matter of charcoal. But it was afterwards discovered, that the same matter exists under other forms. The diamond, which was known to be combustible, was found to yield carbonic acid as the only sensible product of its combustion, and hence came to be regarded as pure carbon. And the mineral substance known by the name of Plumbago or Graphite, was also found to be chiefly carbon with a small portion of iron. It is not certain but that charcoal, even in the purest state in which it can be prepared, contains hydrogen; and Mr Davy has supposed, that in diamond there is a small portion of oxy-

gen. The pure inflammable base, therefore, that to which the name of Carbon is appropriated, is perhaps unknown to us; and analogy, as well as the phenomena it presents in its combination with iron, might lead to the suspicion of its being metallic. ' The quantity of foreign matter with which it is combined in these substances, appears, however, to be small. It farther exists as a principal ingredient of all vegetable and animal substances, and is extensively distributed in the mineral kingdom: Diamond, as its purest form, may first be considered.

Sect. I.—*Of Diamond.*

The Diamond, the gem which, from its lustre and hardness, is of greatest value, is found in India and in Brazil. It occurs crystallized, is colourless or tinged of various shades, transparent, and has a laminated structure; in hardness it is superior to every other substance; its specific gravity is 3.5.

From its high refractive power, Newton conjectured that the diamond must be an inflammable body. It was found to be dissipated when placed in the focus of a powerful burning mirror, and even in the heat excited in a furnace. In the latter mode of making the experiment, its surface was observed to be luminous; and at length it was ascertained, that at a temperature sufficiently elevated it suffers a real combustion. The object of inquiry was then to ascertain what is the product of its combustion; La-

voisier, making experiments with this view, observed, that if the diamond were not highly heated, its surface became covered with a thin coating of charcoal, and when by raising the heat higher the combustion was rendered complete, the only sensible product was carbonic acid. He concluded, therefore, that there exists a great analogy between diamond and charcoal in chemical constitution.

Mr Tennant, some years afterwards, burning the diamond by the aid of nitre in a gold tube, concluded from the product of carbonic acid, that the quantity afforded by a given weight of diamond is the same as is afforded by the same weight of charcoal, and hence inferred, that the diamond differs from charcoal only in the state of aggregation and its crystallized form. Guyton, from a series of experiments, advanced a different opinion. Placing the diamond in pure oxygen gas, and heating it by directing on its surface the solar rays concentrated by a lens, he observed, as Lavoisier had before done, that its surface was first charred; when the heat was applied in more intensity this disappeared, and it began to burn with a glow of light. On estimating, at the end of the experiment, the quantity of carbonic acid it produced, it exceeded considerably the quantity that would have been produced from the consumption of the same weight of charcoal, 100 parts of carbonic acid, as he stated the results, being obtained from the disappearance by combustion of 17.88 of diamond, while the same quantity only is formed from the combustion of 28 of charcoal. He concluded, therefore, that the difference between these two substances is, that

the diamond is the pure carbonaceous base, while charcoal is an oxide of carbon.

The mode, however, in which Guyton estimated the quantity of carbonic acid was not free from objections, and more lately Messrs Allen and Pepys have repeated the experiment of the combustion of these substances in oxygen gas, and have found that the proportions of oxygen consumed, and of carbonic acid formed from equal weights of each are the same; whence they have concluded, as Mr Tennant had before done, that they differ merely in aggregation and form. I shall have to state that there is some reason to conclude, that charcoal contains a small quantity of hydrogen, and Mr Davy has supposed, that diamond may contain a minute quantity of oxygen. These differences may exist without being capable of being discovered by any difference in the products of combustion, as the small portion of hydrogen in charcoal will form water, which will be retained in combination with the carbonic acid gas.

The diamond requires a high temperature to cause it to burn, and, even when kindled in oxygen gas, does not evolve so much caloric as to support the necessary heat. It presents different appearances, according to the temperature; its surface being blackened if the heat is not sufficiently high, and the illumination being brighter as it is raised.

The diamond is scarcely acted on by any other agent. By sulphuric acid heated on it, it appears to be charred; the other acids do not affect it, an inertness evidently owing to its state of aggregation.

Sect. II.—*Of Plumbago, &c.*

This substance, the Black Lead of Commerce, is a mineral production. Its relation to carbonaceous matter, and at the same time the existence of iron in it, were first observed by Scheele; and from subsequent experiments by Pelletier and Monge, it was inferred to be a compound of carbon and iron, containing from 5 to 10 of iron in 100 parts. Guyton supposed, that it consumes more oxygen in its combustion than charcoal, and that, therefore, though an oxide of carbon, it approached nearer to the pure inflammable base. This conclusion rested on no decisive evidence; and Messrs Allen and Pepys have found, that the carbonaceous matter of it consumes the same quantity of oxygen, and affords the same quantity of carbonic acid as charcoal. Mr Davy regards it as carbon combined with iron, and has supposed, that as it exists in this combination, the carbon approaches to the metallic state, the compound being a conductor of electricity, opaque, with considerable lustre. It so far approaches in chemical characters to the diamond as to be little acted on by any chemical agent, and to be so imperfectly combustible as to require a very elevated temperature, and the continued application of external heat to cause it to burn.

The substance named Mineral Carbon, Incombustible Coal, or Anthracite, appears, so far as regards its carbonaceous matter, to be in a similar state. It differs from other

coals in containing no bitumen; and it is much less combustible, burning only at an elevated temperature, and scarcely evolving so much heat as is sufficient to sustain its combustion. With carbonaceous matter it contains portions of silex, argil, and iron. Guyton had supposed it to be an oxide of carbon at a lower degree of oxidation than common charcoal; but Allen and Pepys have found that it consumes in burning the same quantity of oxygen, and affords the same quantity of carbonic acid; and its inferior combustibility is probably owing to its state of aggregation.

Sect. III.—*Of Charcoal.*

Charcoal is obtained from the imperfect combustion of wood; the wood cut into billets being reared in a pile which is covered with earth or turf, apertures being left to regulate the circulation of air, by which the combustion, when the wood is kindled, is supported. This combustion is carried on as slowly as possible; the volatile principles of the wood, particularly its oxygen and hydrogen, with a portion of its carbon, form volatile products, which are disengaged; and there remains at length the black porous substance which forms common charcoal, retaining frequently the figure and texture of the wood. To prepare it thoroughly, it requires to be exposed to a red heat with the exclusion of the air: this is done by covering it with sand. By the same method, well prepared charcoal may at

once be obtained from wood, a heat sufficiently intense having been applied.

From the nature of this process, it is obvious that there must exist in the charcoal any other matter not volatile which entered into the composition of the wood; and accordingly it always contains portions of saline and earthy matter, chiefly carbonates of potash and lime, with a little oxide of iron. But these are present in comparatively minute quantities, and do not appear to modify its properties. Apart from these charcoal was regarded in the modern system of chemistry as pure carbon. Guyton, however, as has been already stated, supposed it to be an oxide of carbon; while Allen and Pepys, finding that it consumes the same quantity of oxygen, and forms the same quantity of carbonic acid, established again the former opinion.

There are some facts, however, which still render this doubtful, and which are favourable to a conclusion advanced by Berthollet, that charcoal contains hydrogen. In particular, when charcoal is burnt in oxygen gas a sensible quantity of water is deposited; when it is urged with a strong red heat, a quantity of elastic fluid is given out, composed of carbon and hydrogen; and when heated with sulphur, in the experiments already referred to, sulphuretted hydrogen, or super-sulphuretted hydrogen is disengaged.

It is true, that there are some sources of fallacy, whence it might be supposed that these results arise. If charcoal is not thoroughly calcined, a portion of the hydrogen of the vegetable matter may exist in it, which however may

not be essential to it, and may be expelled if the charcoal is more completely prepared. It appears too, that charcoal imbibes humidity very rapidly, absorbing it even from the air, and in such experiments this may be the source of the hydrogen which appears.

The operation of both these causes is unquestionable in some of the experiments which have been made on this subject, but there are others in which we can scarcely admit their influence, and in which the existence of hydrogen in charcoal is still indicated. In particular, when charcoal has been thoroughly calcined by exposure to an intense heat, and immediately on its removal from the fire, without being allowed to cool under exposure to the air, is mixed with sulphur, the mixture, when urged by heat, affords both sulphuretted and super-sulphuretted hydrogen, and in such quantities, that the hydrogen existing in these products cannot be supposed to be derived from the sulphur alone. Mr Davy also finding that a small quantity of aërial fluid is given out in submitting charcoal in the best state of preparation to the intense heat of a galvanic battery, has supposed that it contains a minute proportion of hydrogen.

There are even some facts from which the existence of a little oxygen in charcoal may be inferred, particularly the singular one observed both by Lavoisier and Guyton, that the diamond, when heated in oxygen gas, is charred on its surface. And theory would lead us to conclude, that minute portions both of oxygen and hydrogen may exist in it, for being obtained from products in which these elements exist, and from which they are expelled by heat, in

proportion as their expulsion proceeds, the affinity of the carbon to the remaining portions must become stronger from the increase in its relative quantity; and minute quantities may, and probably will be retained with a force, which even a very intense heat will be unable to overcome. The only difficulty in this view of the subject arises from the fact apparently established, that the same quantity of carbonic acid is produced in burning from charcoal as from diamond, and the same quantity of oxygen consumed. But if the quantity of hydrogen is small, the water which it will form may exist in the elastic form combined with the carbonic acid, and add so far to its volume, as that this shall appear equal to the volume of carbonic acid produced from the combustion of the same weight of diamond, though this contain no hydrogen. And as hydrogen combines with rather a larger proportion of oxygen than carbon does, this may even give rise to the apparent equality in the consumption of charcoal and diamond, though the former contain even a small quantity of oxygen as well as of hydrogen.

From all these considerations, it must appear doubtful, if the pure carbonaceous base is still known to us in its insulated form. And the observation by Mr Davy is very just, that minute differences in chemical composition may produce great differences in external and physical characters.

Charcoal well prepared is brittle and porous, tasteless and inodorous; it is also procured by some processes in the state of a powder. It is infusible in any heat that a furnace can raise; but by the intense heat of a very power-

ful galvanic apparatus, it is hardened, and at length is both fused and volatilized. In its common state it gives out, when exposed in close vessels to a heat above redness, an elastic fluid, consisting principally of a variety of carburetted hydrogen: this diminishes as the heat is raised, and at length the production of it ceases. But even when it has been brought to this state, a small portion of gas is expelled by the more intense heat which galvanism excites. This evolution of aëriform matter is to be ascribed, in the earlier stages of the process, probably principally to the decomposition of water which the charcoal had imbibed, and accordingly part of it is always carbonic acid: the smaller quantity evolved at more intense heats is probably derived from the minute portion of hydrogen and perhaps of oxygen combined with the carbonaceous base. By this high degree of calcination the charcoal is rendered a better electrical conductor.

Charcoal is insoluble in water, and is not affected by it, nor does it at low temperatures produce on the water any change. It absorbs a small portion of it, and hence, in cooling, it imbibes it from the atmosphere so as sensibly to increase in weight. At the temperature of ignition it decomposes water, the products being carbonic acid gas and a variety of carburetted hydrogen gas.

A very singular property belonging to charcoal, is that of absorbing the different aërial fluids in considerable quantity without forming with them any intimate combination. If the charcoal, when ignited, is allowed to cool without exposure to the atmosphere, on exposing to it any gas the absorption takes place, and exceeds many times

the volume of the charcoal. The extent of it is different with different aërial fluids: carbonic acid, muriatic acid, and ammonia, are largely absorbed, while oxygen, nitrogen, and hydrogen, are absorbed more sparingly. The condensed gas appears to suffer no chemical change; and the greater part of it is again expelled by a heat inferior to that of boiling water, and also to a certain extent by immersion in water. Neither is there any apparent alteration in the properties of the charcoal. It is therefore a mere mechanical condensation, produced, probably, however, by a certain attraction exerted by the carbonaceous matter to the aërial fluid. Two gases thus condensed in the pores of the charcoal have been found to combine; oxygen and hydrogen when absorbed together, for example, forming water, and this being accompanied with a sensible elevation of temperature.

When the action of oxygen and of hydrogen gases is favoured by humidity, they appear to dissolve small portions of charcoal at common temperatures. At the temperature of ignition they form with it intimate combinations. In burning, charcoal combines with oxygen gas, forming carbonic acid. And if hydrogen gas be passed over charcoal in an ignited tube, an elastic fluid formed from their combination is obtained. Nitrogen does not unite with it. It appears to form combinations with sulphur, either alone or with hydrogen, some of the products from the mutual action of sulphur and charcoal at high temperatures being compounds of this kind, as has been already noticed.

The alkalis scarcely sensibly dissolve charcoal when it is

pure, though in its common state they receive from it a dark brown colour. It decomposes a number of the acids by abstracting their oxygen, some suffering this decomposition at a low, others only at a high temperature.

One very singular property, undoubtedly chemical, belonging to charcoal, remains to be stated: it is that of removing the odour, taste, and colour of a number of vegetable and animal substances, when triturated or digested with them by the medium of water. Thus, all saline substances, which, from the adherence of vegetable or animal extractive matter, are of a brown colour, may, after this process, be obtained white by a second crystallization: carbonate of ammonia, which is fetid and dark coloured when obtained from the decomposition of animal matter by heat, is rendered perfectly white and pure by sublimation from charcoal powder. Resins, gum-resins, balsams, and essential oils, even those that have the strongest smell, are rendered nearly inodorous when they are rubbed with charcoal and water, or when solutions of them in alkohol are macerated with the charcoal, or filtrated repeatedly through it; and a number of the vegetable tinctures and infusions lose their colour, smell, and much of their taste, by the same process. It is from this agency that charcoal powder removes the offensive smell and taste which water acquires from keeping in wooden casks, and that it obviates even the putrescence of animal matter. To produce these effects, it is necessary that the charcoal should have been well calcined and newly prepared, or at least should have been long exposed to the air. A certain quantity too is necessary, more or less, according to the

effect required. It is not very obvious by what kind of agency the charcoal produces these effects.

Sect. IV.—*Of Carbonic Acid.*

This is the Fixed Air of Dr Black, the first of the aëriform fluids which was submitted to accurate examination. He investigated a number of its properties, and the changes it produces in chemical combinations, particularly with the alkalis and earths. Bewly and Bergman discovered its acid powers, which, from being comparatively weak, had escaped Dr Black's observation.

Though this acid is produced without difficulty by the direct combination of its constituent principles, it is usually obtained by other processes. It exists, combined with lime, in the different varieties of limestone, marble, and chalk; and if any of these be exposed to a strong red heat, the affinity of the acid to the lime is so far weakened, that it assumes the elastic form. Or, if the affinity of another acid to the lime is introduced, the same result is obtained without applying heat. If into a bottle fitted with a bent tube, small fragments of chalk or marble are put, and if to this diluted sulphuric or muriatic acid is added, a strong effervescence is immediately excited from the disengagement of the carbonic acid gas, the sulphuric or muriatic acid combining with the lime: the gas may be collected over water, by which it is not immediately absorbed in any considerable quantity.

The experiment of the formation of this acid, however, by the direct combination of its principles, is of importance, as determining its composition with regard to their proportions. Lavoisier, in performing this experiment by burning charcoal in oxygen gas, the charcoal having been previously thoroughly ignited to avoid as much as possible any error from the production of water, which is always observed when this precaution is not taken, fixed the proportions of the principles of the acid at a mean at 28 of charcoal and 72 of oxygen; and with this the results of the experiments of Clement and Desormes, and more lately of Messrs Allen and Pepys, almost exactly agree, the proportions assigned by the latter chemists being 28.6 of carbon and 71.4 of oxygen. It is not perfectly certain, as has been already remarked under the history of charcoal, but that a little water may be formed, from the small portion of hydrogen which that inflammable substance probably contains, and may exist in the carbonic acid gas; but the quantity, if it do exist, must be regarded as very minute. It appeared, from some of these experiments, that in this formation of carbonic acid gas there is a sensible condensation; but this appears to have arisen from the operation of other circumstances: and in those performed by Allen and Pepys it was not observed, the oxygen gas combining merely with charcoal to form carbonic acid, by which its density was altered, but its volume not changed.

The composition of carbonic acid has been established by its analysis. This is effected by a concurrence of affinities: a few pieces of phosphorus are put at the bottom

of a coated glass tube, and over this is put a quantity of marble (carbonate of lime) in powder, or what renders the experiment more easy of execution, carbonate of potash or soda dried. The part of the tube containing the carbonate is placed across a small furnace, so as to be brought to a red heat: the heat communicated to its extremity is sufficient to volatilize the phosphorus, and this passing over the ignited carbonate, decomposes the carbonic acid, by attracting its oxygen: phosphoric acid is thus formed, which unites with the base of the carbonate, and the carbonaceous base of the acid remains diffused through the mass in the state of charcoal perfectly black. It may be collected by dissolving the saline matter, and when dried has all the properties of common charcoal. The decomposition is probably produced by the joint affinities of the phosphorus, and the alkaline or earthy base with which the carbonic acid is united to its oxygen, aided by the state of condensation of the acid, or to its being acted on in a nascent state as disengaged by the heat. Potassium, from the strength of its affinity to oxygen, decomposes carbonic acid with facility, burning in the gas, and precipitating charcoal. And a partial abstraction of its oxygen is even effected by some of the metals, as iron or zinc, at a high temperature.

Carbonic acid has a greater specific gravity than the other elastic fluids: it is compared with atmospheric air as 0.0018 to 0.0012, or is one half heavier; it is inodorous, has a pungent taste; it proves eminently fatal to life, an animal immersed in it being immediately killed, and even

when diluted with two or three parts of atmospheric air, it exerts a deleterious power.

Carbonic acid in its elastic form is absorbed by water, the water, at a mean atmospheric pressure and temperature, absorbing nearly its own volume. The absorption is promoted by agitation, and the quantity absorbed is increased by cold, or by augmented pressure. The water, when largely impregnated with it, sparkles when shaken, and has a pungent taste; the gas escapes on exposure to the atmosphere: it is entirely expelled by boiling, and is disengaged by freezing.

The acidity of carbonic acid is weak, and tests of some delicacy are required to discover it. Its taste is scarcely perceptibly sour, either in its elastic or liquid form; it reddens, however, the more delicate vegetable colours, as that of litmus; and though it adheres with little force to the bases with which it combines, this Berthollet ascribes to its greater tendency to pass into the elastic state; and judging from its powers of saturation, it may even be regarded as superior in acidity to a number of the other acids.

It combines with the alkalis, earths, and metallic oxides, forming salts denominated Carbonates. In these combinations, at least with the alkalis, is displayed the peculiarity, that the alkaline properties are rather impaired than neutralized; it is at least difficult to establish neutralization, and the compounds, even when obtained of uniform composition by crystallization, retain to a certain extent the alkaline properties; they have the alkaline taste, change to a green the vegetable colours, and combine with oils so as to form soaps. The alkalis in this state were there-

fore formerly regarded not as compounds; they were supposed to be in their purest form, were named Mild Alkalis, to distinguish them from what were named Caustic Alkalis, which were supposed to be less pure. Dr Black shewed, that the mild state, as it was named, is owing to the presence of carbonic acid; and Bergman proved, that in this state they are to be regarded as compound salts. They generally form, however, with an excess of base, and it is not very certain if they can be obtained otherwise, at least in a crystallized state. The property by which they are peculiarly distinguished, is that of effervescing strongly on the addition of any acid, the carbonic acid being disengaged, and assuming the elastic form. They are also easily decomposed, at least partially, by heat, the carbonic acid being expelled. In the earthy carbonates, however, it is retained with more force, and requires a much higher heat.

Sub-carbonate of Potash.—It is under the form of this salt that potash is afforded in the processes by which it is usually obtained, as in the incineration of the wood of plants. It therefore forms the base of this product,—the potash or pearlash of commerce, which also contains, however, other saline substances, particularly sulphate and muriate of potash, and earthy and metallic matter. From these, it is in part freed by dissolving the pearlash in an equal weight of warm water; the foreign substances being sparingly soluble, remain in a great measure undissolved; the clear liquor is poured off, and is evaporated until a pellicle appear on its surface; on cooling and remaining at rest for a few hours, it deposites a little muri-

ate of potash, and being poured off from this and evaporated, the sub-carbonate is obtained. The chemists have also employed other processes to procure it, such as burning tartar at a red heat: this substance consists of potash, combined with tartaric acid,—a vegetable acid having a compound base of carbon and hydrogen, and which, therefore, when decomposed by heat, affords carbonic acid, with which the potash combines. By deflagrating tartar with nitre, a similar product is formed, and also by deflagrating nitre with charcoal, the charcoal being converted into carbonic acid by the oxygen afforded by the decomposition of the nitric acid, and the carbonic acid combining with the potash, which is the base of the nitre. As obtained by these processes, the sub-carbonate of potash is even purer than in the state in which it is procured from the pearlash of commerce.

Sub-carbonate of potash, obtained in a concrete state by evaporation, is generally in the form of coarse grains, as it is not susceptible of regular crystallization. From the excess of alkali it contains, it is deliquescent; and if exposed to the air, it soon attracts as much water as dissolves it. Its taste is acrid; it changes the vegetable colours to a green, and combines with oils, forming a saponaceous compound. It is decomposed by the acids; its carbonic acid being disengaged with effervescence. A considerable portion, but not the whole of its acid is expelled by a strong red heat. It consists of about 60 of alkali, 28 or 30 of carbonic acid, and 6 of water, with a little siliceous earth, sulphate of potash, and argil.

Carbonate of Potash may be obtained by leaving the

solution of the sub-carbonate exposed to the air for a considerable time, carbonic acid being imbibed from the atmosphere, and thus crystals of the neutral carbonate are deposited. Or it is formed more directly by passing a current of carbonic acid gas through a solution of the sub-carbonate of such a strength that crystals form spontaneously. One part of the sub-carbonate dissolved in three of water affords a solution of the proper strength. The crystals are bevelled quadrangular prisms; they do not, like the sub-carbonate, deliquesce. They require, at a mean temperature, four parts of water for their solution, and produce, while dissolving, a degree of cold. They are much more soluble in hot water, the water taking up even $\frac{5}{6}$ of its weight; but if the temperature be that of boiling water, part of the carbonic acid assumes the elastic state, and rises through the liquor. The taste of this crystallized salt is more mild than that of the sub-carbonate, though still alkaline; it has no causticity, but it unites with oils, and changes the vegetable colours to a green: it can scarcely therefore be regarded as the neutral carbonate. It consists, according to its analysis by Pelletier, of 40 of potash, 43 of carbonic acid, and 17 of water. It is little used but for some medicinal purposes, but the sub-carbonate in the state of the potash and pearl-ash of commerce is applied to many uses in the arts, principally from the alkali it contains.

Potash is capable of combining with a less portion of carbonic acid, but still so as to form a crystallizable salt. It is also easily super-saturated by dissolving the sub-carbonate in water, (one ounce in ten pounds), and by the

assistance of cold and pressure impregnating the solution strongly with carbonic acid gas; the liquor, when a sufficient quantity of carbonic acid has been combined in it, is pleasantly acidulous, with some pungency, and the alkali thus super-saturated proves less irritating to the stomach than in any other state.

Carbonate of Soda.—The salt which usually receives this name is in strictness of nomenclature a sub-carbonate, for its taste is alkaline, and it changes the vegetable colours to a green. It is extracted from the saline matter obtained by the combustion of marine plants, the barilla of commerce; the purer kinds of barilla being lixiviated with warm water, and the solution being evaporated, so that on cooling it shall crystallize. The crystals are octohedrons; they are efflorescent, so as in a dry atmosphere to be soon reduced to a powder. They require, at a medium temperature, twice their weight of water for solution, and are more abundantly soluble in hot water, the saturated solution crystallizing on cooling. Exposed to heat, they suffer the watery fusion from the action of a large quantity of water of crystallization; as this is dissipated, the salt appears as a dry white powder, which by an increase of heat may be fused and partially decomposed. The proportions of the crystallized salt are 21.58 of soda, 14.42 acid, and 64 water of crystallization. Soda more fully saturated with carbonic acid may be obtained either by transmitting carbonic acid gas through a solution of the sub-carbonate, or, according to a process now received in the London Pharmacopœia, mixing one part of it with three parts of sub-carbonate of ammonia, the carbonic

acid of the latter salt being transferred to the soda, and the ammonia being distilled off. The residual liquor affords crystals of carbonate of soda. The alkali may also be super-saturated with carbonic acid by the same process as that followed with the carbonate of potash; and this super-saturated solution is like the other in medicinal use.

Carbonate of Ammonia.—Ammonia, by combination with carbonic acid in different proportions, affords various products, in which, however, the alkali is not altogether neutralized. Though they exist in a concrete state, they are volatile, retain the pungent ammoniacal odour and taste, and change the vegetable colours to a green. The combination is easily established; by presenting the two gases to each other, they instantly unite and form a concrete salt. It is more usually obtained, however, economically, in an indirect mode, by decomposing muriate of ammonia by carbonate of potash or lime.

Equal parts of chalk, dried, and of muriate of ammonia, are mixed together, and put into an earthen retort, or an iron pot, to which a capital is adapted, and which is connected with a large receiver. Heat is applied, by which a double decomposition is effected, the lime attracting the muriatic acid, and the ammonia, the carbonic acid. The muriate of lime remains in the vessel, and the carbonate of ammonia being volatilized, is condensed on the sides of the receiver in the form of a crust. Sometimes it is obtained by another process in solution in water. Equal parts of muriate of ammonia and of sub-carbonate of potash are put into a retort with two parts of water, and heat is applied; a double decomposition likewise

takes place in this case, the muriatic acid uniting with the potash, and the carbonic acid with the ammonia; the carbonate of ammonia passes over with the aqueous vapour, which, when condensed, is sufficient to dissolve it.

Carbonate of ammonia is also obtained in large quantity in the decomposition of animal matter by heat. It is thus procured from bones, and forms the impure product which has been named salt of Hartshorn.

The composition of these products varies so much, that, according to their analysis by Mr Davy, the quantity of ammonia is from 20 to 50 in 100 parts. The carbonic acid and water are super-abundant in it, as the temperature at which the compound has been formed is low; that formed at 300° contained he found above 50 of alkali, while that formed at 60° contained only 20; but in none of them is the alkali neutralized.

Sub-carbonate of ammonia is very soluble in water; at a mean temperature it requires only twice its weight, and at 212° less than its own weight is sufficient for its solution. Its saturated solution deposites crystals, the figure of which appears to be octohedral. Exposed to a very moderate heat, it is entirely volatilized, but is easily condensed, and its deposition on the sides of the vessel is of a regular dendritical form. It effloresces on exposure to the air, and its odour becomes weaker, perhaps from the loss of its moisture, or from the absorption of carbonic acid.

This salt is used in medicine as a stimulant and diaphoretic, and as a stimulating perfume.

Carbonate of Barytes exists native. When obtained by adding carbonic acid to barytic water, or by decomposing muriate of barytes by an alkaline carbonate, it is in the form of a white powder, of considerable specific gravity; is not soluble in water in any appreciable quantity, but is dissolved in small quantity when the water is impregnated with carbonic acid. This artificial carbonate is decomposed by heat, its carbonic acid being easily and completely expelled, owing, as has been supposed, to the presence of water which favours the transition of the acid to the elastic form; while in the artificial carbonate which contains less water, the decomposition is much more difficult; though by a heat sufficiently powerful, Dr Hope has shewn that it can be effected. The addition of a little carbonaceous matter favours the decomposition, by converting the carbonic acid into carbonic oxide.

Carbonate of Strontites is precipitated, on adding carbonic acid, or a solution of an alkaline carbonate, to a solution of strontites, or of a strontitic salt. With an excess of acid it becomes soluble. The artificial carbonate, like that of barytes, is more easily decomposed than the native.

Carbonate of Lime exists in nature in great abundance and under a variety of forms. It is formed artificially, by adding carbonic acid to lime-water; by agitating water impregnated with that acid with lime, or by decomposing any of the soluble salts of lime by any of the alkaline carbonates; but its chemical properties are generally described from those varieties of it which exist native in a state of purity. It is very sparingly soluble in water, and

in those forms of it in which the cohesion is considerable, appears altogether insoluble. By an excess of carbonic acid, solubility is communicated. When exposed to heat, it first loses what water it contains, and, if transparent and hard, becomes white, opaque, and friable. If the heat be augmented, the carbonic acid is expelled, and pure lime remains. This operation is performed on a large scale, on the different varieties of the native carbonate, marble, chalk, and more particularly limestone, to obtain lime for the numerous uses to which it is applied. The experiments of Sir James Hall have proved, that if the separation of the carbonic acid from its combination with the lime be prevented by the requisite pressure, the carbonate may be fused, and by a heat comparatively moderate, intermediate between 20° and 30° of Wedgwood's scale, according to the more or less perfect compression. A substance is thus formed, having considerable hardness and closeness of texture, and approaching by these qualities, as well as in fracture and specific gravity, to the finer kinds of limestone or marble. Bucholz has since discovered, that even without compression carbonate of lime is fused when it is submitted to heat in a large mass. The acids expel the carbonic acid from carbonate of lime, with effervescence; and this property of effervescing strongly on the contact of an acid, affords a discriminating character of carbonate of lime. The native carbonate perfectly pure, consists of 55 of lime, and 45 of acid.

Carbonate of Magnesia is prepared for medicinal use by dissolving equal weights of sulphate of magnesia and sub-carbonate of potash separately in twice their weight of

water; mixing them together, and immediately diluting with eight parts of warm water: the magnesia attracts the carbonic acid; and the compound being insoluble, is precipitated, while the sulphate of potash that is formed remains in solution. The mixture is made to boil for a few minutes: after cooling a little, it is poured upon a filtre: the clear fluid runs through, and the precipitate of carbonate of magnesia is washed with water till it is tasteless. When the process is conducted on the large scale, the bittern, or liquor remaining after the crystallization of sea salt, which is principally a solution of muriate and sulphate of magnesia, is substituted for the pure sulphate, and this is precipitated by a solution of pearlash, or of carbonate of ammonia procured by distillation from animal substances.

Carbonate of magnesia is perfectly white, nearly tasteless, possessing little coherence in its texture, and of a specific gravity not more than 2.3. It is very sparingly soluble in water; requiring at least 2000 times its weight, at the temperature of 60°. In this state, however, it is rather a sub-carbonate. When acted on by water impregnated with carbonic acid, it is dissolved; and from this solution allowed to evaporate spontaneously, the carbonate of magnesia is deposited in small hexagonal prismatic crystals, which are transparent and efflorescent: they are soluble in 48 parts of water, at 60°; and, by slow evaporation, this solution again affords crystals. These consist of 25 of magnesia, 50 of acid, and 25 of water; while the proportions of the common carbonate are, from 45 to 55 of earth, from 25 to 48 of acid, and from 15 to 30 of water.

Carbonate of Argil can scarcely be formed: water impregnated with carbonic acid dissolves a portion of the earth; but in evaporating the solution, the carbonic acid is expelled; and when an argillaceous salt is decomposed by an alkaline carbonate, the argil is precipitated, and retains little carbonic acid combined with it.

The other earthy carbonates are scarcely known. Carbonate of Zircon is insoluble. Carbonate of Glucine, obtained by double decomposition, is precipitated in a soft state, and is not easily dried; is insipid, insoluble in water, and is not rendered soluble by an excess of acid.

Water impregnated with carbonic acid dissolves small portions of some of the metals, particularly iron and zinc. By indirect modes it can be combined with the oxides of the other metals, forming compounds afterwards to be noticed.

Sect. V.—*Of Carbonic Oxide.*

Charcoal, in burning, combines with that proportion of oxygen which converts it into carbonic acid. But an intermediate product in the state of an oxide, it has been supposed, can be obtained by processes in which oxygen and charcoal are combined in a different mode, or in which carbonic acid is decomposed and its oxygen partially abstracted.

The processes in which the production of carbonic oxide was first observed, consist in exposing mixtures of

certain metallic oxides, particularly the grey oxide or scales of iron with charcoal to a red heat; a very large quantity of elastic fluid is disengaged, which consists partly of carbonic acid: but when this is abstracted by agitation with water, there remains an elastic fluid inflammable, and which, in burning, is converted into carbonic acid; it has hence been regarded as a gaseous oxide of carbon. On this hypothesis it must be supposed, that in its formation the oxygen of the metallic oxide has combined with the charcoal, and from the excess of charcoal present, has formed this oxide rather than carbonic acid.

There are other processes in which a product strictly analogous is obtained, from the partial decomposition of carbonic acid. Thus, if native carbonate of barytes, or dried carbonate of lime, be mixed with zinc or iron-filings, and exposed to a low red heat, there is an abundant production of elastic fluid: this contains a small portion of carbonic acid, but it consists principally of an inflammable gas, which, like the former, is converted into carbonic acid in burning, and towards the end of the process this gas is even disengaged perfectly pure. Its production, on the supposition that it is a pure oxide of carbon, must be ascribed to the metal abstracting a portion of the oxygen of the carbonic acid disengaged from the carbonate of barytes or carbonate of lime. And this decomposition, so as to afford this product, is established by another process still more direct,—passing carbonic acid gas repeatedly through an iron-tube, containing clean iron wire at a red heat; the iron is oxidated, and the carbonic acid, if the process is continued sufficiently long, is converted into carbonic oxide.

Some chemists, Berthollet in particular, have supposed that this gas always contains a portion of hydrogen, and is therefore a ternary compound, not a pure carbonic oxide. When obtained from processes in which charcoal is employed, the hydrogen, which there is some reason to believe exists in this inflammable substance, may enter into combination with the oxygen and carbon which form the elastic product; and accordingly the gas produced by this process has been observed, in burning, not only to form carbonic acid, but to deposite also a portion of water. In the processes in which it is obtained from the partial decomposition of carbonic acid, the hydrogen supposed to be contained in it must be derived from the small portion of water which that acid is supposed to hold combined.

There is considerable uncertainty with regard to the existence of hydrogen in well calcined charcoal, or the presence of combined water in carbonic acid, and hence it is difficult to form a decided conclusion with regard to this question. The production of a portion of water in the combustion of this gas is no proof that hydrogen is essential to its composition, for the hydrogen affording this may exist in the state of carburetted hydrogen merely mixed with it, and besides, as obtained by other processes, there is no deposition of water. Its production from the decomposition of the carbonic acid existing in carbonate of barytes, a compound in which the carbonic acid has been supposed to exist without even that small portion of water which the acid contains in its usual form, and its production also from carbonic acid gas, which has been previous-

ly exposed to the action of muriate of lime, so as to abstract any water, render more probable the conclusion that hydrogen is not essential to the constitution of this elastic fluid, and at least prove that the quantity of that element in its composition must be extremely small. It is therefore on the whole perhaps the most probable opinion, that it is an oxide of carbon.

There is one fact, however, rather singular with regard to this gas, which has been supposed favourable to the supposition that hydrogen is one of its elements,—this is its comparative levity. It is rather lighter than atmospheric air: oxygen gas is heavier: when combined with carbon, a heavier ingredient, it might, in retaining the elastic form, be expected still to become specifically heavier, and it actually does so in forming carbonic acid; yet, in increasing the proportion of carbon farther so as to form carbonic oxide, it becomes specifically lighter. This is an anomaly, which it has been supposed can be accounted for only on the supposition that hydrogen exists in the latter gas, and communicates its comparative levity. Some weight is due to this, yet there are some similar anomalies in other cases of chemical combination, and it cannot therefore be regarded as conclusive.

Carbonic oxide is permanently elastic. Its specific gravity is to that of atmospheric air as 967 to 1000. It is absorbed in small quantity by water, 100 cubic inches condensing 2 of the gas; but it has no acid taste, nor either in this condensed state or in its liquid form does it contract any union with the alkalis or earths. It burns with a blue lambent flame, but does not explode when previous-

ly mixed with atmospheric air and kindled, nor does it combine with much oxygen; for although it is necessary to its complete combustion, that an excess of oxygen should be present, 100 cubic inches of it consume not more than 35 cubic inches of the oxygen gas. It forms a quantity of carbonic acid gas equal in weight to the carbonic oxide and oxygen consumed. From the products Cruickshank inferred that it consists of 21 of oxygen and 8.6 of carbon. Clement and Desormes state them at 58.4 of oxygen and 41.6 of carbon. The gas produced from the mutual action of charcoal and metallic oxides deposites a little water in burning, whence Cruickshank stated its composition at 15 of oxygen, 7 of carbon, and 1 of hydrogen. It is more probable, however, that it is the same with the other, and that the small quantity of hydrogen exists rather in the state of carburetted hydrogen mixed with the carbonic oxide.

Sect. VI.—*Of Oxy-carburetted Hydrogen Gases.*

There are obtained, in different processes, inflammable elastic fluids, which, in their combustion, afford carbonic acid and water in different proportions, and which appear, therefore, to be compounds of carbon, hydrogen, and oxygen, and as such may have the common name of oxy-carburetted hydrogen applied to them. There is, however, much difficulty in discovering their composition, especially with regard to the proportions of their constituent parts,

and it is even not easy to establish their specific distinctions, so as determine whether some of them are not mixtures of others. In this imperfect state of our knowledge on this subject, it will be sufficient to point out those of them which are afforded by uniform processes, and to state briefly their properties, and the best established facts with regard to their analysis.

If water be passed over charcoal in a tube raised to a red heat, a large quantity of elastic fluid is obtained, consisting partly of carbonic acid, and partly of an inflammable gas; the former having been formed by the combination of the oxygen of a portion of the water with part of the charcoal, the other from the combination of the hydrogen of the decomposed water with another portion of charcoal; the carbonic acid is abstracted by agitation with water; the inflammable gas remains. It has been named Carburetted Hydrogen, on the supposition that it is a compound of carbon and hydrogen. This, however, is very doubtful. The quantity of carbonic acid produced does not bear the due proportion to the quantity of inflammable gas which it ought to do, did the whole of the oxygen of the decomposed water enter into combination with carbon so as to form that acid; a portion of oxygen, therefore, enters into combination with the hydrogen and carbon, and the inflammable gas is thus a ternary compound of these elements. It accordingly deposites a quantity of water in its combustion; this, Cruickshank supposed, might have pre-existed in it, but the quantity is too large to admit of this supposition, especially as the carbonic acid produced must also hold a portion of water combined.

This gas has a specific gravity compared with atmospheric air as 11 to 23. It is inflammable, but less so than pure hydrogen; it burns with a blue lambent flame. 100 measures of it combine in burning with 66 measures of oxygen, and produce 40 of carbonic acid gas, with 9 grains of water deposited, besides the quantity which may be retained dissolved by the carbonic acid gas. It is extremely deleterious in its action on the living system when received into the lungs. An animal breathing it pure is almost instantly killed; and even when diluted with 20 parts of atmospheric air, it produces, when respired, sickness, vertigo, fainting, and other symptoms of exhausted power. It has the peculiar effect on the blood of giving to it a florid red hue.

Other elastic fluids, composed principally of carbon and hydrogen, with probably a proportion of oxygen, are disengaged in the decomposition of various vegetable products by heat. Thus, by passing the vapour of camphor through a red hot tube, one is obtained considerably heavier, and which, in burning, consumes more than double the quantity of oxygen, 100 cubic inches combining with 176 of oxygen gas, and forming 116 of carbonic acid gas, with 18 grains of water deposited. The vapour of ether or of alkohol passed through an ignited tube affords similar gases, rather lighter, however, and consuming in their combustion less oxygen. 100 cubic inches of the gas from ether combines in burning with 170 of oxygen gas, and afford 108 of carbonic acid with 18 grains of water deposited: of the gas from alkohol 100 cubic inches in burning combine with 118 of oxygen, and afford 75 of

carbonic acid gas with 13 of water deposited. The gas which arises from marshes, disengaged probably from the slow decomposition of vegetable matter, is similar to the gas from camphor or ether decomposed by heat; and Dr Henry has found, that the gas which collects in coal mines, and is known by the name of Fire Damp, is of a similar nature with an intermixture of carbonic acid gas and atmospheric air.

All these elastic fluids can be analysed by the operation of another powerful chemical agent upon them,—oxy-muriatic acid gas. If mixed with them condensation speedily takes place, and the whole is converted into water, carbonic acid, and muriatic acid: the oxy-muriatic acid, according to the theory which has usually been received of its composition, being a compound of muriatic acid and oxygen, and affording this oxygen to the hydrogen and carbon of the inflammable gas. A similar action is exerted, accompanied with detonation, when the electric spark is transmitted through the mixture of these gases. Carbonic oxide does not detonate with oxymuriatic acid gas, and this, independent of other characters, discriminates it from these gases, and farther renders it probable that no hydrogen exists in its composition.

An elastic fluid of the same family, but possessed of characters still more distinctly marked, is that which has received the name of Olefiant Gas. It is formed during the latter stage of the process of the formation of what is named Sulphuric Ether, by the action of sulphuric acid on alkohol at a high temperature; or it can be obtained directly, and in large quantity, by mixing three parts of sul-

phuric acid by weight with one part of alkohol, and submitting the mixture in a retort to a moderate heat. An effervescence is soon excited, the elastic fluid disengaged is the olefiant gas mixed with a portion of sulphurous acid gas; the latter is abstracted by agitation with water, and the former remains pure.

This gas derives its name from the singular chemical property it exhibits, that, when mixed with oxymuriatic acid gas, condensation of the two gases quickly takes place, and a liquid is produced from their mutual action, which collects first in a film on the surface of the water, and afterwards into globules having all the appearance of oil; it is rather heavier than water, and hence the globules soon sink; it is whitish and semi-transparent, has a smell somewhat aromatic and a sweetish taste. By agitation with water it is dissolved. The theory of its production is not very well ascertained; for it remains doubtful whether oxygen is communicated from the oxymuriatic acid to the entire principles of the olefiant gas, so as to convert them into this product, or whether it combines principally with its hydrogen, leaving the other principles in that state of combination whence it is formed. Mr Davy has found, that muriate of potash is formed by the action of potassium on it, and has supposed, therefore, that it may be a compound of oxymuriatic acid, carbon and hydrogen.

Olefiant gas has a specific gravity very nearly the same as atmospheric air, the difference being only as 909 to 1000. It has an odour slightly fetid; is absorbed in small quantity by water; it burns with a dense oily flame, and the emission of much light; and if previously mixed

with a sufficient quantity of atmospheric air or oxygen gas, detonates with much violence. Of any of these inflammable gases, it is the one which consumes the largest quantity of oxygen in its combustion, and gives the largest product of carbonic acid; 100 measures of it requiring, according to Dr Henry's experiments, 325 of oxygen for its perfect combustion, and producing 200 measures of carbonic acid. From its greater specific gravity compared with the other inflammable gases, it is evident that its principles are in a state of greater condensation; and from the large quantity of oxygen it consumes, it is also evident, that not much of that element exists in its composition, but that it must consist chiefly of carbon and hydrogen. Berthollet has supposed that it is composed of 75 of carbon and 25 of hydrogen.

Olefiant gas is disengaged in other processes, though not perfectly pure. It is formed by passing the vapour of alkohol either over ignited siliceous or argillaceous earth. From the gas which is disengaged in the decomposition of wood, and of some inflammable vegetable products by heat, burning with a dense oily flame, it is probably olefiant gas in a state of greater or less purity. It appears, too, that the gas disengaged from the bituminous matter of coal by heat, and which has been applied to the purpose of affording illumination by its combustion, is of a similar nature. It burns with a dense oily-like flame, even when it has been freed by washing from the bituminous matter suspended in it; and it consumes in burning, as Dr Henry has found, a very large quantity of oxygen gas, and affords a large product of carbonic acid. It appears, however, from his observations, not to be precisely the

same with the olefiant gas, though it is undoubtedly of analogous constitution. The gases disengaged from the decomposition of oil and of wax by heat are similar, and the flame they give in burning consists chiefly of this elastic fluid evolved by the heat, and in a state of combustion.

With regard to all the gases which have now been described, it may be remarked, in concluding their history, that it is not improbable that their chemical constitution is not uniform, but is liable to variations from the operation of the circumstances under which they are formed. Carbon, hydrogen, and oxygen, are principles having mutual affinities so equally adjusted, that they appear to be capable of entering into union in numerous, and perhaps in indefinite proportions, and the slightest variation of temperature, and of other circumstances, will have a material influence on their combination. The operation of such circumstances is accordingly conspicuous in the different nature of the elastic fluids disengaged in the above processes, from very slight differences in the processes by which they are procured. It is far from being improbable, too, as Dr Henry has remarked, that these gases may often be disengaged in a state of intermixture, by which they will appear to be still more diversified than they actually are. He has supposed, with Mr Dalton, that all these gases may be mixtures of two species, the Carburetted Hydrogen, obtained in the decomposition of water by charcoal, and the Olefiant Gas, with sometimes portions of carbonic oxide or pure hydrogen, but this is more doubtful.

CHAP. IV.

OF PHOSPHORIC ACID, ITS BASE, AND THEIR COMBINATIONS.

Phosphoric acid, by decomposition, affords phosphorus, a substance distinguished by its high inflammability, and which, so far as the processes of analysis have been carried, is the base of this acid, forming it by combination with oxygen. With a smaller proportion of oxygen, it forms Phosphorus Acid. With hydrogen it produces an elastic compound. It unites with sulphur and the metals, and is chemically acted on by the alkalis and earths.

Sect. I.—*Of Phosphorus.*

It was known to some of the alchemists, that a substance might be procured which burns spontaneously on exposure to the air. Kunckel made known the process by which they obtained it, that of distilling urine to dryness, and urging the solid residuum with a strong heat, the phosphoric acid existing in the salts of the urine being

decomposed, and its oxygen abstracted by the animal matter. By the addition of charcoal, this decomposition is facilitated: and the product is also increased, by an improvement introduced by Margraaf, that of adding a portion of muriate of lead, which, by abstracting the phosphoric acid from the soda and lime with which it is in part combined, allows it to be more easily decomposed.

Still the process was offensive and difficult; and phosphorus is now obtained with more facility, by decomposing phosphoric acid in a purer form. Scheele discovered, that the solid matter of bones, obtained by burning them to whiteness, is a compound of phosphoric acid and lime. This reduced to powder is submitted to the action of half its weight of sulphuric acid, diluted with from 10 to 20 parts of water, aiding their mutual action by the application of a moderate heat. The sulphuric acid exerts an affinity to the lime, and combines with a portion of it; the phosphoric acid, holding the remaining lime in combination, is obtained by lixiviating the materials with boiling water; the solution of super-phosphate of lime thus procured is evaporated to dryness; the dry mass is mixed with half its weight of charcoal powder, and the mixture is urged with a fire gradually raised in an earthen retort with a wide neck, to which a copper tube is adapted, the extremity of which dips in water; the charcoal attracts the oxygen of the phosphoric acid, and the phosphorus is volatilized and condenses, partly in the tube and partly in the water. The process, from the great inflammability of the product, requires considerable care. The phosphorus has a brown colour, from the presence of a small quantity

of carbonaceous matter, which is removed by straining it through leather when melted under warm water, or by digesting it with a little nitric or oxymuriatic acid. When melted under water it is run into moulds, so as to be formed into cylindrical pieces.

Phosphorus, when pure, is nearly colourless, and is semi-transparent. It has the consistence of wax, with rather more brittleness. Its fracture is often radiated, shewing a crystalline structure, and by slow cooling it can even be crystallized in octohedrons. It melts at 99° of Fahrenheit, is volatilized at 219°, and boil at 554°.

Exposed to atmospheric air it emits white fumes, and in the dark appears luminous,—appearances arising from its combustion. If heated to 100 this is brighter; and at 160 it burns with the emission of much heat and light. Its rapid combustion is also excited by friction without heat. In oxygen gas its combustion is extremely vivid, and the heat and light intense. A fact rather singular is, that the slow combustion at low temperatures does not take place in oxygen gas as it does in atmospheric air; the heat requires to be raised to above 80, or even to 100; and below 60, the phosphorus, if the oxygen is pure, has not even in the dark any luminous appearance. From the experiments made to determine the cause of this peculiarity, it appears, that the slow combustion of phosphorus in atmospheric air is an indirect process; the phosphorus is dissolved in small quantity by the nitrogen gas, and in this state being presented to the oxygen, combines with it: hydrogen gas has the same property of dissolving it, and hence a little nitrogen or hydrogen, added to oxygen

gas, in which phosphorus is placed, causes immediately the luminous appearance from the slow combustion.

The slow combustion of phosphorus in atmospheric air affords a very simple eudiometrical process. The air measured in a tube, divided into 100 equal parts, is transferred into another tube rather larger, in which it is exposed to the action of a cylinder of phosphorus, supported on a glass rod; the oxygen is gradually abstracted, and the product of the combination is absorbed by the water over which the air is confined. The diminution of volume is ascertained at the end of the experiment, by transferring the air into the graduated tube. This method is easy in the execution: the result is obtained in a few hours; and it has the advantage of indicating when the process is complete, the rise of white vapours from the phosphorus and its luminous appearance in the dark continuing while any oxygen is present, and ceasing when the whole of it has been abstracted. It requires only one correction; the nitrogen gas dissolving a small portion of phosphorus, receives from this an increase of volume, and hence the diminution with this method is never so great as with some of the others. The augmentation of volume amounts to about a fortieth; allowance is therefore to be made for this, so that if the residual gas, when the experiment has been made on atmospheric air, be equal to 80 parts, indicating an abstraction of oxygen equal to 20, the real volume is 78, indicating an abstraction of oxygen equal to 22.

Phosphorus is easily oxygenated by other substances. It burns in oxy-muriatic acid gas, and in nitric oxide gas,

and also in nitrous acid vapour, and receives oxygen from nitrous acid.

When saturated with oxygen, it forms a concrete acid, the Phosphoric. When the oxygenation is less perfect, what is named Phosphorous Acid is produced. The existence of an oxide of phosphorus has also been supposed, but is not clearly established.

Phosphorus forms with hydrogen an elastic compound, highly inflammable. Its compounds with sulphur in different proportions are likewise more inflammable than pure phosphorus. With charcoal it appears to form an imperfect combination. It unites with the greater number of the metals, and forms compounds retaining to a certain extent metallic lustre. With the metallic bases of the alkalis, it forms similar compounds. The alkalis and alkaline earths act upon it, and enable it to decompose water, whence phosphuretted hydrogen is produced.

Inflammable liquids, as alkohol, ether, and the oils, either expressed or volatile, dissolve phosphorus, especially when their action is aided by very moderate heat. The solutions in oils are luminous when exposed to the air, with scarcely any sensible heat. The solution in alkohol gives a vivid momentary illumination when dropped on water, and the phosphorus is precipitated from it.

Phosphorus has been regarded as a simple substance. Mr Davy, submitting it to the action of galvanism, found hydrogen to be produced from it in such quantity, that it can scarcely be considered as an accidental ingredient; and farther, finding that when acted on by potassium, the compound formed, when submitted to the action of an

acid, evolves less hydrogen than the same quantity of uncombined potassium would have done, he concluded that it contains oxygen, that it is a compound therefore of a substance unknown, with small quantities of oxygen and hydrogen. His subsequent researches have scarcely confirmed this, but have rather rendered it probable, that the phenomena whence the conclusion had been drawn arise from the presence of a little water in phosphorus.

Sect. II.—*Of Phosphoric Acid.*

Phosphoric acid, obtained by the combustion of Phosphorus, is a flocculent substance of a white colour, which deliquesces on exposure to the air. The phosphorus, in burning, absorbs its own weight and a half of oxygen: the acid, therefore, consists of 60 of oxygen, and 40 of phosphorus.

Phosphoric acid is obtained most economically from the decomposition of the phosphate of lime of calcined bone, by sulphuric acid, by the process already described. To the solution of super-phosphate of lime, carbonate of ammonia is added, the ammonia of which combines with the phosphoric acid, forming phosphate of ammonia, which remains in solution, while the carbonate of lime, formed by the union of the carbonic acid with the lime, is precipitated: the phosphate of ammonia is procured solid by evaporation, and being exposed to a full red heat, the ammonia is expelled, and the acid is fused. It is still liable to retain

a minute portion of lime. It is therefore best obtained in a state of purity by the oxygenation of phosphorus. This is done either by the action of nitric acid, or simply by exposing sticks of phosphorus to the air, in a wide vessel, in which the vapours of the phosphorus acid, formed by the spontaneous combustion of the phosphorus, are condensed. A small portion of nitric acid is added to the liquid to complete the oxygenation, the water is evaporated, and, by raising the heat, the phosphoric acid may be fused. It then forms a glassy-like substance, nearly transparent, which, from exposure to the air, attracts humidity, and forms a liquid, dense, colourless, and inodorous.

Phosphoric acid has a high degree of acidity. Its affinities to the alkalis and earths are strong; and it exceeds the other acids, with the exception of the fluoric, in the power of neutralizing the alkaline properties. It does not act with much energy on the metals or inflammables, owing to the strength of affinity with which the oxygen is retained in combination with its base; but it combines with the metallic oxides. Its salts are named Phosphates. The alkaline phosphates are soluble and crystallizable, and melt into a glass. The earthy phosphates are in general insoluble.

Phosphate of Potash can scarcely be crystallized, but forms, by evaporation of its solution, a gelatinous mass, which attracts humidity from the atmosphere; its taste is saline, with a degree of sweetishness. Exposed to heat, it liquefies, and, after the expulsion of the water, is fused by the application of a red heat into a glass.

PHOSPHATE OF SODA, a salt employed in medicine, and for some chemical purposes, is prepared, by adding to the acidulous phosphate of lime, obtained from the decomposition of burnt bones by sulphuric acid, as much of a solution of carbonate of soda as may be sufficient to saturate the phosphoric acid; phosphate of lime is precipitated, and the water holding dissolved the phosphate of soda, is separated by filtration; by evaporation the salt is crystallized, its formation in regular crystals being promoted by a slight excess of alkali. The form of the crystals is a rhomboidal prism. They effloresce on exposure to the air, are soluble in three parts of cold water, and in half that quantity of boiling water. The taste of this salt being purely saline, without any bitterness, it has been introduced into the practice of medicine as a substitute for other aperient salts. As it melts easily, and promotes the fusion of the earths and metallic oxides, it is used as a flux, in analyses performed by the blow-pipe.

PHOSPHATE OF AMMONIA is soluble in four parts of water at the temperature of 60; it crystallizes in prisms, which are neither efflorescent nor deliquescent. By exposure to heat, it is fused into a transparent glass, and decomposed, part of its ammonia being expelled. Heated with charcoal, its acid suffers decomposition, its oxygen being abstracted, which is not the case with the other phosphates. Like the phosphate of soda, it may be used with advantage in analyses by the blow-pipe. A triple compound of phosphoric acid, soda and ammonia is obtained from several of the animal fluids, and was known to the older chemists by the name of Microcosmic Salt.

PHOSPHATE OF BARYTES is in the form of an insipid white powder, of considerable specific gravity: it is insoluble in water; is fusible at a high temperature; and is not decomposed by exposure to heat mixed with carbonaceous matter.

PHOSPHATE OF STRONTITES, when perfectly neutral, is very sparingly soluble in water, requiring about 2000 parts for its solution. It melts into an enamel by the flame of the blow-pipe; giving a phosphorescent light.

PHOSPHATE OF LIME, formed by decomposing the solution of an alkaline phosphate by muriate of lime, is in the state of a white powder, insoluble, and which is imperfectly vitrified by a very intense heat. It exists in the mineral kingdom under different forms, and is the base of calcined bone. When partially decomposed by an acid which exerts an affinity sufficiently powerful to lime, it is converted into a super-phosphate, which is soluble, and, by evaporation of its solution, crystallizes in silky fibres or in brilliant scales, which, by heat, are fused into a transparent glass.

PHOSPHATE OF MAGNESIA, formed from the direct combination of the acid and the earth, crystallizes in prisms which are efflorescent, soluble in about 50 parts of cold water, and in a smaller quantity of boiling water, and which by heat melt into a glass. PHOSPHATE OF ARGIL forms a white insipid powder: it melts before the flame of the blow-pipe into a transparent globule. PHOSPHATE OF ZIRCON is insoluble. PHOSPHATE OF GLUCINE is in the form of a white powder, or of a viscous substance, insipid, and insoluble in water, but rendered soluble by an excess of acid. It is melted by heat into a transparent vi-

treous globule. PHOSPHATE OF ITTRIA, formed by complex affinity, is insoluble, being thrown down in a gelatinous precipitate.

SECT. III.—*Of Phosphorous Acid.*

THIS acid is formed in the slow combustion of phosphorus in atmospheric air. It constitutes the white vapour which arises from the surface of the phosphorus, and which attracts water from the atmosphere, so as to be condensed, and forms a dense liquor, which has a smell slightly fetid, and a taste extremely sour. When exposed to heat, part of the water is volatilized; and as this proceeds, a vapour is formed, which, disengaged at the surface, affords a dense white smoke, attended even with a luminous appearance, visible in the dark, and, by continuing the heat until this ceases, the phosphorous acid is deprived of its peculiar smell, and is converted into phosphoric acid. From this experiment, some chemists have been disposed to consider phosphorous acid as merely phosphoric acid, holding a portion of phosphorus dissolved, the luminous vapour being probably phosphorus held in solution by the watery vapour. By longer exposure to the air, the acid passes slowly and imperfectly to the state of phosphoric acid. The change is effected more speedily by adding a little nitric or oxy-muriatic acid.

Phosphorous acid unites with the alkalis and earths, forming salts named Phosphites. These, in several of

their properties, resemble the phosphates. They are distinguished from the phosphates, by appearing luminous when heated by the blow-pipe, and by affording, by distillation, a small quantity of phosphorus. They detonate, too, with oxy-muriate of potash, and precipitate gold from its solution, in a metallic state. They pass very slowly into phosphates from exposure to the air. Those formed from the alkalis are soluble and crystallizable; those from the earths are insoluble, but acquire solubility from an excess of acid. They are so unimportant as not to require farther notice.

Sect. IV.—*Of Phosphuretted Hydrogen.*

This compound of phosphorus and hydrogen exists in the elastic form. It is obtained by combining with phosphorus a substance which, by a resulting affinity, shall enable it to decompose water. Thus, if one part of phosphorus is heated with 10 or 12 parts of a solution of potash, the alkali exerts this operation, one portion of the phosphorus combines with oxygen from the decomposition of the water, and forms phosphoric acid, with which the potash combines; another portion of the phosphorus is dissolved by the hydrogen of the decomposed water, and the elastic compound is disengaged. Another process is to combine phosphorus with dry lime, by causing the phosphorus to pass in vapour over lime inclosed in a tube, which is raised to a red heat. This phosphuret of lime

dropt into water instantly decomposes it, and phosphuretted hydrogen rises in the gaseous form, the lime favouring the action of the phosphorus on the water, as the potash does in the other process.

The distinguishing property of this gas is its high inflammability, in consequence of which it takes fire whenever it is presented to the atmospheric air. It cannot, with safety, be mixed with this air, even in small quantities; it is therefore merely allowed to burn as it escapes from the water in which the extremity of the retort containing the materials producing it is immersed. Presented in single bubbles to oxygen gas, its combustion is still more violent, and is accompanied with intense light. The products of the combustion are phosphorous acid and watery vapour, and a singular appearance is presented by these: the bubble of gas, as it escapes and inflames, expands into a horizontal ring of light white vapour, which enlarges in diameter as it rises, until it breaks; this is phosphorous acid wafted by the watery vapour, and it owes this form to the eccentric impulse of the explosion.

This gas is permanently elastic; it is sparingly soluble in water; its smell is fetid, very similar to that of putrid animal matter, though more faint. It has no sensible acidity. By remaining over water it is decomposed. From the products of its combustion, it is obvious that it is a compound of phosphorus and hydrogen; perhaps with a portion of oxygen. Its elements appear, too, to combine in different proportions; for the gas disengaged at the commencement of the process by which it is usually obtained, is not so highly inflammable as that which is afterwards formed.

Sect. V.—*Of Phosphuretted Sulphur.*

Sulphur and phosphorus combine by the application of heat, the mixture of them being usually heated under water to avoid the combustion of the phosphorus, and even the experiment in this way requires to be conducted with caution. The compound is more fusible than the phosphorus alone; its fusibility is greatest when it is formed from about equal parts, the mass remaining liquid at temperatures above 60°; in other proportions it is solid but soft. In its formation a portion of water appears to be decomposed; and when the heat is raised a little high, phosphuretted hydrogen is disengaged, and sometimes so rapidly as to produce an explosion. A portion of oxygen therefore probably exists in the composition of the compound. Dr Briggs has given a process in which the sulphur and phosphorus are combined in the dry way: heat being applied to them in a tube firmly corked by plunging it in warm water, and raising the heat gradually until the water boil.

Dr Briggs has observed, that this compound is different from that formed under water. When a small proportion of sulphur has been used, it is solid when cold, and has a crystallized appearance; the other is spongy and friable. The former is less inflammable than the latter, but is rendered equally inflammable by kindling it in the tube with a hot wire, and allowing it to burn for a few seconds, oxy-

gen probably being communicated to it from the air, or from the water formed by the combustion. Both are more inflammable than phosphorus, and hence these compounds are employed in forming the phosphoric match bottles; a very small proportion, however, of sulphur being added to the phosphorus, as with too large a quantity the compound is soft.

CHAP. V.

OF BORACIC ACID, ITS BASE AND COMBINATIONS.

The salt named Borax has long been known in commerce, and applied to some uses in the arts. It is a native production brought from Thibet in an unrefined state. It consists of soda combined with a peculiar acid, which has derived from it the name of Boracic Acid. The acid is procured either by dissolving the borax in warm water, and adding sulphuric acid, which combines with the soda, and the solution on cooling deposites the acid in soft scales, which are freed from any adhering sulphuric acid or sulphate of soda by a second crystallization; or adding to sulphuric acid, diluted with an equal weight of water, two parts of borax in powder, and applying a moderate heat; the sulphuric acid combines with the soda, the boracic acid is volatilized by its affinity to the watery vapour, and condenses in scales in the neck of the retort.

Boracic acid has been decomposed, at least partially, by the application of galvanism, and by the action of potassium. When it is submitted to the action of a powerful galvanic battery, a dark coloured inflammable substance, Mr Davy found, is produced at the negative surface, which, when heated, burns slowly and reproduces acid matter. When the boracic acid was heated with an equal weight of potassium, vivid combustion was produced, and a substance obtained in the form of an olive coloured glass, which, when dissolved in water, deposited an olive coloured powder. This substance, exposed to heat, is neither fused nor volatilized, nor does it undergo much change except being rendered more dense. When heated under exposure to the atmosphere, it takes fire and burns with a red light; in oxygen gas it burns more vividly. In both cases boracic acid is formed. It is also oxygenated by nitric, sulphuric, and oxy-muriatic acids, and boracic acid is produced. It is not dissolved by hydrogen nor nitrogen: it combines with sulphur; and forms soluble compounds with the fixed alkalis. This substance, Mr Davy regards as standing in the same relation to boracic acid, that sulphur or phosphorus does to sulphuric or phosphoric acid, though it is probably not the simple base. In combining with potassium it forms a compound having a degree of metallic lustre, in which probably the pure base is contained. To this base Mr Davy assigns the name of Boracium; it may be metallic, and the olive coloured substance is perhaps an oxide. Gay Lussac and Thenard discovered the same inflammable matter, and ob-

served the different states of oxidation through which it passes before it forms the acid.

Boracic acid is in the form of white brilliant scales, soft to the touch; its taste is bitterish, with a slight degree of sourness; it reddens the vegetable colours. It is not altered by exposure to the air; is soluble in 20 parts of cold water, and in 5 of boiling water. It is also soluble in alkohol, and, what is a distinctive character of it, gives to the flame of alkohol in burning a green colour.

Exposed to a moderate heat it swells; when the heat is raised to redness, it is fused into a glass, which is soluble again in water. By the most intense heat it is not volatilized; but if water be present, the aqueous vapour elevates with it a portion of the acid.

Boracic acid combines with the alkalis and several of the earths, forming compounds named Borates. These retain the property of communicating a green colour to the flame of alkohol. They are decomposed by all the acids, the carbonic excepted, in the humid way; but in the dry way, the boracic acid, from its great fixity, is able at a high temperature to decompose those salts, the acid of which has a tendency to assume the gaseous form. The alkaline borates are very soluble in water, while the earthy are the reverse.

Borate of Potash, like the other borates, has a tendency to form with an excess of alkali; it is soluble in water; by slow evaporation its solution affords prismatic crystals, which are not changed by exposure to the air. It is fused into a glass by heat.

Borate of Soda, the Borax of Commerce, is a native

production, being obtained from a lake in Thibet, from the sides of which it is dug up, and where there appears to be a constant reproduction of it. In the state in which it is imported, it is impure, but is purified by calcination, solution and crystallization. In the state in which it is met with in the shops, it is in the form of crystalline masses, of a figure irregular, but approaching to an hexaedral prism. It is not perfectly neutral, but contains an excess of soda, which seems necessary to cause it to crystallize, the solution of the neutral salt forming by evaporation a gelatinous mass: it is soluble in 12 parts of cold, and in 6 parts of boiling water; it is very slightly efflorescent, when exposed to a moderate heat, it melts from the water of crystallization it contains; when this is evaporated, there remains a spongy white mass, named Calcined Borax. If the heat be raised to ignition, this is melted into a pellucid glass which suffers no decomposition. It is decomposed by the greater number of the acids and by potash and the earths, the former uniting with its alkali, the latter with its acid. From the facility with which it melts and brings other substances into fusion, it is of use in some arts, as in making of glass, especially the finer glass for imitating the gems, in assaying minerals by the blowpipe, and in soldering the more valuable metals.

Borate of Ammonia, though little known, has been described as being obtained by evaporation of its solution in prismatic crystals, of a sharp taste, and which change the vegetable colours to a green, evidently, therefore, containing an excess of alkali.

Borate of Barytes.—This compound, formed by adding boracic acid to barytic water, is precipitated in the form of a white powder, insipid, and insoluble.—Borate of Strontites forms a similar precipitate, which appears, however, to have an excess of base, and which dissolves in 130 parts of boiling water.—Borate of Lime is precipitated in the state of an insoluble powder, white and insipid.—Borate of Magnesia is obtained by evaporation, in a crystalline mass, of no regular form. With the addition of lime, it forms a mineral substance, known by the name of Boracite. It occurs crystallized, in cubes, which are so hard as to scratch glass; semi-transparent; of a white colour, with a shining lustre.—Borate of Argil is obtained by evaporation of its solution, in the form of a viscid substance, through which minute crystals are interspersed, having a very astringent taste.

Boracic acid acts very feebly on the metals, but may be combined with their oxides by a complex affinity.

CHAP. VI.

OF FLUORIC ACID, ITS BASE AND COMBINATIONS.

This acid exists in the mineral known by the name of Fluor Spar, in which it is combined with lime, and from which it was obtained by Scheele, who made known its

principal properties. It has since been discovered in a few other minerals; and the discovery, rather unexpected, has more recently been made, that it exists in the animal kingdom, particularly in the enamel of the teeth, and in the fossil or petrified teeth of the elephant.

It was ranked as one of the undecomposed acids, its base being altogether unknown. By the action of potassium, however, on it, phenomena have been produced, indicating its decomposition.

When potassium is heated in fluoric acid gas, Mr Davy found that it burns; a great portion of the gas disappears; and if a sufficient quantity of potassium has been employed, the residual gas is hydrogen, and the quantity of it is less as the acid gas has been more free from water. A substance of a chocolate colour is formed. This burns when heated in atmospheric air, or in oxygen; oxygen is absorbed, and acid matter formed. It may be concluded, therefore, that it contains the base of the fluoric acid; but it is probably not this base in a pure state, but in a state of oxidation combined with potassium. Experiments with results nearly similar were performed by Gay Lussac and Thenard.

To obtain fluoric acid, fluor spar in coarse powder is submitted to the action of twice its weight of sulphuric acid. The operation must be performed in a leaden retort, from a singular property of this acid, that it dissolves siliceous earth, and hence acts on glass. The sulphuric acid combines with the lime of the fluor spar, and the fluoric acid assumes the gaseous form. The gas may be collected over mercury, as it is absorbed by water; or if it

is to be condensed, the retort is connected with a leaden receiver, containing a sufficient quantity of water. Yet it is difficult to obtain it pure; it is liable to have a slight contamination of lead, and a portion of silex often adheres to it, derived from the fluor spar. From this it may be freed, by saturating it with an alkali, and decomposing this compound by an acid.

Fluoric acid gas is permanently elastic, and heavier than atmospheric air; it has a pungent suffocating odour, is corrosive, and highly acid. It has a strong attraction for water, so that when presented to the atmosphere, white vapours are immediately formed from its attracting the watery vapour; and when dry, it takes water, as Gay Lussac and Thenard have remarked, from almost every other gas. When transparent, however, it does not appear to retain much combined with it. It is largely absorbed by water, and the liquid when saturated is highly acid and caustic; it emits white vapours, but the whole of the acid gas cannot be expelled from it. Either in the gaseous or liquid state, it does not act very powerfully on the metals or inflammables.

It combines with the alkalis and earths, forming salts named Fluates. They are generally deliquescent, and not easily crystallized: the fluoric acid, in power of neutralizing the alkaline properties, exceeds the other acids: hence, if this be admitted as the test of the strength of acidity, it is the most powerful of the acids, and its apparently less energetic action is to be ascribed to its not being obtained liquid in a sufficient state of concentration.

Fluate of Potash is very soluble in water, and its so-

lution evaporated does not crystallize, but becomes gelatinous, or forms a foliated mass, which, when urged by heat, is melted and decomposed.—Fluate of Soda has scarcely so much affinity to water; it affords, when evaporated to the consistence of honey, small oblong crystals.—Fluate of Ammonia, when in solution, becomes gelatinous on evaporation, and in this jelly crystals form which are deliquesent, melt on exposure to heat, and are sublimed with partial decomposition.—Fluate of Barytes being considerably more soluble than fluate of lime, this acid has been employed as a test to discriminate between these two earths.—Fluate of Strontites being of sparing solubility, is precipitated when it is formed.—Fluate of Lime, in its native state, forms the Fluor Spar, which is often regularly crystallized. Obtained by digesting liquid fluoric acid on lime, it is in a very different state: the solution, even when evaporated to a jelly, does not afford crystals. It is insipid, and insoluble in water. It is phosphorescent from heat, a property which belongs also to the native fluate. It is fused, by a violent heat, into a transparent glass.—Fluate of Magnesia, obtained in solution, by digesting fluoric acid on magnesia, is gelatinous.—Fluate of Argil does not crystallize, but assumes on evaporation the consistence of a jelly; its taste is astringent.

Fluate of Silex is a compound so singular as to require more distinct notice, this earth being scarcely acted on by any other acid in the humid way. It combines with the fluoric acid, either when the acid in its gaseous state, or combined with water, is brought to act on it, or

on almost any compound containing it. Thus, when the acid is disengaged from fluate of lime, if the experiment be made in a glass-vessel, part of the silex of the glass is dissolved; or if a little flint in powder has been mixed with the materials, the fluoric acid gas holds dissolved a large portion of silex. It retains it in solution, when received over quicksilver; but when presented to water, a considerable portion is separated, and forms a gelatinous matter, retaining a little acid; and the acid, absorbed by the water, has a portion of the earth combined with it. If the liquid fluoric acid be kept in a glass-vessel, it acts slowly upon it; or if digested with quartz or flint in powder it becomes impregnated with silex, and after a length of time crystals are deposited, which are affirmed to be fluate of silex. From the strong affinity of this acid to silex, it retains a portion of it in combination with other salifiable bases, forming ternary compounds; or if previously combined with these bases, it still acts on and dissolves a portion of siliceous earth. The acid from this power is employed to engrave on glass, being applied either in the gaseous or liquid form.

CHAP. VII.

OF MURIATIC ACID, OXY-MURIATIC ACID, AND THEIR COMBINATIONS.

From Sea Salt, an acid is procured by distillation with sulphuric acid, formerly known to chemists by the name of Spirit of Salt, now named Muriatic Acid. It exists as a permanent gas, but is condensed by water in very large quantity, and forms a liquid acid of considerable strength.

This acid resists the usual methods of chemical analysis, and its composition, therefore, was altogether unknown. Girtanner had supposed hydrogen to be its base, from finding that this element is evolved when it is submitted to the action of oxidifiable bodies: and on similar grounds Berthollet supposed it to have a compound base of hydrogen and nitrogen,—conjectures not supported on any decisive evidence, as any relation which it apparently had to hydrogen might be accounted for from the portion of water combined with it.

More lately, some singular facts have been established with regard to the influence of water in combination with muriatic acid, and these have even suggested to Mr Davy a very different view of the constitution of this acid. On obtaining the acid gas as dry as possible, and heating potassium in it, there is a violent chemical action

with ignition; the acid gas wholly disappears; more than one-third of its volume of hydrogen gas is evolved; and on the supposition that this is derived from water contained in the muriatic acid gas, there is reason to infer, that the acid in its common aëriform state must contain one-third of its weight of water. Mr Davy farther found, that muriatic acid could not be disengaged from its dry combinations by other concrete acids, from muriate of lime, for example, by dry phosphoric or boracic acid, by the application of heat; but if water were added, it is extricated in large quantity,—an experiment which apparently proves the necessity of water to the constitution of muriatic acid gas. Similar results had been obtained by Gay Lussac and Thenard. It had also been known, that when muriatic acid is subjected to the action of the electric spark, hydrogen is evolved, and this, even when the gas had been previously rendered as dry as possible, by being exposed to substances which have a strong affinity to water.

All these facts may be explained on the hypothesis that muriatic acid contains water in a state of intimate combination; but Mr Davy has, from other speculations, been led lately to give a different theory of them. In submitting muriatic acid to the action of substances which afford oxygen easily, it is converted into a substance which, being supposed to be a compound of muriatic acid and oxygen, has been named Oxy-muriatic Acid. This conclusion Mr Davy has called in question: oxy-muriatic acid he regards as a simple body, and muriatic acid as a compound of it with hydrogen. The grounds on which this last conclusion rests, being connected with the theory of

the constitution of oxy-muriatic acid, will be best stated under its history.

Muriatic Acid is always obtained from sea-salt decomposed by sulphuric acid, one part of the acid being added to two parts of the salt. The sulphuric acid combines with the soda, which is the base of the salt; and the muriatic acid, which is the other ingredient, is disengaged, and assumes the elastic form. The gas may be received over quicksilver, as it is largely and rapidly absorbed by water; or if it is to be procured in the liquid form, the retort containing the materials is connected with the bottles of Woolfe's apparatus, in which water is placed, by which its condensation is effected, a moderate heat being applied, by the medium of a sand-bath, as long as any acid is produced. When the process is carried on on the large scale, the distillation is facilitated by diluting the sulphuric acid with a portion of water.

Muriatic acid gas, when free from watery vapour, is transparent and invisible; it is pungent and suffocating; its specific gravity is, to that of atmospheric air, as 1929 to 1000. It extinguishes combustion, and does not burn. By water it is instantly condensed in very large quantity, the water absorbing not less than 360 times its volume of the gas, by which its weight is doubled; and this absorption is attended with a rise of temperature. Ice melts in it, condenses it, and produces cold.

In the liquid muriatic acid obtained by the usual process of distillation, the water is not completely saturated with the gas; its specific gravity seldom exceeds 1.170, and the strongest that can be easily procured is that of

1.196: when of this strength, it contains, according to Kirwan's estimate, 25 of real acid. In its common state it has a yellow tinge, but this arises from impurity; and by distilling it from a little muriate of soda, it is obtained colourless. It emits white vapours, having a pungent smell, and, even when largely diluted, has a very sour taste, and reddens the vegetable colours. As it does not directly communicate oxygen, it does not act with much energy on inflammable substances; and it dissolves metals only by enabling them, by the resulting affinity it exerts, to decompose water and attract its oxygen; hence these solutions are attended with a disengagement of hydrogen gas. It combines with all the metallic oxides; it also unites easily with the alkalis and earths. Its salts are named Muriates; the alkaline and earthy muriates are soluble and crystallizable, and have in general that taste more peculiarly denominated saline.

Muriate of Potash has a taste saline and slightly bitter; it is soluble in three parts of cold, and in half its weight of boiling water, the latter solution crystallizing on cooling; its crystals have a cubic form, but are not regular: they are slightly deliquescent, and they decrepitate when heated. This salt, obtained by some indirect chemical processes, is used in the manufacture of alum, and as a flux in melting some of the metals.

Muriate of Soda is the salt which exists in largest quantity in nature. It is the principal saline ingredient of the ocean, forming, when it is extracted, what is named Sea Salt, and it exists in immense beds in the earth forming Rock Salt. In the latter, it is generally pure, or has

only a slight contamination. In the former it is less pure, a portion of other salts adhering to it, greater or less according to the method in which it is procured. In warm climates it is frequently obtained by spontaneous evaporation, the sea-water being admitted into shallow trenches by the sea-side, and spread over an extensive surface: as it becomes concentrated by the evaporation of the water, the liquor is removed, by sluices, from one trench to another, until at length the muriate of soda crystallizes spontaneously, and with scarcely any intermixture of the other salts. In colder climates, the sea-water is evaporated in large boilers by the direct application of the heat, and the evaporation is carried so far, that the muriate of soda concretes in small crystals on the surface of the boiling liquor: as obtained by this mode, a small portion of muriate and sulphate of magnesia adheres to it, which render it slightly deliquescent, and somewhat impair its antiseptic power. The processes of spontaneous and hasty evaporation are sometimes conjoined, and a salt of intermediate purity is obtained.

Muriate of soda crystallizes by slow evaporation in cubes; it has a saline taste with scarcely any bitterness; is soluble in less than three parts of cold water, and its solubility is very little increased by raising the temperature even to 212°; hence it crystallizes from its solution, not by cooling, but only by slow evaporation. Its crystals neither deliquesce nor effloresce; they decrepitate when suddenly exposed to heat, the water of crystallization being dissipated in vapour; the salt melts at a red heat, and at a more intense heat is volatilized without decom-

position. It is decomposed by the fixed acids, which expel the muriatic acid, especially when aided by heat.

Muriate of soda is in common use to counteract the process of putrefaction in animal matter, and the theory of its antiseptic operation is not well understood: it is taken universally as a condiment to food, and it is employed in a number of chemical arts. The decomposition of it, so as to obtain its alkaline base, is a process of much importance, as affording a source whence soda can be abundantly procured. It has been attempted on the large scale by the intermedium of oxide of lead, of carbonate of potash, of lime and iron, of sulphuric acid, and the sulphate of soda being afterwards decomposed by the joint action of iron, lime, and charcoal; some of these processes are, from local circumstances, frequently carried on with advantage.

Muriate of Ammonia.—This is the sal-ammoniac of commerce, an important salt from the uses to which it is applied, and which is generally prepared on a large scale. The processes are various, but in general a sulphate of ammonia is procured by maceration from soot, or by saturating the impure ammonia obtained in the distillation of animal substances by adding sulphuric acid; it is decomposed by muriate of soda, and the muriate of ammonia, formed by the operation of a double affinity, is sublimed. It is thus obtained in large semi-spherical cakes of a crystalline structure. By solution in boiling water and cooling it may be crystallized, its crystals being four-sided prisms. It is soluble in $3\frac{1}{2}$ parts of water at 60°, and in its own weight of boiling water. It is volatilized by heat. It is used in soldering the metals, and in

some of the processes of dyeing; and it is from this salt that ammonia is usually procured.

Muriate of Barytes is soluble in three parts of cold water, and in a smaller quantity of hot water; it crystallizes from the latter solution on cooling in quadrangular tables. It is also soluble in alkohol.—Muriate of Strontites is so soluble as to require not more than its weight of water at 60° to dissolve it: in boiling water it is still more soluble, and it crystallizes from this solution on cooling in slender six-sided prisms: its crystals are deliquescent.—Muriate of Lime is also extremely soluble, and, from its strong affinity to water, imbibes it rapidly. By cooling its saturated solution, it may be obtained crystallized in six-sided prisms; these crystals are so deliquescent that they are not easily obtained dry, they liquefy on exposure to the air, and they combine rapidly with ice or snow, causing it to melt, and thus producing intense cold.—Muriate of Magnesia has such an affinity to water that it can be obtained in acicular crystals only by exposing its concentrated solution to sudden cold: these crystals are very deliquescent, and dissolve in less than their weight of water: the taste of this salt is extremely bitter.—Muriate of Argil can scarcely be crystallized, its solution becoming gelatinous on evaporation; it has the astringency of the other argillaceous salts.—Muriate of Glucine is soluble in water, and, by evaporation, can be obtained in small crystals.—Muriate of Zircon is also soluble, and affords, by evaporation of its solution, transparent needle-like crystals.—Muriate of Ittria assumes a gelatinous form. On Silex muriatic acid appears to exert some action, as, when this

earth is newly precipitated, it is sensibly dissolved by the addition of the acid.

A compound acid is formed by the mixture of muriatic acid and nitric acid, which has some peculiar properties, and which in particular dissolves gold with facility,—a property from which it received from the alchemists the name of Aqua Regia. It is obtained by mixing one part of muriatic with two parts of nitric acid; during their combination the formation of oxy-muriatic acid is indicated by its odour, nitric oxide gas is disengaged, and a portion of it is also retained in the liquid, giving it a dark orange colour. It has been concluded, therefore, that in the mutual action of these acids, part of the nitric acid is decomposed, its oxygen is transferred to the muriatic acid, and to the oxy-muriatic acid thus formed the peculiar powers of the compound have been ascribed. It appears, however, to be chiefly a compound of nitric and muriatic acids, and its energetic action on the metals appears to be owing to the latter acid by a disposing or resulting affinity promoting the decomposition of the former, favouring therefore the communication from it of oxygen to the metal, with which in its oxidated state it then combines. It is named Nitro-muriatic Acid, and is employed in some of the processes of assaying.

Sect. II.—*Of Oxy-muriatic Acid.*

Scheele discovered, that in the action of muriatic acid on black oxide of manganese, the acid sustains very important changes in its properties. A gas is disengaged of a greenish yellow colour, having an intolerable suffocating odour, not so easily condensed by water as muriatic acid gas, having much less acid power, and peculiarly distinguished by the property of destroying the vegetable colours. According to the views of chemical theory then adopted, he concluded, that this change is produced in muriatic acid by phlogiston being attracted from it by the black oxide of manganese. He therefore named it Dephlogisticated Muriatic Acid.

This theory, expressed according to the language of the more modern chemical system, implied merely, that the muriatic acid received oxygen. The new product, therefore, was named Oxy-muriatic Acid, and this view of its constitution appeared to be confirmed by other facts. The oxide of manganese, on which it had acted, was found to be deprived of much of its oxygen: when the acid was submitted to the action of substances having an attraction to oxygen, as, for example, to the metals, these were found to be oxidated, while muriatic acid was at the same time reproduced: by the simple experiment even of exposing the solution of the oxy-muriatic acid in water to the rays of the sun, very pure oxygen gas was found to be produced, accompanied with the transition to muriatic

acid; or, lastly, if the oxy-muriatic acid were combined with alkaline bases, these compounds afforded a large quantity of pure oxygen when decomposed by heat, and in this case too muriatic acid was obtained. All these facts appeared to prove unequivocally, that the product of the action of muriatic acid on oxide of manganese is a compound of that acid with oxygen, and, in conformity to this, it was farther found, that it might be formed by the action of muriatic acid on other substances capable of affording oxygen.

Notwithstanding the apparent strictness of these conclusions, they have lately been called in question by Mr Davy, and the opposite theory has been advanced, that oxy-muriatic acid contains no oxygen, but, so far as our knowledge of it extends, is a simple substance belonging to the same class with oxygen, or possessed like it of the property of communicating acidity to the combinations into which it enters. He was led to doubt of the existence of oxygen in oxy-muriatic acid gas, from finding, that charcoal, if free from hydrogen, heated in it, produces no change, though, as this inflammable has so strong an attraction to oxygen, it ought to abstract it if it existed in the oxy-muriatic acid, especially as the oxygen has been supposed to be retained in this acid by a weak affinity. When hydrogen gas and oxy-muriatic acid gas are presented to each other, they are converted into muriatic acid: according to the common theory, this must be supposed to arise from the combination of the oxygen of the oxy-muriatic acid with the hydrogen, forming water. But Gay Lussac and Thenard have found, that no water is deposited in the experiment. Mr Davy farther found,

that oxy-muriatic acid forms combinations with inflammables and metals; but in these compounds, while water was excluded, he could discover no indication of the presence of oxygen. He remarks, therefore, that there is no experimental evidence of the existence of oxygen in oxy-muriatic acid; and the direct inference from the production of muriatic acid by the mutual action of oxy-muriatic acid and hydrogen is, that it is a compound formed by their combination. On this hypothesis may be explained all the facts whence the common theory of the constitution of oxy-muriatic acid has been inferred.

This view, singular as at first it appears to be, may no doubt be maintained; yet the opposite theory, I would remark, may still be defended, and the investigation of this important subject is not yet sufficiently advanced to admit of any certain conclusion being drawn. Its relation to the general theory of acidity has been already considered.

The process employed by Scheele to obtain oxy-muriatic acid, consists in distilling with a moderate heat muriatic acid diluted with an equal weight of water from black oxide of manganese. It is more economical, and succeeds equally well to mix with the oxide, muriate of soda and sulphuric acid; four parts of muriate of soda being taken with one of black oxide, and three of sulphuric acid previously diluted with two of water. Their mutual action is favoured by a very gentle heat. The sulphuric acid combines with the soda of the muriate of soda, and disengages the muriatic acid, which, according to the common theory,

receives oxygen from the black oxide of manganese, or, according to the hypothesis of Davy, the oxygen of the oxide combines with the hydrogen of the muriatic acid and forms water, while the other principle of the acid, the Oxy-muriatic Acid as it is named, is disengaged.

The oxy-muriatic acid produced in this operation is disengaged in the elastic form, and if it is to be submitted to examination under this form, it may be received over warm water. It may be condensed by passing it through cold water in the bottles of Woolfe's apparatus, and may thus be procured in the liquid form.

Oxy-muriatic acid gas, though it retains its elasticity at low temperatures under a common atmospheric pressure, may be condensed by applying powerful pressure to it. It is the only gas that is visible, being discovered by its yellowish green colour; it is heavier than atmospheric air; its odour is intolerably suffocating, and even when largely diluted with atmospheric air it produces a sense of suffocation when it is respired.

It is absorbed by water in a quantity larger as the temperature is low; at 50° the water takes up about twice its volume. When the water is saturated with it, if it be cooled below 40° it suffers a kind of congelation, soft scales are formed in it, and even crystals in the form of quadrangular prisms; these are the compound of the oxy-muriatic acid and water: a moderate heat soon liquefies it. The solution has a yellowish green colour, and its odour is that of the acid itself; its taste is rather styptic than sour, and, like the gas itself, it has the property of destroying the vegetable colours.

Liquid oxy-muriatic acid is decomposed by exposure to light, pure oxygen gas being disengaged, and muriatic acid produced. According to the common theory, this is owing to the separation of the oxygen from its combination with the muriatic acid: according to the theory advanced by Mr Davy, it must be supposed owing to the hydrogen of part of the water combining with the oxy-muriatic acid, and forming muriatic acid, while the oxygen of the decomposed water appears in the elastic form. From the quantity of oxygen given out during the exposure to the solar light, compared with the quantity of muriatic acid found to be in the residual liquid, Berthollet inferred, that 100 parts of oxy-muriatic acid consist of 89 of muriatic acid and 11 of oxygen. Chenevix, from the products of the decomposition by heat of the salt which oxy-muriatic acid forms with potash, concluded, that the proportions are 84 of muriatic acid, and 16 of oxygen.

Oxy-muriatic acid gas supports the combustion of a number of inflammable substances. A lighted taper burns in it; phosphorus takes fire when immersed in it, and a number of the metals, as antimony, arsenic, copper, or others, if introduced into it in leaves or filings, burn spontaneously. For the success of the experiment the gas must be pure, and the temperature above 70°. In these combinations it has usually been supposed that the oxygen of the oxy-muriatic acid is combined with the inflammable or metallic substance, and that with this the muriatic acid combines. According to Mr Davy, compounds are formed of the inflammables or metals with oxy-muriatic acid; it is only when water is communicated to them that oxygen is afforded, the oxygen of the water being transferred to the

inflammable or metallic base, while the hydrogen forms with the oxy-muriatic acid, muriatic acid which unites with the oxide.

Hydrogen and oxy-muriatic acid gases act on each other very slowly at a low temperature, unless water be admitted, which favours their mutual action. If the electric spark be transmitted through the mixture of them they disappear, and muriatic acid gas is produced. Dalton and Gay Lussac have also observed, that a similar rapid combination is produced when they are exposed to solar light. Carburetted and sulphuretted hydrogen gases are decomposed by it, and it decomposes ammonia.

Sulphur, if introduced in fusion, burns in oxy-muriatic acid gas; if not in fusion it combines with it, and forms a liquor of a red colour, which Dr Thomson, who observed its production, has considered as a compound of oxide of sulphur and muriatic acid. Mr Davy supposes it to be a compound of oxy-muriatic acid and sulphur.

In its liquid form oxy-muriatic acid does not act with much energy on inflammables. Some of the metals, however, are dissolved by it, oxygen being previously communicated to the metal either from the acid or the water.

The most important chemical property of this substance is displayed in its action on the vegetable colours. Many of them it entirely destroys; and even those which are most deep and permanent, such as the colour of indigo, it renders faint, and changes to a light yellow or brown. Berthollet applied this agency of oxy-muriatic acid to the process of bleaching, and with such success as to have entirely changed the manipulations of that art. The method of applying it has been successively improved. It

consisted at first, in subjecting the thread or cloth to the action of the acid in the gaseous form, but the effect in this way was unequally produced, and from the too powers ful action of the acid gas, the strength and texture were sometimes injured. It was then applied, condensed by water, and in a certain state of dilution, the thread or cloth being prepared by previous boiling in water, to extract as much as possible of its colouring matter, being then boiled in a weak solution of potash, and afterwards immersed for a few hours in the diluted oxy-muriatic acid; and thi- alternate application of the acid and alkali being continued until the colour was discharged. To avoid the offensive suffocating odour of the acid, the improvement was introduced of condensing the acid gas by a weak solution of potash: lime diffused in water being more economical, was afterwards substituted; even slaked lime in the state of powder has been employed, the compound it forms with the acid being dissolved in water, so as to form the bleaching liquor of the proper strength. Under all these forms the oxy-muriatic acid was supposed to produce the bleaching effect, by imparting oxygen to the colouring matter: the colour by this oxygenation is weakened, and the colouring matter is at the same time supposed to be rendered more soluble in the alkaline solution, alternately applied, and of course more easily extracted by its action. More lately, the improvement has been introduced of employing the potash alone, its solvent power being aided by applying it with the steam of water, at a high temperature under increased pressure.

The relation of oxy-muriatic acid to the alkalis and earths is peculiar. When presented to the alkali in a

concentrated state, it does not directly combine with it, but undergoes decomposition; a portion of it returns to the state of muriatic acid, and the other portion, with a quantity of oxygen, enters into combination with part of the alkaline base. It has been concluded from this, that no combination of the oxy-muriatic acid with the alkalis exists. This appears, however, to be a mistake: when the acid and the alkaline solution are much diluted, their mutual action is rendered less energetic: this decomposition, therefore, does not take place, but their direct combination is established; the proof of which is, that the liquor thus formed retains the characteristic property of oxy-muriatic acid, that of weakening or destroying the vegetable colours. These combinations, however, cannot be obtained in an insulated state, as there is no mode of concentrating their solution without giving rise to that re-action which produces decomposition.

Sect. III.—*Of Hyper-oxymuriatic Acid.*

When a current of oxymuriatic acid gas is passed through an alkaline solution of a certain strength, a salt is deposited by spontaneous crystallization, which, by analysis, is found to contain a larger portion of oxygen, compared with the quantity of muriatic acid it contains, than it could do, supposing it to be a compound of oxymuriatic acid. It has also been found, that a portion of the oxymuriatic acid returns to the state of muriatic acid, a quantity of that acid, combined with a portion of the

alkali, being found in the liquor. It has been concluded from these facts, in conformity to the established theory of the composition of oxymuriatic acid, that one portion of it yields oxygen to the other, one returns therefore to the state of muriatic acid, the other passes to the state of an acid containing still more oxygen than the oxy-muriatic acid, and each combines with a portion of the alkali present, so as to form neutral compounds. The acid in the latter state has, in conformity to this view, been named Hyper-oxymuriatic Acid, and its salts are denominated Hyper-oxymuriates.

This theory of course cannot be admitted, according to the hypothesis which Mr Davy has proposed of the nature of oxymuriatic acid. The existence, however, of a large quantity of oxygen in the composition of the salts named Hyper-oxymuriates, is fully established; and without admitting the existence of any acid corresponding to hyper-oxymuriatic acid in their composition, Mr Davy has supposed that these salts are ternary compounds of oxymuriatic acid, oxygen, and the base of the alkali of which they are formed. Any discussion with regard to these opposite views would, in the present state of the inquiry, be premature.

The existence of the acid named Hyper-oxymuriatic, has been inferred rather from the formation of the salt supposed to contain it, than from its being obtained in an insulated state; for in this state it does not appear that it can be procured so as to be submitted to chemical examination. When the salts supposed to contain it are submitted to the action of another acid, as the sulphuric or nitric, a greenish yellow vapour is disengaged, the liquor

around the salt becomes of an orange colour, but no sensible product can be obtained: if heat is applied to favour the action, an explosion is produced, or if this is avoided, the vapour disengaged has an intermixture of oxygen and oxymuriatic acid gases. Hyper-oxymuriatic acid, therefore, if it do exist, is unknown in a perfectly insulated state, and there are only the salts named Hyper-oxymuriates supposed to contain it, the history of which is to be delivered. From the large quantity of oxygen they contain, they act with violence on inflammable bodies, producing with them deflagration or detonation by mere trituration: they afford very pure oxygen when decomposed by heat; they produce no precipitates with metallic salts, as the muriates do; neither do they retain the power of the oxymuriates of impairing the vegetable colours.

Of these salts the Hyper-oxymuriate of Potash is best known. To prepare it, a solution of four parts of subcarbonate of potash in sixteen parts of water, from which the carbonic acid is abstracted by the action of lime, is put into the bottles of Woolfe's apparatus, and a current of oxymuriatic acid gas is passed through it, from a retort containing the materials from which this acid is disengaged: this is continued until the alkali is neutralized: the salt named Hyper-oxymuriate of Potash is deposited in scales, while a portion of muriate of potash remains in solution. The rationale of the process has been already stated: according to the theory hitherto received, the oxymuriatic acid is supposed to suffer decomposition, one portion returning to the state of muriatic acid, the other receiving the oxygen which this has yielded, and forming, by uniting with the alkali, hyper-oxymuriate of

potash: according to Mr Davy's views, the salt which has received this name is a ternary compound of oxymuriatic acid, oxygen, and potash or potassium.

Hyper-oxymuriate of potash crystallizes in scales, in needle-like crystals, or in thin quadrangular plates, white, and of a silvery lustre. It is soluble in 17 parts of water at 60°, and in two parts and a half at 212; it melts from the application of a moderate heat: when heated to redness it is decomposed, and very pure oxygen gas is expelled, amounting to more than a third of the weight of the salt. From this decomposition, Chenevix endeavoured to determine the composition both of the salt itself, and of the hyper-oxymuriatic acid which it is supposed to contain: 100 grains freed from the water of crystallization yield 38.3 of oxygen, and the residue contains 20 of muriatic acid, these being combined with 39.2 of potash, and 2.5 of water of crystallization: the two former are supposed to constitute hyper-oxymuriatic acid, the proportions of the elements of which, therefore, in 100 parts, are 65 of oxygen, and 35 of muriatic acid.

Hyper-oxymuriate of potash is decomposed by the acids. Thrown into sulphuric acid it decrepitates, the liquor acquires an orange colour, and a dense yellowish green vapour is disengaged. If heat is applied, an explosion with a vivid flash of light takes place; if the acid be diluted so as to admit of the application of heat with safety, the elastic fluid which is disengaged is a mixture of oxymuriatic acid and oxygen. The action of nitric acid is similar, but less violent. Muriatic acid is converted into oxymuriatic acid. The elastic fluid disengaged in these decompositions acts with considerable force on inflamma-

ble substances; two or three grains of the salt, for example, mixed with half the quantity of sulphur, charcoal, resins, or oils, forming mixtures which are kindled by the contact of sulphuric or nitric acid.

The salt itself acts with still more energy on inflammable bodies. If a grain or two be triturated with half its weight of sulphur or charcoal, or if the mixture in these proportions be struck forcibly, a loud detonation is produced. A similar effect is produced when several of the metals are employed; and with phosphorus the detonation is so violent, that it can be made with safety only on a very small quantity. These mixtures are also inflamed by the electric discharge and by applying heat. These effects appear to arise from the rapid combination of the oxygen of the salt with the inflammable body, and the formation in general of an elastic product.

The other hyper-oxymuriates scarcely require particular notice. The hyper-oxymuriate of soda is not so easily obtained pure as that of potash, as it is nearly of the same degree of solubility with muriate of soda, and is therefore not easily separated from it by crystallization. It crystallizes in cubes, is deliquescent, and is soluble in three parts of cold water. Hyper-oxymuriate of ammonia is formed by decomposing carbonate of ammonia by hyper-oxymuriate of lime; is very soluble in water and in alkohol, and is decomposed by a slight elevation of temperature. Hyper-oxymuriate of barytes is soluble and crystallizable, as is also that of strontites; hyper-oxymuriate of lime is deliquescent, and soluble in water and alkohol; hyper-oxymuriate of magnesia has nearly the same properties.

END OF VOL. I.

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ELEMENTS

OF

CHEMISTRY.

BY

J. MURRAY,

LECTURER ON CHEMISTRY, AND ON MATERIA MEDICA AND PHARMACY, EDINBURGH.

IN TWO VOLUMES.

VOLUME SECOND.

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BOOK VI.

OF METALS, AND THEIR COMBINATIONS.

OF all the classes of inanimate natural productions, that of Metals appears to be best defined, the substances united under it having qualities extremely appropriate. Their peculiar lustre, perfect opacity, great density, and tenacity, are properties which, to the same extent, belong to none of the other varieties of matter, and which, possessed by each metal, serve to distinguish it without ambiguity.

The progress of science has, however, in this as in many other examples, modified or subverted our artificial distinctions. Of these characteristic qualities, that of tenacity, under the forms of ductility and malleability, has been found not to belong to all the substances referred to the class; and still more recently, the discovery of the bases of the alkalis and earths has demonstrated, that a high degree of density is not possessed by substances which have all the other metallic properties. The ideas connected with an established system of classification, in some mea-

sure oppose the changes to which such discoveries lead. The metals destitute of ductility and malleability were for a time placed as a subordinate order, under the appellation of Semi-metals; and chemists at present hesitate whether the alkaline and earthy bases are metallic. We can scarcely, however, on any principles of sound arrangement, refuse them this rank; and it is only because the established system of chemical knowledge is still so much connected with the former distinctions, and that time is required to mature such innovations, that I have already considered the alkalis and earths as distinct orders, and have given under their history that of the metallic bases of which they are formed.

Excluding these substances, the number of substances admitted as metals amounts to twenty-seven. Seven of these only were known to the ancients, and of the others the greater number is of very recent discovery, and some of them have only doubtful claims.

Of the physical properties characteristic of the metals, that of *density* used to be regarded as one of the most distinctive. The specific gravity of fossil substances not metallic seldom exceeds 2 or 3, water being 1, and the heaviest of them is not more than 4.5, while the lightest of the metals exceeds 6, and many of them are more than ten times heavier than water. The metalloids, as the substances obtained from the alkalis and earths have been named, are, however, lighter than water.

Opacity so far belongs to the metals, that when in the thinnest plates into which they can be reduced without the continuity being broken, they transmit no light, while the

most opaque substance of any other class becomes translucent under a similar mechanical division. The only exception with regard to the metals, is afforded by gold, which, in very thin leaves, transmits a green light, a proof that the property is merely relative, and that transparency would be acquired under a sufficient extension. Still opacity peculiarly belongs to the metals, and in conjunction with the peculiar lustre to which it gives rise, is the only property strictly characteristic; for now that the properties of density, of ductility, and malleability, cannot be regarded as essential, there is nothing in the diamond, and perhaps even in sulphur, but their transparency, that can prevent them from being ranked as metallic. And as the assigning the property of opacity alone, as distinctive of metals, would be imposing a mere arbitrary distinction, all these substances strictly belong perhaps to one class.

The opacity of the metals, and the closeness of their texture, causing the entire reflection of light from their surface, they hence possess a high degree of *lustre* or brilliancy. Many of them lose this from the tarnish they suffer from exposure to the air; but in their fresh fracture they all exhibit it. It is increased also by the high polish of which they are in general susceptible.

The property of tenacity, or strong cohesion of parts, appears in the metals under two forms, *ductility* and *malleability*. By the former is understood that modification of tenacity whence a body can be drawn into fine wire; by the latter, that in consequence of which it can be beat or extended into thin leaves. Though both properties are connected, they are still distinct, and are possessed in very

different degrees by different metals. Where hardness accompanies tenacity, the extension into leaves is difficult, while that into wire is easily executed; hence iron can be drawn into finer wire than any other metal, or possesses the greatest ductility, while it has little malleability. Platina has nearly the same character. In the soft metals, on the contrary, tenacity appears usually under the form of malleability; thus gold, tin, and lead, can be extended in thin plates, without being capable of being drawn into very fine wire. Silver and copper, being metals of medium hardness, have both properties, nearly perhaps in equal proportions. In a number of the metals, the brittleness is such as to prevent their extension to any great degree of fineness under either form. The extension of the metals is facilitated by a certain degree of temperature, this favouring their expansion, increasing the distances between their particles, and probably lessening their hardness or rigidity; but if heated beyond a certain temperature, brittleness is communicated probably from the attraction of cohesion being weakened. Hence the metals are in general brittle when heated near to their melting-point.

The quality of *hardness* belongs to the metals, but is possessed by the different metals in very different degrees, so as to serve as one of those properties by which the individuals of the class may be distinguished from each other. In all of them it can be increased by different artificial methods, principally by cooling them suddenly when they have been highly heated. This hardness, acquired from the hasty approximation of the particles, is accompanied with a corresponding degree of brittleness. The softness and

tenacity can be restored by again heating them, and allowing them to cool slowly.

In their relations to caloric, metals observe the same general laws as other bodies. They are superior to all others in conducting power. Their *fusibility* is very various. Quicksilver is so fusible as to require a reduction of temperature equal to —40° to congeal it; while other metals, as molybdena, or manganese, can with the utmost difficulty be fused. In congealing, they so far assume a crystalline arrangement as to exhibit an internal structure peculiar to each; and by slow cooling, several of them can be made to assume regular crystalline forms, generally those of the cube and octaedron. In volatility they are likewise extremely various. Quicksilver passes into vapour *in vacuo* at natural temperatures; it boils under a medium atmospheric pressure at a temperature a little below 700. Arsenic is even more volatile, while the greater number require very intense heats to convert them into vapour.

Metals, in relation to electricity, conduct it better than any other bodies. They evolve it by mutual contact, whence their power of generating galvanism.

Metals exert affinities to other substances, so as to be susceptible of numerous combinations. They unite with oxygen, with sulphur, phosphorus, and carbon, and with each other; and when combined with oxygen, they farther combine with acids, and in general with alkalis and earths. Of these combinations, that with oxygen is the most important, and a number of general facts have been established with regard to it.

The combination of a metal with oxygen in general

takes place, when it is favoured by a sufficient elevation of temperature; and it is this which constitutes the striking and important change which many metals suffer when heated under exposure to the air. The metal loses its lustre, scales form upon its surface, and as this proceeds, it loses altogether its tenacity, density, and other characteristic properties; and is converted into a powder, dull, and in general earthy in its appearance. This process was formerly named Calcination, and the product was denominated a Metallic Calx. According to the theory of Stahl, it arose from the dissipation of the phlogistic or inflammable principle, which he supposed to exist in metals in common with inflammable substances; and the product of the process, according to this view, is the substance or base of the metal, with which the phlogiston had been combined. The important fact, however, had been established, with regard to several metals, that the metal, in suffering this change, increases in weight—a fact altogether at variance with the hypothesis: it had been farther discovered, that the admission of the air is necessary to the process. Bayen, about the period of the commencement of the researches of pneumatic chemistry, discovered the very important fact, that from certain metallic calces, particularly those of quicksilver, a large quantity of aerial fluid might be expelled by the application of heat in close vessels, the calx at the same time returning to the metallic form. The weight the metal gains in calcination he ascribed to the absorption of this aerial fluid, and his experiments he regarded therefore as so far subversive of the theory of Stahl. It was afterwards discovered, that the air

thus expelled is oxygen gas; it was shewn by more ample and decisive evidence, that the presence of atmospheric air is indispensible to metallic calcination; it was proved, that the air suffers during the process a diminution of volume and weight; that this is owing to the abstraction of part of its oxygen; and that the increase of weight which the metal suffers, is equivalent to the weight of the quantity of oxygen which disappears. Lavoisier, by whom some of these facts were established, concluded from them, that the calcination of a metal is merely its combination with oxygen, and that the general process is therefore so far analogous to the process of combustion.

The oxidation of a metal, by the agency of atmospheric air, takes place in different metals with different degrees of facility. In general, it is necessary to raise the temperature considerably higher than a natural temperature, and to many of them it is necessary to apply very intense heats. Some are oxidated at the temperature at which they melt; others, even when in perfect fusion, undergo no change; some are oxidated when the heat is raised sufficiently high to convert them into vapour; and others, as gold or platina, resist oxidation at either temperature, and can scarcely be made to undergo it from the action of oxygen in its elastic form. The application of heat, in promoting metallic oxidation, is to be explained on the same principles as its agency, in favouring in general chemical combination. It acts by lessening the cohesion of the metal, which is an obstacle to the combination; this is concentrated, however, to a certain extent, by its necessarily augmenting the elasticity of the oxygen gas;

and hence, where the mutual affinity between the metal and the oxygen is weak, the combination is not effected.

The phenomena which accompany the combination of a metal with oxygen, are various. In general, it takes place slowly, and hence there is scarcely any sensible evolution of light, and no such extrication of caloric, as to enable the combination to proceed independent of the continued application of heat. In some, however, the oxidation is so rapid as to give rise to the phenomena of combustion: thus zinc and iron burn vividly at a temperature a little higher than that of ignition; tin and arsenic burn at the same temperature, with a more feeble flame; and at more intense heats, nearly all the metals suffer combustion.

The substances formed by the combination of oxygen with metals, are in general oxides. With regard to several of them, however, the oxidation can also be carried so far as to produce compounds with distinct acid powers.

Metallic oxides have few common characteristic properties. They are usually of an earthy appearance, without the lustre, tenacity, or density of the metals. Several of them may be vitrified, when they form glasses more or less transparent, of dark colours. Their chemical relations are entirely different from those of the metals; they exert affinities to the acids, alkalis, and earths, and in their combinations with acids, neutralize the acid properties. In these properties they are analogous to the alkalis and earths; and in strictness of chemical arrangement, they probably form with these substances only one class. The common metallic oxides differ from the alkalis, and seve-

ral of the earths, in being less soluble in water, whence they display less energy in chemical action.

In combining with oxygen, the metals unite with different proportions of it; the proportion, for example, in oxide of gold or silver, does not exceed 7 parts in 100, while in that of iron or manganese, it equals or exceeds 40. If the quantity condensed can be regarded as a measure of the force of affinity which the metal exerts, as Berthollet's views of chemical attraction suggest, we should have a correspondence apparently strict between this criterion and that which is afforded by the comparative facility and difficulty of decomposition; for of the above oxides, those of gold and silver are decomposed with great facility, while the entire decomposition of those of iron and manganese is extremely difficult.

Each metal, in combining with oxygen, combines too with different proportions of it, and these combinations, in conformity to the usual law of chemical attraction, give origin to compounds having very different properties. Quicksilver, with a small proportion of oxygen, forms an oxide of a grey colour; with a large proportion of oxygen, it forms one which is red; manganese forms a white and a black oxide, iron a black and a red; and there are others in which the degrees of oxidation are more numerous, marked by differences of properties sufficiently distinctive. The force with which the oxygen is retained in these combinations is different, being less strong as the proportion of oxygen is greater, from the influence of quantity on chemical affinity. Hence the partial decomposition of an oxide can often be easily effected, while the entire de-

composition requires the introduction of a more powerful force.

It was an opinion generally received among chemists, that these combinations of a metal with oxygen take place in determinate proportions, and that between these proportions there are no intermediate combinations. Thus there were supposed to be a black and a red oxide of iron, the one containing 27 of oxygen, the other 48; but between these two proportions, no direct combination of iron and oxygen was supposed to take place. Proust supposed, that with regard to every metal, there are two determinate degrees of oxidation: Other chemists have allowed that the degrees of oxidation may be more numerous; but have supposed that these degrees are determinate, and are so in consequence of an attribute in the exertion of chemical affinity itself.

This opinion has been called in question, however, and apparently with much reason, by Berthollet. He supposes that the proportions can vary progressively from the term at which the combination of the oxygen and the metal becomes possible, to that at which the oxidation is at the highest degree; that in many cases it actually does so; and that if in others determinate proportions are observed, this is owing to the operation of circumstances which at these proportions limit the combination, and which in general being uniform, give rise to an invariable proportion.

This opinion of Berthollet not only accords better with correct views of chemical affinity, but has the advantage of not being incompatible with the facts which have a re-

lation to this subject, while it is more directly inferred from others, which the opposite hypothesis imperfectly explains. There are, for example, two oxides of manganese well determined; the white oxide at the *minimum* of oxidation, and the black at the *maximum* of oxidation. The black oxide is decomposed by heat, and, according to the intensity of this, more or less oxygen is expelled, the colour becoming lighter, and passing through numerous shades. The decomposition is here not limited to determinate proportions, but is indefinite, or at every proportion between the two extremes; and it is a very vague hypothesis to suppose, as has been done, that the shades of colour indicating these numerous degrees of oxidation arise from mixtures of the determinate oxides. The perfect oxide of iron, in like manner, passes, by the action of heat, by numerous shades of colour, from red, through purple to black, or by triturating red oxide of mercury with metallic mercury in various proportions, different tints of grey and yellow are obtained. In all these cases, each shade of colour must be considered as indicating a certain stage of oxidation. But these are so numerous, and pass so imperceptibly into each other, as to prove that the oxidation is not determinate, but may take place in indefinite proportions.

It is no doubt true, however, that the proportions in metallic oxidation are often really determinate, owing to the operation of circumstances nearly uniform in themselves, by which the combination is regulated. The fusion of a metal may be stated as an example of this. If a metal be oxidated at the point at which it melts, as that point

is not variable, the oxide will always be uniform, or one determinate proportion will be observed in the combination. The oxide formed at the point of the volatilization will, from a similar cause, be always the same. And the affinities of acids, and the cohesion of crystallized metallic salts, are often sufficiently powerful to determine the combination, or place limits to the proportions in which it takes place.

It follows, from these observations, that no precise nomenclature can be applied to the denomination of the metallic oxides. To attempt to establish distinctive appellations of the different oxides of the same metal, on supposed determinate and constant degrees of oxidation, would be only to introduce a source of error, which in the progress of the science would be productive of much confusion. The distinctions of the oxides are generally, and perhaps most conveniently, drawn from qualities in which they differ. Colour, as it is the most obvious, is the most usual. But where this is not sufficiently distinctive, the distinction may be drawn from other properties.

Metallic oxides may be decomposed, the oxygen being abstracted, and the metal obtained again in its metallic state. This constitutes the process named Reduction, and it is effected in various modes.

The oxides of some metals are reduced by the operation of caloric alone; those of gold, silver, and quicksilver, are thus reduced by a heat not much superior to that of ignition; and others, by elevation of temperature, suffer at least a partial reduction.

In general, however, it is necessary to introduce the

more powerful agency of other substances exerting an affinity to oxygen. Charcoal is the one most powerful and most convenient in its operation; and hence, the oxides of all the metals, when exposed to a heat sufficiently intense, in mixture with charcoal powder, or with matter capable of being converted into charcoal, as any vegetable substance, are reduced, the carbonaceous matter combining with the oxygen of the oxide, and forming carbonic acid, carbonic oxide, or portions of both, according to the proportions employed, or the force of affinity with which the oxygen is retained. The metal, thus deprived of oxygen, is at the same time fused. The addition of some substances favour the operation by melting, and thus communicating that state of fluidity favourable to chemical action, or by a resulting affinity aiding the formation of carbonic acid by the union of the carbon and oxygen. Carbonate of potash mixed with charcoal, under the form of what is named the *black flux*, prepared by calcining a mixture of one part of nitre with two of tartar, is generally used for this purpose, in experiments on a small scale. In reduction performed on a large scale, lime is useful, partly by the same operation, and partly by contributing to the vitrification and removal of any earthy matter.

Metallic oxides may be reduced by the action of other substances, exerting a strong attraction to oxygen, as, for example, by hydrogen; and even one metal, under certain circumstances, reduces the oxide of another. Light reduces them partially or entirely, as has been already stated; and they are decomposed when placed in the galvanic cir-

cuit, from the different relations of oxygen, and of metallic matter, to the different galvanic poles.

Besides the direct action of oxygen in its elastic form on metals, there are other cases in which the same ultimate result is produced by the transfer of oxygen from compounds in which it exists. Thus metals are oxidated by deflagration with nitre, and by the action of acids, and of water; and these, being more complicated, present some peculiar phenomena.

If a metal be exposed to a high temperature in mixture with nitre, the oxygen disengaged from the decomposition of the acid, combines with the metal, and usually with such rapidity as to produce the phenomena of combustion or deflagration. With regard to several of them, however, a very high temperature is necessary for this; and those which have a weak attraction to oxygen, particularly gold, silver, and platina, suffer the change imperfectly. Those which are more susceptible of oxidation, are in general by this process oxidated to the *maximum*, and frequently the oxide exerts an affinity to the potash, and combines with it. A similar oxidation of metals may be effected by the agency of the hyper-oxymuriate of potash; and mixtures of this salt with a number of the metals detonate from percussion, as has been already stated.

These metals which have a strong attraction to oxygen, receive it from water. Some of them, as iron, do so at a low temperature. At a high temperature, it takes place more rapidly, as it does also at a low temperature, when promoted by the disposing affinity of an acid.

Acids are, of all the classes of chemical agents, those

which act with greatest force in oxidating metals; the acid either directly imparting oxygen to the metal, enabling the metal to acquire it from the decomposition of water, or sometimes by absorption from the atmospheric air. According as one or other of these effects is produced, the action of an acid on a metal is attended with peculiar phenomena. If the acid act by directly affording oxygen, the action is attended with the evolution of the other constituent principle of the acid, either pure or partially oxidated: if it operate by enabling the metal to attract oxygen from the water which is present, then it is accompanied with the disengagement of hydrogen gas. Nitric acid always directly imparts oxygen to metals; and in consequence of this decomposition, nitric oxide, nitrous oxide, or nitrogen gas, is disengaged. Sulphuric acid scarcely suffers decomposition, unless the affinity of the metal to oxygen be aided by a high temperature; and hence, in its concentrated state, it does not act forcibly on metals in the cold; but when diluted, its action is powerful in oxidating the metal by the decomposition of the water. The action of muriatic acid is similar; and hence, those metals only are oxidated by it, as well as by diluted sulphuric acid, which are capable, when aided by the resulting affinity of the acid, of decomposing water. The principles of nitric acid being united by a weaker affinity, it is more susceptible of decomposition; and hence it acts on all the metals, gold and platina excepted, the affinity of these to oxygen being not sufficiently powerful to decompose it.

The effect of an acid, in those cases in which it promotes the oxidation of a metal by the decomposition of

water, is an example of what is named Disposing or Resulting Affinity, or it depends on the united force of attractions, which, but by their co-operation, would not be apparent,—the attraction of the metal to oxygen, of the acid to oxygen, and of the acid to the metal. These co-operating overcome the single affinity of the oxygen to hydrogen; hence the water is decomposed, and the metal, the oxygen of the water, and the acid, enter into one combination.

In a few cases, an acid promotes the oxidation of a metal, by enabling it to attract oxygen from the air. This kind of action is generally exerted by acids of weak power. It is well exemplified in the action of diluted acetic acid on copper or lead.

The action of an acid on a metal, is not limited merely to its causing its oxidation: as the oxidation is effected, the acid uniformly combines with the oxide, and it is this which constitutes the solution of metals in acids. No acid directly combines with a metal, the metal must always be oxidated; hence, if an acid act on a metal, it does so always by first communicating to it oxygen directly or indirectly in the modes above explained, and at the same time it combines with the oxide as it is formed. And hence, the compounds thus formed are the same with those which would be produced, if the acid more directly combined with the metal previously brought to the same state of oxidation by any other mode. If the compound of the oxide and acid is insoluble, or of sparing solubility, it is precipitated as the mutual action proceeds; but if it is sufficiently soluble, it remains in solution in the water of the acid, generally retaining an excess of acid in the combination.

The base, therefore, in immediate union with the acid in all these combinations, is not the metal, but the metallic oxide. It produces perfect neutralization of the acid when the combination is established in the due proportions. These compounds are strictly analogous to those formed by the combination of the alkalis and earths with the acids; they are many of them soluble in water and crystallizable. Being thus of a saline nature, they have been denominated metallic salts; and the same nomenclature is applied to them as to the other orders of compound salts; those which contain sulphuric acid being named sulphates, those containing nitric acid, nitrates, and the same mode being followed with regard to the others. The species is named from the metal which is the ultimate base, as sulphate of iron, nitrate of copper, &c. In the strictness of system, the name ought to be derived not from the metal, but the metallic oxide, as it is this which is the primary base, or is in immediate combination with the acid; but the other nomenclature has from its conciseness been preferred.

Every metal being susceptible of different degrees of oxidation, it is obvious that the same metal may with the same acid form different compounds, according as it is more or less highly oxidated. This accordingly gives rise to striking differences in these combinations, and to a number of important facts with regard to them.

The difference in the nature and properties of these compounds, from the different states of oxidation in which the metal exists combined with the acid, is apparent in many examples. Thus there is one muriate of mercury

insipid, insoluble, and extremely mild; but there is also another in which the metal is more highly oxidated, soluble, and in the highest degree acrid and corrosive.

The facts with regard to the production of these compounds, and the state of oxidation in which they exist, admit of a certain degree of generalization, under which they may be best enumerated. The following are the most important. 1*st*, When a metal is acted on by a diluted acid, or by one having not much energy of action, it is usually less highly oxidated than when acted on by one more powerful, or which, from facility of decomposition, affords oxygen more readily. 2*d*, When the solution takes place in the cold, the degree of oxidation is less considerable than when the mutual action is favoured by heat. 3*d*, The oxidation of the metal may at first be at the *minimum*, but it may pass to a higher degree, from exposure to the air, a quantity of oxygen being absorbed; or a similar change may be produced from a farther decomposition of the acid in the combination, this happening more particularly when heat is applied. 4*th*, The affinity of the metallic oxide to the acids changes as the oxidation varies, becoming in general less powerful, as the degree of oxidation is greater: hence a metal highly oxidated may be insoluble in an acid in which it may be dissolved at a lower degree of oxidation; hence too the cause of a common occurrence displayed by metallic solutions, that from exposure to the air, and sometimes from exposure to heat, they suffer a partial decomposition, a portion of precipitate being thrown down. The change in this case is owing to the metal passing gradually to a higher state of oxi-

dation, and to the affinity of the acid to it, as this takes place, becoming less powerful; whence the whole of the oxide cannot be retained in solution, but a portion of it is precipitated, retaining a little of the acid combined with it. To this also is to be ascribed the fact, that some metallic oxides in a high state of oxidation are insoluble in sulphuric or nitrous acid, but are dissolved by sulphurous, nitrous, or muriatic acid; the latter acids abstracting a portion of the oxygen of the oxide, and, in conformity to this law, allowing the more powerful affinity to be exerted. *Lastly*, from the same cause, one metallic oxide may precipitate another, from its combination with an acid, the action of the one, at a low state of oxidation, being more powerful than that of the other in a higher state of obidation.

When a metal combines at different degrees of oxidation with an acid, are these degrees always determinate; or may it enter into these combinations in degrees of oxidation indeterminate, or at all stages intermediate between the *minimum* and *maximum?* This is an important, and at the same time a difficult question, in relation to the subject of metallic solution. In general, perhaps, it may be affirmed, that in these combinations determinate degrees of oxidation are established, this being done by the powerful affinity of the acid to the metal in a certain state of oxidation. But frequently it appears also, that the degrees of oxidation are indeterminate, or at least are numerous, and not easily obtained uniform.

The different states of oxidation in which a metal can exist in combination with an acid, give rise to a difficulty with regard to the nomenclature of these compounds; the

name of the genus of each series being derived from the name of the acid, that of the species from the name of the metal, it is difficult to convey by the designation, in what state of oxidation the metal exists. Yet nothing frequently is more important than to do this, the different salts formed from the acid and the same metal differing widely in their properties in different states of oxidation, and requiring therefore to be carefully distinguished. The method which appears to be most practicable, and least likely to lead into error, is to derive distinctive epithets, attached to the usual names, from differences in the properties of such salts: we thus speak of the green and the brown sulphate of iron, the mild and the corrosive muriate of mercury. Any method founded on the supposition of determinate degrees of oxidation being established in these compounds, can only lead into error; for were even the supposition just, which it probably is not, all the possible degrees of oxidation cannot be presumed to be exactly known, and the discovery of a new degree of oxidation in the series of the compounds of one genus would require a change of nomenclature through the whole, or at least with regard to all those at a higher degree of oxidation; and what is worse, the names which had been appropriated to some would, in this change, require to be applied to others. The method which some have employed, of prefixing the epithet *oxy* to the usual generic name, to distinguish the compound of the metal at the higher state of oxidation, can serve to distinguish only two compounds of each metal with one acid, while the number may be greater; and is besides incorrect, the syllable *oxy* being, in the system of modern

nomenclature, appropriated to distinguish the compounds of oxygenated acids.

The metallic salts, like the other orders of compound salts, may exist with various proportions of their constituent principles. When these are united in one proportion, the state of neutralization is established; but besides this, combinations may be formed in which there is an excess of acid, or an excess of oxide. When the base predominates, the compound is usually insoluble, and many such combinations have been even regarded as pure oxides; when there is an excess of acid, solubility is communicated, and it is difficult to cause the compound to crystallize. These combinations appear to be unlimited with regard to proportions, or, in all cases, the oxide and the acid may be united in any relative quantity with regard to each other; and in these, as in other cases of chemical union, determinate proportions are established only by the operation of cohesion, or other external forces.

Metallic salts are in general more susceptible of decomposition than the other orders of compound salts. Many of them are decomposed by the action even of water, which exerting a stronger attraction to the acid than to the oxide, combines with the greater portion of it, and hence subverts the combination, instead of merely dissolving it. In this case the usual participation of substances acting on each other takes place; the acid dissolved by the water retains a little of the oxide combined with it; the oxide which is precipitated, retains a small portion of the acid in combination with it; and the neutral metallic salt is thus resolved

into two compounds, one with an excess, the other with a deficiency of acid.

The action of an alkali, and likewise of any of the soluble earths, on these metallic combinations is similar, only more energetic. The alkali exerting a stronger attraction to the acid, abstracts a larger portion of it, but the oxide in its separation still retains a little of the acid in combination with it, and frequently the acid, in entering into union with the alkali, carries a small proportion of the oxide along with it. The oxide which is precipitated generally retains less acid combined with it, than when the decomposition is effected by water, and chemists were even accustomed to regard these precipitates as pure oxides; but, however powerful the action of the alkali may be, or however large the quantity in which it is used, its action is opposed more powerfully, in proportion as the decomposition proceeds, by the increasing relative quantity of oxide to the remaining acid: hence the abstraction of the acid is seldom complete.

The alkali sometimes, in decomposing those salts, reacts on the oxide, and dissolves a portion of it, or when added in excess, forms with it and the acid a ternary combination. Ammonia has in particular this tendency, and sometimes too it has been supposed to decompose the oxide partially, its hydrogen attracting a portion of the oxygen, and thus reducing it more nearly to the metallic state.

The metallic salts, like the other compound salts, are liable to decomposition, from the different relations of the different acids to their bases. Thus many of the metal-

lic nitrates are decomposed in the humid way, by the addition of sulphuric, muriatic, or phosphoric acid; and by the application of heat, other similar decompositions are produced, the acid combined with the oxide being disengaged by onother acid which takes its place. Similar decompositions may be produced by double affinity. All of these used to be ascribed to the relative forces of affinity exerted by the different acids to the oxides; but, like all similar decompositions, they arise as much from the exertion of cohesion, elasticity, and other external forces, by which chemical attraction is modified.

There is one kind of decomposition peculiar to the metallic salts, that in which the oxygen is abstracted from the oxide, so that it is reduced to the metallic state. This kind of decomposition is generally produced by one metal acting on the solutions of another; thus iron precipitates copper from its saline combinations, and copper precipitates silver or quicksilver.

It was conceived, that in these cases the decompositions arise merely from the relative forces of affinity of the metals to oxygen; the metal which is precipitated from any of its saline solutions, being supposed to have a weaker affinity to oxygen than the metal which precipitates it; the latter therefore attracting the oxygen from the former, the one becomes insoluble, and is separated in its metallic form, while the other, by its combination with oxygen, becomes capable of combining with the acid with which the oxide of the other had been united, and is dissolved in its place. The acid is thus regarded merely as the medium which, by communicating fluidity, allows these affinities to be exerted. This

view is probably partly just, yet there can be no doubt, that the actions exerted are more complicated, and that both the acid, by its affinities to the oxides of the respective metals, modifies the results, and that a similar modification is produced by the affinity of the precipitating to the precipitated metal. A proof of the influence of the latter circumstance is derived from the fact, that the metal precipitated has generally a small portion of the other metal combined with it.

If the precipitation in these decompositions takes place slowly, the metal assumes somewhat of a crystalline arrangement, and the accretion of new matter has been observed to take place from the extremities of the filaments already formed, a phenomenon which has been considered as galvanic. Sometimes the abstraction of oxygen is only partial, the one metal attracting part of the oxygen from the other, and both oxides being precipitated.

Similar decompositions are produced by some inflammable substances, as by hydrogen, charcoal, and phosphorus, especially when their action is favoured by the chemical agency of light.

The alkalis exert scarcely any sensible action on the metals in their metallic state; they combine, however, with a number of the metallic oxides, dissolving them in the humid way, and by the application of heat, forming compounds which are sometimes capable of being vitrified. In these combinations the opposite law appears to be observed, from that which regulates the combination of the acids with the metallic oxides,—the affinity exerted by the alkali being more powerful to the oxide in a high than in a low state of oxidation, and these combinations being

hence usually established in the former state. The solutions of certain metallic oxides in alkaline liquors may be decomposed, according to Klaproth, by the action of another metal attracting oxygen from the one which had been dissolved, and precipitating it in its metallic form.

The metals form no combination with nitrogen. Hydrogen, even in its elastic form, is capable of retaining a small quantity of some of them dissolved.

Carbon unites with some of the metals, particularly with iron. Plumbago is a natural, and steel an artificial compound of this kind. Carbon unites too with zinc, but not in any appreciable quantity, so far as has been ascertained, with any of the others.

Sulphur combines with all the metals by fusion, gold and zinc excepted; its combination with some of the metals being attended, as has already been remarked, with the evolution of heat and light, or the sensible phenomenon of combustion, no doubt from a similar cause as that which gives rise to the same phenomena in the combinations of oxygen with combustible bodies,—a diminution in the capacity for caloric, and a change in the chemical relation of the compound to the light existing as a constituent principle in one or both of the bodies combined. The effect has no connection with oxygenation, for it takes place when the metal and sulphur are heated *in vacuo*; the compound is found to be a pure sulphuret, and it is not promoted by the presence of a portion of oxygen, neither heat nor light being evolved, when the metal is employed in the experiment in the state of an oxide.

The compounds of the metals with sulphur have a lustre

approaching to metallic; they are opaque, hard, and brittle, and generally more fusible than the metal of which they are composed. The proportions of their constituent principles have been supposed to be uniform and determinate; but there is more reason to conclude, that they are variable and indeterminate. The attraction by which they are combined, is in general sufficiently strong to prevent the expulsion of the sulphur by heat, or at least to render it only partial; and the decomposition is obtained more completely, only by admitting at the same time the operation of the atmospheric air, the oxygen of which, combining with the sulphur, converts it into sulphurous acid, which the heat expels. By the mutual action of the metal and sulphur, their affinity to oxygen appears to be promoted; and these sulphurets are hence liable to oxygenation from exposure to water, or to a humid atmosphere.

Sulphur combines not only with the metals, but also with their oxides. Its attraction is, however, according to Vauquelin, weaker to these than to the metals, and it becomes weaker as the degree of oxidation is greater.

Sulphuretted hydrogen displays relations to the metals somewhat similar. Its action on the metals is shewn by the tarnish it immediately communicates to their surface. It unites too with the metallic oxides, and from its attraction to them, is capable of decomposing a number of the metallic salts. The precipitates which it forms from these, sometimes result from the immediate combination of the sulphuretted hydrogen with the oxide of the metallic salt. Not unfrequently a more complicated action is exerted in their formation; the hydrogen of the sulphuretted hydro-

gen attracting partially, or entirely, the oxygen of the metallic oxide, while the sulphur combines with the metal, thus reduced either to a low state of oxidation, or altogether to the metallic state. As these precipitates are usually of very dark shades of colour, sulphuretted hydrogen is the most delicate test of metallic matter. It is applied sometimes under the form of its watery solution; there are some salts, however, particularly those to the oxides of which, in a low state of oxidation, sulphur has no strong attraction, from the acid of which the sulphuretted hydrogen is incapable of separating the oxide; with regard to these, the presence of an alkali is necessary to saturate the acid to admit of the formation of a precipitate, and hence the alkaline hydro-sulphurets, or sulphuretted hydro-sulphurets, are more active tests. They not only serve, too, to discover the presence of metallic matter in general, but to detect the different metals by the various colours of the precipitates which they form.

A singular action, not yet well understood, is exerted in some metals by sulphur in combination with an alkali. The compound enters into combination by fusion with the metal, and even with those metals with which sulphur alone does not combine, as with gold; and what is still more singular, the metal is thus rendered soluble in water. The former effect appears to be owing to the alkali preventing the volatilization of the sulphur, and thus allowing a higher degree of heat to be applied, to favour its combination with the metal, than can be applied when the sulphur and metal alone are heated; the combination, too, being perhaps favoured by the affinity which may be exerted by

the metallic base of the alkali. The second effect is more difficult of explanation, nor is the nature of the compound obtained in solution in the water well determined; it is uncertain whether the metal is oxidated, and whether sulphuretted hydrogen exists in the combination.

Phosphorus has relations to the metals similar, under a general point of view, to those of sulphur. From its volatility and inflammability, it cannot easily be directly combined with them, but the combination can be formed by exposing to heat a mixture of the metal with phosphoric acid and charcoal; the charcoal attracting the oxygen of the acid, and the phosphorus, as it is produced, combining with the metal. The metallic phosphurets have a degree of lustre approaching to metallic; they are usually soft, and are fusible and inflammable.

The metals enter into combination with each other by fusion. These compounds are named Alloys. They have uniformly the general metallic properties, opacity, lustre, density, &c. and generally, to a certain extent, the qualities of the respective metals of which they are composed, though these are also liable to be modified by the combination. The compounds with quicksilver are soft, or fluid, according to the proportions; they are named Amalgams. Some of these alloys are valuable from their peculiar qualities.

These combinations are not unlimited, either with regard to the metals which combine, or the proportions in which the combination is established. Some metals combine with great facility; others do not unite, as iron and lead, or iron and quicksilver. Frequently three or more metals

can be brought into one combination. The facility of combining appears to be in some measure regulated by an agreement in fusibility and specific gravity, so that when the mutual affinity is weak, a considerable difference between two metals in these properties will prevent their combination. The same properties, and particularly the specific gravity, regulate to a certain extent the proportions in which they combine. These, in conformity to the law which chemical attraction observes, would be unlimited, and in the greater number of these combinations they actually are so. But in some cases they appear to be determinate, and the influence of the specific gravity in giving rise to this, is well exemplified in a fact sufficiently established, that in a mass of metallic alloy formed by fusion, and allowed to cool slowly, the upper and under parts of the mass are composed of the respective metals which form it in different proportions, the under part containing more of the heavier metal, while the lighter predominates in the portion above. The combination of metals is usually attended with a degree of condensation, though in some cases the reverse happens, there being an enlargement of volume, probably from the crystalline arrangement which the particles of the compound mass assume.

The arts of gilding, silvering, and tinning, and the operation of soldering, depend on the mutual affinities which metals exert.

The metals form no combinations with the earths. The metallic oxides and the earths, however, frequently combine by fusion, and form in general coloured glasses.

The metals are found in nature, either native, that is, in the metallic form, or mineralized, that is, combined with some other substance, by which the metallic properties are so far disguised. They are then, too, said to exist in the state of Ore. The substances with which they are most frequently combined, are sulphur, oxygen, and various acids, particularly the carbonic, sulphuric, muriatic, and phosphoric. These ores occur frequently crystallized, sometimes massive; they form, in a few cases, entire beds; more usually they are distributed in mineral veins, and are associated in these with various earthy fossils, particularly quartz, calcareous spar, sulphate of barytes, and fluor spar. When removed from their original repository, and freed, by pounding and washing, from the stony matter intermixed with them, they are subjected to calcination, fusion in contact with the fuel, and other operations variously adapted to particular ores, by which the foreign substances are separated, and the metal is reduced, and obtained sufficiently pure.

The class of metals has been subdivided into orders under which the individual metals have been arranged. There is no advantage in such subdivisions, which are all either inconvenient or imperfectly defined, and the different metals may be considered in that order in which the transitions are most easy, so as to admit of those being associated which are most strictly connected. Those of recent discovery, and which are imperfectly investigated, may be placed together, and considered after the others; and with regard to some of these the suspicion is probably well founded, that they are undiscovered alloys of known metals.

CHAP. I.

OF GOLD.

Gold has always been placed at the head of the class of metals, and esteemed of the greatest value; a superiority which it derives from the richness of its colour and lustre, which are not altered or tarnished by exposure to air or humidity, from its high ductility and malleability, and its indestructibility by many of the operations by which the other metals are disguised or changed. It is found in nature usually native, and nearly pure; sometimes also, however, in combination with other metals, under the form of alloys, in which its more characteristic properties are nearly concealed. Gold has been supposed to exist, too, in the vegetable kingdom, a minute quantity of it, according to the experiments of Rouelle and others, being capable of being extracted from the ashes of plants.

Native gold, when loosely interspersed or diffused, is in a great measure freed from the foreign substances with which it is mixed, by placing it in a stream of water, on an inclined plane. The metallic residuum is triturated with quicksilver, until all the particles of gold are dissolved: the mercury is distilled off, the distillation being performed in iron retorts, and the gold remains, and is fused. When it is contained in other ores, the ore is roasted, to expel the volatile principles, and oxidate other metals

that may be present, and the remaining gold is extracted by amalgamation with quicksilver, or fusion with lead. It still, as obtained by any of these methods, requires to be farther purified. This is done by the process termed Cupellation, which consists in combining the gold with a quantity of lead, and exposing the alloy to a melting heat in a vessel termed a Cupel, formed of bone ashes, and extremely porous, or in the large way, on the hearth of the refining furnace. The lead is extremely susceptible of oxidation, and at the same time it promotes the oxidation of other metals, and vitrifies with their oxides. They are thus removed; the vitrified matter is absorbed by the vessel, or is driven off by the blast of bellows as it collects on the surface, and the gold at length remains nearly pure. It can contain only silver, which is separated by the solvent power of nitric acid, forming the operation termed Quartation, or Parting.

Gold, when pure, is of a rich yellow colour, and its lustre is not impaired by exposure to air or moisture; its specific gravity is from 19.2 to 19.36; it exceeds therefore in density every metal, platina excepted; its hardness is not considerable, but its tenacity, under the forms both of ductility and malleability, is extremely great: it can be drawn into very fine wire, and in malleability it is superior to every other metal; one grain of it may be made to cover a space of 56 square inches, and in the gilding of silver wire, it has been calculated to be extended 12 times more than this.

Gold melts at 32 of Wedgewood's thermometer, and by an intense heat, as that of a powerful burning mirror, is

volatilized unchanged. It was usually supposed to be incapable of oxidation from atmospheric air or oxygen gas, at any temperature, as it had often been exposed to long-continued intense heats, with the admission of the air, without suffering any apparent change. It is now, however, sufficiently established, that a very intense heat suddenly and momentarily applied causes its oxidation. This effect is produced by an electric discharge transmitted over gold leaf inclosed between plates of glass, or through a fine gold wire inclosed in a glass tube with atmospheric air; gold can even be made to burn by powerful electric sparks; it exhibits a vivid combustion in the galvanic circuit; it burns in the flame of an united stream of oxygen and hydrogen, and is even partially oxidated in the focus of a powerful burning mirror. Lastly, it suffers the same change to a certain extent by being heated with nitre, as has been established by the experiments of Mr Tennant, contrary to an opinion which had been generally received, that it suffers no change from the action of nitre. The oxide of gold is of a purple colour; it is supposed to be at the *minimum* of oxidation, and to contain not more than 5 or 6 parts of oxygen in 100. A yellow oxide is obtained from some of its saline combinations, supposed to contain in the same quantity ten of oxygen. Both these oxides are decomposed, and metallic gold obtained by a heat equal to that which is necessary to its fusion.

Gold is scarcely acted on by any of the acids. Even the nitric acid, which imparts oxygen so readily to the other metals, has scarcely any sensible effect upon it, and it is only when the acid is surcharged with nitric oxide, and

boiled on the gold, that a very minute quantity is dissolved. Oxymuriatic acid, yielding oxygen more readily, dissolves it with more facility; but nitro-muriatic acid is its proper solvent. An acid, composed of two parts of nitric and one of muriatic acid, dissolves it rapidly; and even with a much smaller proportion of nitric acid the solvent power is exerted. The power of this compound acid appears to depend, not on its containing a portion of oxymuriatic acid, as has been supposed, for its solvent effect much exceeds that of the latter acid even in its pure state, but on the muriatic acid, by a resulting affinity, enabling the gold to decompose the nitric acid, and receive oxygen from it; the effect being analogous to that of muriatic or sulphuric acid dissolving a metal by enabling it to decompose water.

The solution of gold in nitro-muriatic acid, when concentrated, is of a rich yellow colour; it contains always an excess of acid, but by evaporation a salt is obtained, approaching to the neutral state, in small pyramidal crystals of the same colour. This salt is the muriate of gold; the nitric acid of the nitro-muriatic acid being either decomposed during the solution, or volatilized in the evaporation; it is deliquescent, is easily soluble in water, and likewise in alkohol and ether; it is decomposed by heat, and by light.

The other salts of gold have scarcely been examined; they may be formed by adding the gold previously oxidated to the acid with which it is designed to be combined. The nitrate and sulphate do not crystallize; the phosphate melts into a glass of a rich red colour.

The solution of gold in nitro-muriatic acid is decomposed by the alkalis. Potash and soda throw down a precipitate of a yellow colour, probably a sub-muriate; by an excess of alkali it is in part re-dissolved. Ammonia exerts a more peculiar action; it forms a precipitate, which, if an excess of alkali were added, would be re-dissolved. This precipitate is highly fulminating, and has been known by the name of *Aurum fulminans*, fulminating or detonating gold. When dry, it explodes from the application of a heat not higher than 300°, or from friction or percussion; and as a very slight degree of friction causes it to detonate, it is necessary to make experiments on it with caution; the explosion is accompanied with an acute report, and a flash of light visible in the dark, and with a considerable exertion of expansive force. It has been ascertained by experiments made with caution on small quantities of it, that in its detonation nitrogen gas is disengaged with watery vapour, metallic gold intermixed with the purple oxide remaining; if heated very gently, so as to decompose it without detonation, ammonia is exhaled; the precipitate, therefore, is a compound of ammonia and oxide of gold, and its detonation is owing to the re-action of the elements of these, the oxygen of the oxide combining with the hydrogen of the ammonia, and forming watery vapour, the nitrogen of the ammonia escaping from the combination, and the elasticity of both being augmented by the extrication of caloric which probably attends these new combinations.

Gold having a weak affinity to oxygen, its saline compounds are easily decomposed by substances which de-oxidate their base. Thus the muriate of gold is reduced by

exposure to light, and by the agency of hydrogen, charcoal, and other inflammables. It is also decomposed partially or entirely by other metals; zinc, iron, and copper, throw down the gold in its metallic state; others precipitate it in the state of the purple oxide. Even some metallic salts, prepared so as to be at the *minimum* of oxidation, occasion similar decompositions. A solution of green sulphate of iron reduces the gold entirely to the metallic state, from its power of attracting oxygen. A solution of tin in nitro-muriatic acid, prepared so as to be in a low state of oxidation, throws down a purple precipitate: this is a compound of the oxides of the two metals, the oxide of tin attracting a portion of oxygen from the oxide of gold; both by this change in the state of oxidation become insoluble in the acid in which each was dissolved; and exerting at the same time a mutual affinity, they are precipitated in combination. This precipitate has been long used, under the name of *Purple Powder of Cassius*, to give a red colour to ornamental glass.

Another decomposition rather singular which muriate of gold suffers, is that from the action of essential oils, alkohol, or ether. If a portion of essential oil be mixed with its solution, the watery portion is separated, the muriate of gold combines with the oil, and this combination can be dissolved in alkohol, forming a preparation known by the name of Potable Gold, which, from its comparative mildness, has sometimes been taken internally, when gold was supposed to possess medicinal powers. From these solutions the gold is gradually precipitated in its metallic

state, the oxygen of the oxide being attracted by the hydrogen of the essential oil.

Gold does not combine with sulphur by fusion, but if melted with an alkaline sulphuret, as sulphuret of potash, a combination is formed, as has already been remarked, which is soluble in water. This solution is decomposed by acids, and the gold is precipitated, whether in a metallic or oxidated state is uncertain, in combination with sulphur. The alkaline hydro-sulphurets also throw down a precipitate from the solution of muriate of gold.

Gold unites with a small portion of phosphorus, the compound is white and brittle, is fusible, and easily decomposed by heat.

With the greater number of the metals it forms alloys; those of them which are of any importance will be noticed under the history of the metals from which they are formed. In general, in these combinations, either its ductility or colour is much impaired. Copper and silver are those which change it least, and as copper renders it harder, this alloy is used for many of the purposes to which gold is applied, such as the fabrication of coin and ornamental vessels or trinkets. The standard gold of this country has an alloy of copper of one part in twelve. Lead, bismuth, and antimony, even in very minute quantity, render gold quite brittle, so that even the vapour rising from these metals in fusion, coming in contact with melted gold, has this effect. Quicksilver too renders it brittle, penetrates it rapidly, and when in sufficient quantity, dissolves it.

Gold, as the most valuable of the metals, is employed as the medium of exchange, which regulates the value of the

others. It is used for many ornamental purposes under different forms. There are various modes, too, of covering the surfaces of bodies with it for similar purposes. The gilding of metals is performed in the most substantial mode, by applying an amalgam of gold and silver to the metal designed to be gilt, generally silver or copper, its surface being previously cleaned and brushed over with a dilute solution of quicksilver in nitric acid, so that a thin film of quicksilver shall be deposited on it, which favours the adherence and union of the amalgam. The quicksilver is volatilized by the application of a slow and equable heat, and the gold remains covering the surface. Other kinds of gilding on metals less substantial, are executed by rubbing the gold in a state of extreme mechanical division, on the surface of the metal heated, or by applying a solution of muriate of gold. Steel is gilt by dipping it in a solution of muriate of gold in ether. Gold leaf is applied to wood, paper, &c. by an adhesive paste: and glass and porcelain are gilded by applying gold by the medium of borax, which vitrifies with a moderate heat.

CHAP. II.

OF SILVER.

Silver is a metal, which, like gold, is rendered valuable by its colour and lustre, its great ductility and malleability,

and not being liable to oxidation from exposure to the air. It is liable, however, to tarnish, by which the beauty of its colour and its lustre are diminished, a change, owing to the operation of minute quantities of sulphuretted hydrogen, diffused through the atmosphere from animal effluvia. Its comparative scarcity has added to its value, and rendered it the medium of exchange next in value to gold.

Silver is found native and mineralized: the substances by which it is usually mineralized, are oxygen, sulphur, muriatic and sulphuric acids, forming, in various states of combination and mixture, a number of ores. Native silver is extracted from the earthy matter mixed with it by washing and amalgamation, the quicksilver with which it has been amalgamated being abstracted by distillation. Its ores are subjected to various processes, principally roasting, and fusion in contact with the fuel. The metallic matter obtained is afterwards melted with lead, and refined by the process of cupellation, as has been described under the history of gold.

Silver has a colour approaching more nearly to pure white than any other metal; its lustre is considerable, and it is peculiarly sonorous, and gives, when struck, a very clear sound. In malleability it is inferior only to gold; in ductility it is equal or nearly so to that metal: it is harder and more elastic than gold; its specific gravity is 10.5.

Silver melts at 22° of Wedgwood's scale; by slow cooling it can be crystallized in octaedrons: it expands consi-

derably in becoming solid. By a very powerful heat, it is volatilized.

Silver, as well as gold, was supposed to suffer no change from the action of atmospheric air at a high temperature. The practicability of its oxidation, however, has been sufficiently established. An electric discharge transmitted over silver leaf, or silver wire, by the high temperature it suddenly excites, gives rise to the formation of vitrified oxide; in the circuit of a powerful galvanic battery, silver leaf burns with great splendour; and its oxidation with the phenomena of combustion is effected, by subjecting it to the intense heat excited by a stream of oxygen gas, directed on burning charcoal, or mingled with hydrogen gas kindled; an oxide of a dark colour is obtained by these processes. Another of a lighter colour is obtained by precipitation from its solution in nitric acid, which, it has been stated, contains 10 parts of oxygen in 100 parts. These oxides are reduced by the operation of an elevated temperature, and the silver is obtained in its metallic form.

Silver is oxidated by several of the acids, which at the same time combine with its oxide. Nitric acid is its proper solvent; but in effecting its solution, the singular phenomenon is displayed which the same acid exhibits with regard to some other metals, and of which no satisfactory explanation has been yet given,—that when concentrated it has no sensible effect on the metal, while the addition of a very small quantity of water causes the action instantly to commence, whence the oxidation and solution of the metal proceed. The solution of silver in diluted nitric acid has at first a greenish colour; but if the silver has been

pure, and in particular free from copper, this arising merely from the presence of a little nitric oxide, soon disappears, and the solution becomes colourless. By evaporation, it affords white tabular crystals, which consist of 64 of oxide of silver, 22 of acid, and 14 of water. This salt is abundantly soluble in water; it acts as a caustic very rapidly on animal matter, and fused and run into cylindrical moulds, it forms the lunar caustic of surgeons, which is in common use as an escharotic, powerful in its action, and easily applied and regulated. It is partially decomposed by heat, and likewise by light; it detonates when heated with combustible bodies, and with some of them, as phosphorus, it detonates on percussion.

The other salts of silver are obtained most easily by adding to the solution of nitrate of silver a solution of a neutral salt, containing the acid with which the oxide of silver is designed to be combined. Thus the sulphate is formed by adding to the solution of nitrate of silver, a solution of sulphate of potash or soda. It is also formed by boiling the sulphuric acid on silver, the acid being decomposed at this temperature, communicating oxygen to it, and combining with the oxide. The sulphate of silver is very sparingly soluble in water; by boiling water upon it, a minute quantity is dissolved, and slender crystals are obtained by cooling.

Muriate of silver can scarcely be obtained from any action of muriatic acid on metallic silver, but it is instantly formed on the addition of the solution of any muriate to the solution of nitrate of silver, and being insoluble, is precipitated. From the extreme insolubility of this salt,

it is the re-agent of greatest delicacy in detecting the presence of muriatic acid. It affords also the most delicate test of the chemical agency of light, being blackened by exposure for a few minutes to the rays of the sun. It is very fusible, melting on the application of a moderate heat in a glass matrass; on becoming solid from cooling, it retains a degree of transparency, is of a pearly colour, is soft, and to a certain extent malleable and fusible; whence, from its resemblance in these properties to horn, it received from the older chemists the name of Luna Cornea, or Horn Silver. By exposing it to a strong heat, it is decomposed; both the acid and oxygen are expelled, and the silver is recovered in its metallic form. The reduction is favoured by the presence of a small portion of alkali; one part of the sub-carbonate of potash is added to four parts of the muriate, the mixture being exposed to a red heat in a crucible, or rather in a phial within a crucible, surrounded with sand; and this affords the best process for obtaining pure silver.

Oxymuriatic acid acting on silver, communicates to it oxygen, the muriatic acid uniting with the oxide so as to form merely the common muriate. A hyper-oxymuriate of silver can be formed, however, by transmitting a current of oxymuriatic acid gas through water in which oxide of silver is diffused. This salt is abundantly soluble in water, and crystallizes in rhombs; it is also soluble in alkohol. It is melted and decomposed by heat. It detonates by percussion with inflammable bodies.

Phosphate of silver is insoluble in water, and is hence precipitated copiously when a solution of phosphate of

soda is added to a solution of nitrate of silver. Carbonate of silver, obtained by the addition of an alkaline carbonate in a similar manner, is likewise sparingly soluble; as are the fluate and borate of silver. The carbonate is blackened by light, and is decomposed by heat, affording metallic silver.

The salts of silver are decomposed by the alkalis and earths. From nitrate of silver, potash throws down a yellowish precipitate, probably a sub-nitrate; and the action of soda and lime is similar. The precipitate from the addition of ammonia is grey or black, but it has not, like the precipitate from the solution of gold by ammonia, any detonating power.

A fulminating silver can be prepared, however, which far exceeds the fulminating gold, or indeed any other fulminating preparation, in power. The process was given by Berthollet; it consists in dissolving silver in nitrous acid, diluted with three parts of water; to the solution, poured off from any undissolved matter, lime-water is added as long as any precipitation is occasioned, avoiding any excess of it; the precipitate is washed with distilled water, and dried by exposure to the air. This precipitate is stirred in liquid ammonia; the liquor is poured from the insoluble matter; on exposure to the air, a pellicle forms on its surface which at length subsides. This is the fulminating silver; such is its tendency to explosion, that it cannot be touched, the slightest impulse or agitation causing it to detonate; and so violent is the detonation, that the experiment cannot be made with safety on a quantity larger than a grain. The theory of its detonation is consider-

ed as similar to that of fulminating gold: it probably consists of oxide of silver and ammonia, the whole elements being united by affinities so nicely balanced, that the slightest external force subverts them, and causes new combinations: the oxygen of the oxide unites probably with the hydrogen of the ammonia, and forms watery vapour: the nitrogen must at the same time assume the elastic form, and the augmentation of elasticity in these products, by the caloric suddenly extricated, may be the cause of the violence of the detonation. The superiority of this preparation in detonating power to fulminating gold, may be owing to the oxide of silver containing a larger proportion of oxygen, and combining with a larger quantity of ammonia, so that there are condensed in the fulminating silver, a larger quantity of the elements disposed to enter into the combinations whence these elastic products are evolved.

Another fulminating silver is prepared by a process similar to one by which a fulminating quicksilver is prepared, to be afterwards described; but it is considerably inferior in detonating power.

The salts of silver are decomposed by inflammable substances, and by the greater number of the metals, the oxygen being attracted from the oxide, which is their base, and the silver precipitated in the metallic form. Among the metals, copper and quicksilver produces this precipitation with great facility, probably from the mutual affinity exerted between the precipitating and the precipitated metal. Copper is thus employed to recover silver from its solution in nitric acid, as a mode of obtaining it free from other

metals, the small quantity of copper with which the precipitated silver may be alloyed, being removed by cupellation. Quicksilver employed in a peculiar manner in the precipitation of silver, causes its crystalline arrangement, similar in appearance to arborescence, hence forming what has been named Arbor Diannæ. The simplest mode is to dissolve along with the silver half its weight of quicksilver in nitric acid, and to drop into this solution, diluted with forty-eight times its weight of water, a small piece of a soft amalgam of silver; filaments of reduced silver soon shoot out from the amalgam.

Silver combines by fusion with sulphur, forming a compound of a very dark violet colour, with a certain degree of metallic lustre, opaque, soft, and brittle. Sulphuretted hydrogen tarnishes silver very rapidly, and from its continued action, thin scales of sulphuret of silver are formed. A precipitate probably of a similar nature is thrown down from the salts of silver, by the hydro-sulphuretted alkaline solutions. The alkaline sulphurets, fused with silver, form a compound soluble in water, from which the acids precipitate sulphuret of silver.

Silver and phosphorus may be combined by the general process which has been already described, as affording the easiest mode of uniting phosphorus with the metals. This phosphuret is white, of a granular structure, soft and brittle.

Silver unites with the greater number of the metals, suffering in general a diminution in its ductility and malleability, but acquiring frequently a greater degree of hardness. It unites with gold without any loss of ductility, while it

communicates to the gold hardness and elasticity; when in a large proportion, however, it debases its colour. When the silver amounts to one-fifth of the mass, the colour is green, and this alloy is used for ornamental purposes. The alloy of gold and silver being more fusible too than gold, is employed in soldering this metal. Copper added in small proportion to silver, renders it harder without much impairing its ductility, and hence this addition is usually made when it is to be fabricated into coin or plate. The standard silver of this country contains one-sixteenth of copper.

Silver is used as the medium of exchange next in value to gold, and is applied to ornamental purposes, to which it is well adapted by its lustre, and the purity and beauty of its colour. It is applied to the surface of other metals in various modes. The most substantial plating is a mechanical operation; a thin plate of silver being applied to a bar of copper, with a little borax between them to facilitate their union, when a sufficient heat is applied; the bar is afterwards passed through the rolling press; it is extended, and the silver, from its greater malleability, is likewise extended so as to cover the surface of the copper. Other modes are, to apply an amalgam of silver to copper, driving off the quicksilver afterwards by heat, or by rubbing on the surface mixtures of oxide or muriate of silver with muriate of soda, or ammonia, or supertartrate of potash, and applying heat so as to favour the reduction of the silver on the surface of the copper, and its adhesion on it. The silver is recovered from its intermixture with copper, by boiling them in sulphuric acid, the sulphate of copper which is

formed being removed by washing, the sulphate of silver remaining insoluble; or by substituting for sulphuric acid, a mixture of it with nitric acid, or, what is more economical, with nitre; this mixed acid dissolving silver without dissolving copper.

The solution of nitrate of silver is used in analytic chemistry, to discover the presence of muriatic acid in any state of combination. Largely diluted, it forms what is named indelible ink, employed in marking linen which is to be bleached, lines traced with it becoming dark on exposure to light.

CHAP. III.

OF PLATINA.

This is a metal of modern discovery, the produce of the mines of Peru, and occurring always in the native state, generally in small grains of metallic lustre, a greyish white colour, ductile and malleable, and having a specific gravity not less than 17. It is mixed with various earthy and metallic fossils, and is alloyed with a small quantity of iron, so as to be sensibly magnetic. But besides these foreign substances, it has within these few years been discovered, that there occur with the metal to which the name of platina is still appropriated, others not previously known; and

the existence of not less than four distinct metals has been supposed to be established by these researches. The history of these may be delivered after the history of platina itself.

It is to be remarked, however, in proceeding to the history of this metal, that if the conclusions with regard to the existence of these other metals be just, the properties of platina in a state of purity are not exactly known; for in any process which has been employed to obtain it from its native state, though they may be in part abstracted, it must retain an alloy of one or more of them to a greater or less extent.

Platina in its native form is so infusible, that the grains can scarcely be agglutinated by the application of even the most intense heat; other methods therefore are necessary to obtain it in the state of a metallic mass. The one which has been usually followed, is to dissolve crude platina in nitro-muriatic acid; on adding to this solution a solution of muriate of ammonia, a precipitate is thrown down, consisting of the oxide of platina in combination with portions of muriatic acid and ammonia: on urging this precipitate with a fire gradually raised to an intense degree, the acid and the ammonia are expelled, the oxide is reduced, and a spongy metallic mass obtained, which, by pressure or percussion while at a red heat, is rendered more dense. The metal in this state is still, however, in general so imperfectly agglutinated, and it is at the same time so infusible, as not to be easily worked. It is therefore subjected to other methods. One of the most practicable in the large way, is to alloy it with arsenic, by whch it is rendered so fusible

as to be easily cast into bars, and the arsenic being afterwards volatilized by exposure to a fire gradually raised, until the platina is obtained malleable. Another is, to combine the spongy metallic platina with quicksilver; the solid amalgam is moulded when soft in bars, it quickly becomes hard, and is afterwards exposed to a heat under a muffle sufficient to dissipate the quicksilver. It is then strongly ignited, until it is sufficiently ductile to admit of being laminated and forged. It is obvious that, as obtained by any of these methods, it must be alloyed to a certain extent with the metals naturally associated with it.

Platina, in the dense state into which it is brought by the usual processes, is of a white colour, with a slight shade of grey, with metallic lustre: in hardness it is superior to the greater number of the metals; it is very malleable, though its hardness prevents it from being easily extended in leaves; it is highly ductile, and can be drawn into very fine wire. Its specific gravity exceeds that of the other metals; and hence it is the heaviest known substance; the specific gravity has been estimated from 20.8 to 24; and it must vary according as it has been more or less hammered, and as it is more or less alloyed. It suffers less expansion from heat than the other metals in general do, and it is also inferior to them in conducting power.

Platina is a metal extremely infusible. The point at which it melts exceeds that at which the pyrometrical pieces of Wedgewood cease to contract, and cannot therefore be exactly estimated; it has been supposed to be higher than 150, or even 160, of the scale of this pyrometer. By the aid of fluxes, as of borax, its fusion may be effected

with more facility. It so far partakes of the property of welding, otherwise peculiar to iron, as to soften, while at the same time it remains ductile at a heat much inferior to that necessary to melt it; whence two pieces of it by forging can be united firmly together.

Platina is not very susceptible of oxidation. Its lustre suffers no diminution from exposure to air or humidity; nor does it lose its metallic qualities when exposed even to intense heats, with the admission of atmospheric air. By a very intense heat, however, suddenly applied, as that from the discharge of an electrical battery, by which it is not only fused but volatilized, it is oxidated. It suffers also oxidation from the action of nitre at a high temperature. Mr Chenevix endeavoured to estimate the proportion of oxygen in the oxides which exist in its saline compounds. Having decomposed the nitrate of platina by heat, he obtained an oxide of a yellow colour, which by a higher heat was reduced to the metallic state. This oxide, he concluded, consists of 87 of metal and 13 of oxygen. In the progress of its reduction, it assumed at one stage of the process a green colour, remaining so for some time. This he supposed to denote a different degree of oxidation, and the proportion of oxygen in this green oxide he estimated at 7 in 100 parts.

Platina is scarcely acted on by any of the acids, but the nitro-muriatic, and the oxy-muriatic: even nitric acid boiled on it, does not change its lustre. Nitro-muriatic acid is its proper solvent, and the muriate afforded by this solution is the only salt of this metal that has been particularly examined. When the acid is composed of three parts of

muriatic, and one of nitric acid, it dissolves the largest proportion of the metal: as the mutual action proceeds, a black powder is deposited, which consists principally of some of the foreign metals contained in native platina. The solution is of a dark reddish-brown colour, and by evaporation it affords crystals of the same colour, but usually of various shades.

This solution is decomposed by the alkalis; when a solution of potash is added, in a short time small reddish octohedral crystals are deposited; if an additional quantity of alkali be afterwards added, a yellow flocculent precipitate is thrown down. Ammonia gives rise to similar results. Soda throws down only the yellow precipitate. These precipitates are ternary compounds of oxide of platina, with a portion of muriatic acid, and of the alkali by which the precipitation has been produced; there being also present in their composition, a small quantity of one of the metals associated with native platina, as is immediately to be stated.

From the nature of these precipitates, they are likewise formed by adding to the solution of muriate of platina, a solution of a neutral salt containing these alkalis. Thus precipitates are formed by muriate of potash, or muriate of ammonia, and even by the sulphates or nitrates of these alkalis. This kind of precipitation of the solution of platina by a neutral salt containing the same acid, as the acid of the solution, being rather uncommon, has been frequently the subject of investigation with chemists, the facts with regard to it were found difficult of investigation, and it is only lately that they have been elucidated.

From the addition of muriate of ammonia to a solution of platina in nitro-muriatic acid, it was known that precipitates were successively thrown down of different shades of colour, being at first of a light yellow, becoming afterwards deeper, and at length of a reddish-brown. These were supposed to arise from different degrees of oxidation, but it has been established by the experiments of Descostils, and of Fourcroy and Vauquelin, that the difference arises from the presence of one of the metals associated with native platina, that which has been named iridium: the red precipitate is a ternary combination of the oxide of this metal with muriatic acid and ammonia; the yellow precipitate is that which platina, apart from this metal, gives from the action of muriate of ammonia; and it too is a ternary compound, being composed of portions of the acid and alkali with the oxide of platina. The black powder, which separates during the solution of crude platina in nitro-muriatic acid, consists principally of this iridium; and the more perfectly it has been separated, the colour of the red precipitate produced by the addition of muriate of ammonia to the solution is less intense; and it is to the same substance that the dark colour of the crystals obtained by the evaporation of the solution of platina is owing. It is only from the yellow precipitate, submitted to reduction by the application of heat, that platina pure, or at least free from iridium, can be obtained.

The solution of muriate of platina is decomposed by several of the metals and metallic salts, which de-oxidize it partially or entirely. Muriate of tin is, by an action of this kind, a very delicate test of it, a bright red colour being

assumed when a few drops are added to the solution of platina, diluted with a very large quantity of water. It is not precipitated, as the greater number of metallic salts are, by prussic acid, or the prussiates.

Platina and sulphur do not unite by fusion, owing probably to their weak mutual affinity, and the extreme infusibility of the metal. It combines, however, with the alkaline sulphurets; and sulphuretted hydrogen added to its solution causes a precipitation.

It combines with phosphorus; the compound is of a silvery-white colour, brittle and very hard; it is fusible, and when urged by a strong heat, is decomposed, the phosphorus being expelled; hence the combination with phosphorus has been employed as a method of rendering platina fusible and capable of being worked.

Platina combines with the greater number of the metals; but our knowledge of its real alloys is altogether imperfect, from platina, as hitherto employed in these combinations, having been used alloyed more or less with the metals with which it is naturally associated. With gold an alloy is formed of a yellowish-white colour, highly ductile and elastic, and of a specific gravity of 19. The alloy with silver is of a dull colour, and harder than pure silver. With quicksilver platina was supposed not to combine, but the amalgamation can be effected when the platina is in that spongy state in which it is procured by the decomposition of the ammoniaco-muriate by heat.

Platina is a metal of considerable value, from its hardness, its infusibility, and not being liable to be acted on by the greater number of chemical agents. It is from these

qualities adapted to many chemical purposes, and hence is employed in the construction of tubes, evaporating basons, and crucibles, and in the form of wire for galvanic experiments. From its infusibility, it is adapted by its expansion to measure high temperatures, and it has accordingly been applied as a pyrometer. From its property of suffering less expansion than other metals from heat, and not being liable to rust, it is superior to others for the construction of the pendulum-spring of watches. Other metals, copper for example, can be covered with a coating of it, by applying an amalgam prepared from the trituration of the spongy platina with five parts of quicksilver, to the surface of the copper, and applying heat so as to favour the volatilization of the quicksilver, and the adhesion of the platina. Brass or steel may be coated with platina by a process similar to that by which they are gilded,—adding sulphuric ether to a solution of platina, removing the etherial solution from the acid liquid beneath it, and dipping into this the polished steel or brass. Platina has also been applied to porcelain-painting, by means of the flux by which gilding or painting is effected, and serves to diversify the painting with gold.

CHAP. IV.

OF IRIDIUM.

This is the first of the metals which, it has been stated, have beenl ately discovered to exist in native platina; and of which, as our knowledge is still imperfect, and their claims to the rank of distinct metals are not altogether certain, it will be sufficient to give a general account, without much minuteness of detail.

Iridium constitutes the principal part of the black powder which is deposited during the solution of the grains of native platina in nitro-muriatic acid, and which, in part dissolved, communicates to the solution and the crystals it affords by evaporation, a red colour. It may therefore be obtained, either from the black powder, or from the dark red precipitate which is thrown down from the solution, by the addition of muriate of ammonia, and which consists chiefly of the oxide of this metal, with portions of ammonia and muriatic acid.

It is obtained from the precipitate by the action of heat alone, the acid and ammonia being expelled, and the oxide reduced; the black powder affords it with the same facility: when heated merely before the blow-pipe, it loses its black colour, and becomes white, and acquires metallic lustre: when fused with borax, it forms white metallic

scales. In this state, however, the metal is not perfectly pure, it has an alloy of iron, and of another metallic substance, which Vauquelin supposed to be chrome, but which Tennant has inferred is a new metal, which he has named Osmium. To obtain the iridium free from these, more complicated processes are necessary, consisting primarily in subjecting the black powder to the alternate action of potash in fusion, and muriatic acid; the alkali dissolving the other metals, the acid dissolving the iridium with a portion of iron. From the muriatic solution, the iridium may be obtained, by precipitating it in its metallic form by immersing plates of zinc in the solution; or by evaporating the solution to dryness, removing the muriate of iron by alkohol, and afterwards reducing the muriate of iridium by exposure to heat; or lastly, simply by evaporating the muriatic solution to dryness, dissolving it again in water, and by a second operation, obtaining from it octaedral crystals; these, by exposure to heat, afford iridium.

This metal is of a white colour, brittle, hard, and easily reduced to powder; it is fused and volatilized by heat, it is also oxidized; by applying a strong heat to crude metallic platina in an earthen retort, a sublimate of a blue colour is obtained, which is oxide of iridium; or by calcining the metal with potash, its oxide is formed by the action of the air, and combines with the alkali. In its saline combinations, it also displays phenomena, which appear to prove its existence in different states of oxidation. Thus the solution of it in muriatic acid, is of a deep green colour: by mere dilution with water, it becomes

blue; when heated it becomes red; and when in this state it is submitted to the action of substances capable of deoxidating it, the red colour is removed, and the green or blue restored. It is from these changes of colour, which are characteristic of this metal, that Mr Tennant named it Iridium.

Iridium, in its metallic state, is scarcely acted on by any acid; even the nitro-muriatic acid, with the assistance of heat, dissolves a very small portion of it: it is more soluble when alloyed with platina. When it has been oxidated by exposure to the air, aided by the action of potash at a high temperature, it dissolves easily in the acids; the solution in nitric acid is of a red colour; in sulphuric or muriatic acid it is green or blue, according to the state of dilution: the alkalis throw down from these solutions precipitates of the same colour. The greater number of the metals give rise to a dark-coloured precipitate, and remove the colour of the solution. Sulphuretted hydrogen has a similar effect.

This metal does not unite with sulphur by fusion. It combines with some of the other metals; both gold and silver alloyed with it remain malleable; the iridium is not separated by cupellation, but only by solution in nitro-muriatic acid.

CHAP. V.

OF OSMIUM.

In submitting the black powder which is precipitated during the solution of native platina in nitro-muriatic acid, to the action of potash or soda, at a high temperature, the metallic matter is oxidated; and while one portion of it becomes soluble in muriatic acid, another portion of it enters into union with the alkali, forming a compound which is soluble in water. The latter Mr Tennant has regarded as the oxide of a new metal, to which, from the strong smell it has in its oxidated state, he has given the name of Osmium.

Th oxide of osmium, obtained in combination with the alkali by the above process, is separated by the addition of an acid; and, what is a very singular property, it can be obtained in solution in water by distillation. The solution is limpid, has a sweetish taste, and a pungent peculiar smell. It does not redden the vegetable colours, but paper stained with the colour of violet, exposed to the vapour arising from it, loses much of its blue tinge, and becomes grey. This oxide is obtained in a more concentrated state, by distilling the black powder from crude platina with nitre; a fluid of an oily appearance distils over, which on cooling forms a colourless semi-transparent

solid mass, soluble in water. This concentrated solution stains the skin of a dark colour.

Oxide of osmium parts with its oxygen without difficulty. It becomes black when diffused in alkohol or ether, and soon separates in black films. The greater number of the metals deprive its solution speedily of smell, and a black or grey oxide is precipitated, consisting of the osmium in a metallic state, with the oxide of the metal by which it has been precipitated. If quicksilver be employed to precipitate it, an amalgam is obtained; by applying a sufficient heat the quicksilver is volatilized, and a powder remains, of a dark grey or blue colour, which is metallic osmium. This is the process by which Mr Tennant procured it. The metal he found not to be very fusible nor volatile; exposed to a strong white heat in a cavity in a piece of charcoal, it was not melted, nor did it suffer any apparent alteration. When heated in a similar manner with gold, or with copper, it melted, and formed alloys with these metals. When heated wit the access of air, it is oxidated, and the oxide evaporates, diffusing its peculiar smell.

In its metallic state, osmium does not appear to be acted on by the acids, not even by the nitro-muriatic acid. By exposing it to heat with potash it is oxidated, and enters into combination with the alkali, forming a compound soluble in water, from which the oxide may be precipitated by acids.

A striking property by which this metal in its oxidated state may be recognized, is displayed in the action of infusion of galls upon it. Added to its solution, it produces a

purple colour, which soon becomes of a vivid blue. The solution of oxide of osmium become yellowish, on the addition of pure ammonia, or of carbonate of soda; and a bright yellow is acquired from the action of lime. The peculiar smell, and the volatility of this oxide, are still more characteristic, and undoubtedly distinguish it from every other substance.

CHAP. VI.

OF RHODIUM.

Dr Wollaston, submitting to examination the liquid which remains after the precipitation of the solution of crude platina in nitro-muriatic acid by muriate of ammonia, found reason from his experiments to conclude, that it contained two new metals, one which he named Rhodium, the other Palladium. The following is the process by which these were separated, and the present metal, rhodium, obtained.

Crude platina, having been dissolved in nitro-muriatic acid, was precipitated by muriate of ammonia. In the remaining liquid, to which the water with which the precipitate was washed was added, a piece of zinc was immersed, until no farther action appeared to be exerted on it. The iron contained in the crude platina remained in solution: the other metals had been precipitated in a black

powder, estimated to amount to betweeen 40 and 50 grains. This precipitate, which by previous experiments was known to consist of platina, rhodium, palladium, copper, and lead, was digested in very dilute nitric acid, by which the two latter metals were removed. The remainder was digested in nitro-muriatic acid, which dissolved the greater part. To the solution was added 20 grains of common salt; and when the whole had been evaporated to dryness with a gentle heat, the solid matter, consisting of the triple salts of soda and muriatic acid, with oxide of platina, of palladium, and rhodium, was washed repeatedly with alkohol, till it came off nearly colourless. There remained undissolved the triple salt of rhodium, which is thus freed from all metallic impurities. When dissolved in water, and decomposed by zinc, a black powder was obtained, in quantity corresponding to about 4 grains from the 1000 grains of crude platina dissolved. This powder, exposed to heat, continued black; with borax it acquired a white metallic lustre, but appeared infusible by any degree of heat. Like platina, it is rendered fusible by arsenic, as it also is by sulphur: the arsenic, or the sulphur, is expelled by a continuance of the heat; but the metallic button obtained does not become malleable. Its specific gravity, as far as could be ascertained, appeared to exceed 11.

From the triple salt of oxide of rhodium, soda, and muriatic acid, the pure alkalis throw down a yellow oxide, which is dissolved by adding an excess of alkali. It is also soluble in the acids; its solution in muriatic acid does not crystallize by evaporation; muriate of ammonia or of

soda causes no precipitation from it; the solution in nitric acid also does not crystallize; the rhodium is precipitated from it by silver, copper, and other metals.

Rhodium unites with all the metals, quicksilver excepted. Its alloys with gold and silver are malleable; the colour of gold is little altered, even when the rhodium amounts to one-sixth of the mass. In dissolving it in nitro-muriatic acid, the rhodium remains undissolved.

The properties assigned to this metal are not very distinctive, and it is not very improbable that it may be an alloy of some of the others.

CHAP. VII.

OF PALLADIUM.

This metal exists with rhodium in the liquor remaining after the solution of native platina has been precipitated by muriate of ammonia; and in the process already described under the history of rhodium, it has been remarked, that the soda-muriate of palladium being soluble in alcohol, while that of rhodium is insoluble, they are thus separated from each other. To the solution of the former salt, muriate of ammonia is added to precipitate any platina that may be present. There is then added to it prussiate

of potash, which throws down a precipitate of a deep orange colour. This dried and exposed to heat affords a metallic residuum, which, when heated with borax, acquires metallic lustre, but does not melt before the blowpipe; a little sulphur added to it causes its fusion: from the globule thus obtained, the sulphur is expelled by urging it with the flame, and a spongy malleable mass remains. Dr Wollaston, the discoverer of this metal, has given other processes to procure it. One of the most simple is, to add to a solution of crude platina a solution of prussiate of mercury; a occulent precipitate of a yellowish colour gradually accumulates; this is prussiate of palladium, and when decomposed by heat, it affords the metal in a pure state.

Palladium is of a greyish-white colour, and when polished has considerable lustre; it is ductile and very malleable; in hardness it is superior to forged iron; its specific gravity is from 11 to 11.8; like platina, it is less expansible, and is a less perfect conductor of heat, than the greater number of the metals. It requires a heat of a considerable intensity to fuse it. Heated under exposure to the air, it is not oxidated, and its oxides obtained by other methods are reduced by heat.

This metal is acted on by a number of the acids. Nitric, sulphuric, muriatic, and nitro-muriatic acids, acquire from it a rich red colour, and dissolve a portion of it. These solutions are decomposed by the alkalis and earths, precipitates of an orange colour being thrown down, which are partly re-dissolved if the alkali is added in excess. The sulphate, nitrate, and muriate of potash, or of am-

monia, produce precipitates likewise of an orange colour from the saturated solutions of the salts of palladium, which are triple salts.

The alkalis act on palladium even in its metallic state. Exposed to the action of melted potash, it loses its lustre and part of its weight, and part of the metal is oxidated and combined with the alkali. Ammonia digested on it acquires a bluish tinge, and holds a small portion of oxide in solution, the oxidation in these cases being formed by the action of the air.

All the metals, with the exception of gold, silver, and platina, precipitate palladium in its metallic state from its saline solutions. Green sulphate of iron also throws it down. Muriate of tin forms a precipitate of a dark orange or brown colour; sulphuretted hydrogen gives a precipitate of a dark brown colour; prussiate of potash one of an olive colour; prussiate of mercury, a precipitate of a yellowish white colour; and as this re-agent does not precipitate platina, this affords a very good test to distinguish between these metals. This precipitate by prussiate of mercury from the nitrous solution of palladium explodes when heated to 500° of Fahrenheit.

Palladium combines with sulphur, and is instantly fused when sulphur is thrown upon it at a high heat. The sulphuret is white and brittle.

It forms combinations with a number of the metals. Its alloy with gold is of a grey colour, harder than gold, but less ductile even than the palladium. Its alloy with silver is likewise grey and hard. Platina and palladium enter into fusion at a heat not higher than that at which palladium

itself melts, and an alloy is formed similar to the preceding in colour and hardness. Its other alloys are likewise in general hard and brittle.

Palladium had been supposed by Mr Chenevix to be an alloy of platina and quicksilver; and there are some facts established by his experiments, and those of some other chemists, which prove that these two metals, by combination, modify very powerfully the properties of each other, and acquire even some of those characteristic of palladium, particularly that of being precipitated in the metallic state by sulphate of iron. The synthetic experiment of the formation of palladium has not succeeded, however, with other chemists; no analytic experiment has been successful in establishing its composition, and its properties appear to be sufficiently characteristic to entitle it to be ranked as a distinct metal. This interesting discovery is still farther confirmed by that lately made by Mr Cloud, that it exists apart from platina, forming a native alloy with gold; and Dr Wollaston has also observed it in a distinct form in the grains of native platina.

CHAP. VIII.

OF QUICKSILVER, OR MERCURY.

This is distinguished from all the metals by its perfect fluidity at common natural temperatures: it becomes solid at —39° of Fahrenheit, and has then considerable mal-

leability. In its liquid state it is perfectly opaque, and has the metallic lustre; its specific gravity is 13.5. In passing to the solid state it suffers considerable condensation, equal, as has been calculated, to $\frac{1}{33}$ of its volume: this gives its specific gravity in the solid state, at 14.17; by actual experiment, it has been found to be 14.46. In its congelation, it assumes a crystalline structure, and it can even be obtained in small octaedral crystals.

Quicksilver occurs native in small quantity. Its usual state is mineralized by sulphur; and from this ore it is extracted by distillation, the separation from the sulphur being facilitated by the intermedium of lime or iron. It is also purified by distilling it a second time from a portion of iron filings.

The temperature at which quicksilver is volatilized under a middle atmospheric pressure, is between 600° and 700° of Fahrenheit, being stated on different authorities at 655°, 660°, and 672°.

At the same temperature as that at which it is volatilized, it is oxidated by the action of atmospheric air. When kept boiling gently, its lustre diminishes, a film forms on its surface, and small scales of a brick-red colour accumulate, the oxygen of the air being at the same time absorbed. The operation is not easily conducted without loss from the volatilization of the mercury; but it is best performed in a glass matrass, with a shallow bottom, and the neck drawn out to a small aperture, a small quantity only of quicksilver being put into it, and the heat being applied steadily by a sand-bath. This red oxide contains

7 of oxygen in 100 parts; it is reduced by the heat of ignition to the metallic state.

There is also reason to conclude, that quicksilver is susceptible of oxidation, even at natural temperatures. It is to be regarded as a metal in a state of fusion; and in this state, the cohesion being so much diminished, the greater number of the metals combine with oxygen. From quicksilver, by agitation continued for some time, a grey powder is obtained, which some have regarded as the metal mechanically divided, but which it is more probable is an oxide, as it is soluble in muriatic acid, which quicksilver is not. This oxidation appears to be effected with more facility, when the continuity of the quicksilver is interrupted, and its surface extended by the interposition of any viscuous matter, as mucilage, honey, or fat; and in this way are formed a number of medicinal preparations, the efficacy of which depend on this oxide. The proportion of oxygen in its composition has been estimated at 4 in 100 parts.

Besides these oxides, it appears to be proved, that mercury exists in other degrees of oxidation in its saline combinations; though the precise proportions are not easily determined. Thus there are two muriates of mercury, differing in the degree of oxidation. The oxide in one of them, Mr Chenevix inferred, contains 15 of oxygen in 100 parts, that in the other 10.7. Another chemist, Zaboada, has more lately inferred, that the oxide in the former contains not more than 10 parts, and that in the latter little more than 5 in 100 parts. The degrees of

oxidation in the solutions of the metal in nitric acid, appear to be more numerous, and probably even indefinite.

The greater number of the acids act on quicksilver, or at least are capable of combining with its oxides.

Sulphuric acid exerts little action upon it in the cold, but if heat be applied it is decomposed, the quicksilver is oxidated, sulphurous acid is disengaged, and the oxide combines with the remaining acid. The combination is different according to the proportions of acid and metal applied, and the degree of heat and its continuance. In general, it has an excess of acid, and even with this excess it crystallizes in slender prisms, thus forming a mass, soft, and partly liquid, composed of these crystals. This saline mass is very acrid, deliquescent, and soluble in water. If washed with water, a considerable part of the acid is removed, holding combined with it a portion of oxide; and the neutral sulphate at length remains, less acrid, and much less soluble in water, but which is still so far soluble as to afford by evaporation prismatic crystals. It consists, according to Fourcroy's analysis, of 75 of mercury, 8 of oxygen, 12 of acid, and 5 of water. These combinations are liable to diversity, too, not only from the proportion of acid, but also from the degree of oxidation of the metal, according to the manner in which they have been effected.

If any of these sulphates of mercury be urged with a heat gradually raised until the mass becomes dry, the metal is more highly oxidated, and the excess of acid is entirely dissipated. On pouring on this dry mass boiling water, it acquires a lively yellow colour, forming a preparation which has been long known by the appellation of

Turbith Mineral, now named Yellow Sub-sulphate of Mercury. The water in this process produces the usual effect which it has when it decomposes metallic salts. Exerting a stronger attraction to the acid than to the metallic oxide, it combines principally with the former; still, from the influence of quantity on chemical affinity, the acid carries with it a portion of the oxide, and conversely from the operation of the same force, the oxide which is precipitated, retains a portion of the acid combined with it; the neutral sulphate is thus resolved into a supersulphate which the water dissolves, and a subsulphate which remains undissolved. The quantity of the latter is greater as the acid has been more completely expelled by the previous application of heat. It is necessarily liable to be variable in its composition; it consists of from 76 to 84 of mercury, with from 10 to 15 of sulphuric acid. As a mercurial medicinal preparation, it is harsh and uncertain in its operation, and is therefore seldom used.

Sulphate of mercury suffers decomposition from the action of the alkalis and earths, precipitates of various shades of yellow and grey being formed, all of them probably sub-sulphates. Ammonia re-acts on the precipitate, and forms a ternary compound, which may be obtained crystallized, and which, according to Fourcroy's analysis, consists of 39 of quicksilver, 33 of ammonia, 18 of sulphuric acid, and 10 of water.

Nitric acid acts on quicksilver with great facility, oxidating it, and combining with the oxide, forming a perfect solution. The product of this action varies, however, considerably, particularly with regard to the state of oxida-

tion, according to the circumstances under which it is exerted.

If the acid is diluted with rather more than an equal part of water, and if no heat is applied to accelerate the solution, the metal attracts a small portion only of oxygen, and in this imperfectly oxidated state, combines with the acid. If the acid is less diluted, and if the action of the metal on it be promoted by heat, a compound is formed with the oxide at a higher degree of oxidation. Both these solutions, when concentrated, crystallize, a mass being deposited, consisting of a congeries of slender prisms. Both salts are corrosive, deliquescent, soluble in water, and their solubility is so much increased by heat, that on applying a moderate warmth, they dissolve.

In these combinations, there is no reason to suppose that determinate degrees of oxidation are established; there appears to be a series of compounds in which the metal is oxidated indefinitely from the *minimum* to the *maximum*, and hence the solution is liable to variation from the slightest diversity of circumstances. The compound at the *maximum* of oxidation, is not easily obtained by the action of nitric acid on metallic mercury, but is formed by the direct combination of the oxide and acid. It is obvious, too, that these combinations may be diversified from an excess or deficiency of acid. In general, the acid is in excess, and it always is so when the mutual action has been exerted in the cold; and this excess of acid renders the compound more soluble, and more susceptible of dilution with water without decomposition. If the acid is boiled on the metal, the solution has at length an excess of oxide, and is incapable of dilution with water without decompo-

sition, a sub-nitrate sparingly soluble being precipitated; while a portion of the combination approaching to the state of the neutral compound remains dissolved.

Nitrate of mercury is decomposed by the alkalis and earths, and in these decompositions are well displayed the differences which arise from the different states of oxidation of the metal. Potash, soda, or lime, added to the solution, in which the metal is at a low degree of oxidation, throws down a precipitate of a greyish colour, with a tinge of yellow; when added to the solution in which the metal is at a high degree of oxidation, the precipitate is yellow, more or less bright; and between these are precipitates of various shades, according to the state of the mercurial solution. All these precipitates are sub-nitrates, the oxide separated by the alkali retaining a portion of the acid combined with it.

The action of ammonia on these solutions is more peculiar. From the solution containing the mercury at a high state of oxidation, it throws down a white precipitate, which is a ternary combination of the oxide with portions of the acid and alkali; the proportions, according to Fourcroy's analysis of it, being 68.2 of oxide, 16 of ammonia, and 15.8 of acid and water. From the solution in which the metal exists at the minimum of oxidation, it throws down a precipitate of a dark grey or blue colour; and between these, precipitates of various shades of grey may be obtained, according as the mercury is more or less highly oxidated.

The grey precipitate (*Oxidum Hydrargyri Cinereum* of the Pharmacopœias) is a preparation much used in medicine; and it is of importance, therefore, to have it un-

form. The directions given for obtaining it have often been imperfect, from the theory of the process not being well understood. The whole depends on the state of oxidation of the mercury in the solution; if it be at the *minimum*, the dark grey precipitate is formed; if it is at any higher degree, then a portion of the ternary white precipitate is formed, which mingling with the other, communicates to it a lighter shade, must render it variable, and give rise to some difference of medicinal power. In conducting the process, therefore, every precaution ought to be taken to moderate the action of the acid on the metal. Five parts of diluted nitric acid, that is, the acid diluted with an equal weight of water, to four of quicksilver, are the proportions ordered in the Pharmacopœia; it may be diluted with one half more water; the quicksilver ought to be added in successive portions, and no heat is applied to accelerate the solution; the liquor is poured off from any undissolved mercury, and is diluted with fifteen parts of water; water of ammonia is then added as long as any precipitation is produced, and the precipitate, which is of a dark grey colour, nearly black, is collected on a filtre, washed with cold water, and dried. In drying, it becomes of rather a lighter shade. The nature of the action exerted by the ammonia in its production, is not altogether evident. The precipitate formed by it is different from that thrown down by potash or soda, hence its action must be peculiar. According to a view given by Fourcroy, the ammonia, in combining with the nitric acid of the solution, and separating the oxide of mercury, partially decomposes it, its hydrogen attracts part of its oxygen, and

hence the oxide is thrown down in even a lower state of oxidation than that in which it existed in the solution. It has been supposed, too, that a portion of ammonia is combined with the oxide, but of this no trace can be discovered from the action of substances upon it, such as lime, by which ammonia, if present, would be expelled. The preparation is a mild mercurial, and is very similar in its operation on the system, to the mercurial preparations formed by trituration.

If any of the solutions of mercury in nitric acid be evaporated to dryness,—a mass is obtained of a yellowish colour, which, when urged with a strong heat gradually raised, becomes of a bright red, much of the acid being expelled or decomposed. This is a preparation which has been long known under the name of Red Precipitate of Mercury; it is now named Oxidum Hydrargyri Rubrum per Acidum Nitricum, in the Edinburgh Pharmacopœia; in the London, Hydrargyri Nitrico-Oxidum. When properly prepared, it is in scales of a brilliant red colour. It is not a pure oxide, but a sub-nitrate, and is accordingly different in its appearance and qualities from the red oxide obtained by the action of atmospheric air at a high temperature. It is probably impracticable to expel the whole of the nitric acid without decomposing the oxide itself; and that a portion of acid does remain in it, may be rendered apparent by a very simple experiment, boiling it in water, the liquor, when filtered, has a metallic taste, and gives a precipitate with water of ammonia, or carbonate of potash. It is employed as an escharotic, and this quality probably depends principally on the portion of

acid it contains. Its proper appellation is Sub-nitras Hydrargyri Rubor. Decomposed by heat, 100 parts of it afford 82 of mercury, and 18 of oxygen gas, the latter having probably an intermixture of nitrogen gas.

Muriatic acid does not act on quicksilver, but it combines with it in the oxidated state, and exerts to its oxides a strong affinity. From the strength of this affinity it appears, even in entering into this combination, to render the degree of oxidation determinate, and accordingly two muriates of mercury, of uniform composition, are known, one or other of which is always formed when the acid is added to the metal in the oxidated state.

The formation of these compounds is well displayed in the action of muriatic acid on the solution of mercury in nitric acid. If the solution be in that state in which the metal is at the *minimum* of oxidation, a compound of the oxide with the muriatic acid is formed, which being insoluble, is precipitated. If the solution, on the contrary, contain the metal at the *maximum* of oxidation, a compound having very different properties is formed, and which, being easily soluble in water, remains dissolved. And if the mercurial solution be even in any intermediate state, the muriatic acid does not combine with the oxide in this state, but resolves it into the two oxides which are the bases of these compounds; and hence portions of both of them are produced, the relative quantities being various according as the solution has contained the metal more or less highly oxidated.

These two preparations have been long known, one by the name of Corrosive Sublimate of Mercury, the other by

the name of Sweet Sublimate of Mercury, or Calomel; they are formed by processes very different from the modes of producing them which have just been described.

The process given in the Pharmacopœias to obtain the first of these preparations, consists in dissolving quicksilver in sulphuric acid, by the application of heat; a portion of the acid is decomposed, its oxygen is communicated to the metal, sulphurous acid being disengaged, and the oxide combines with the remaining acid. By continuing the application of heat, the sulphate of mercury is obtained dry; it is then mixed with twice its weight of dry muriate of soda, and the mixture being put into a glass matrass to which a capital is adapted, heat is applied to it by the medium of a sand-bath, and continued while any matter is sublimed. A double decomposition is produced; the sulphuric acid of the sulphate of mercury combines with the soda of the muriate of soda, while the muriatic acid unites with the oxide of mercury; and as this oxide existing in the sulphate, is in a high degree of oxidation, the muriate formed is the one with the oxide in this state. Being volatile, it is sublimed by the heat applied in its formation, and it condenses in the form of a crystalline cake in the upper part of the matrass. If it is sublimed more slowly, it is obtained in the form of needle-like crystals. It also crystallizes from its watery solution in prisms.

This salt is soluble in water, requiring about 20 parts at 60° for its solution, and not more than 2 parts at 212°. It is also soluble in alkohol. Its taste is styptic, it is extremely corrosive, and acts as a violent poison: in a very small dose it is, however, sometimes administered inter-

nally as a mercurial, and it is used externally as an escharotic. It is decomposed by the alkalis and earths, which precipitate from its solution a sub-muriate of a yellow colour. Ammonia forms a white precipitate, which is a ternary compound, consisting of 81 of oxide of mercury, 16 of muriatic acid, and 3 of ammonia. It has been in use as a mild escharotic, under the name of White Precipitate of Mercury. Muriate of ammonia has a singular effect on the muriate of mercury, that of rendering it much more soluble in water, and forming with it a compound which can be obtained crystallized. This compound, decomposed by potash, affords the same white precipitate. Sulphuretted hydrogen, either pure or combined with the alkalis, throws down from the solution of the muriate of mercury precipitates of a dark brown colour, which appear to consist chiefly of the sulphuretted oxide. A number of the metals decompose it by abstracting the oxygen of the oxide, either partially or entirely; and it even suffers a partial decomposition of this kind from vegetable extractive matter.

The composition of corrosive muriate of mercury has often been attempted to be determined. Even the latest analyses, however, assign different proportions of its constituent principles. According to Mr Chenevix, the oxide which is its base, is composed of 85 of mercury with 15 of oxygen, and 82 parts of this oxide are combined in 100 of the salt, with 18 of muriatic acid. In 100 parts, therefore, there are present 69.7 of mercury, with 12.3 of oxygen, with which 18 of acid are united. According to Zaboada, the oxide which is its base does not contain more

than 10 of oxygen, and 80 of this oxide are combined with 20 of acid. The ultimate proportions, therefore, are 20 of acid, 71.5 of quicksilver, and 8.5 of oxygen.

The process by which the other muriate of mercury is formed, is an indirect one. It consists in triturating the corrosive muriate with nearly an equal weight of metallic mercury, facilitating the trituration by the addition of a little water, and continuing it until the globules are no longer apparent. The powder dried is put into a glass matrass, and sublimed by heat, applied by the medium of a sand-bath. As the new combination which takes place is not perfect on the first sublimation, the mass is reduced to powder, and sublimed a second, or even a third time. The sublimate is then obtained perfect, and free from metallic mercury; it is reduced to a fine powder by levigation, and is thoroughly washed and dried.

In this process the metallic mercury which is added is brought into combination with the principles of the corrosive muriate; it receives, therefore, a portion of the oxygen of the oxide which is the base of that compound, the whole passes to a lower state of oxidation, and the entire oxide thus formed remains combined with the acid of the corrosive muriate. Hence it is obvious, that the new compound differs from the other, first, in its base being mercury at a lower state of oxidation, and, secondly, in this base being combined with a smaller quantity of acid. Though the quantity of acid be smaller, it appears, however, to be as much as the oxide requires for its saturation, for it is incapable of neutralizing an additional portion of acid; and this is strictly conformable to a general law, ex-

emplified in many metallic combinations, that a metal at a high degree of oxidation, requires a larger quantity of acid for its saturation, than when the oxidation is less perfect.

These two compounds, then, are muriates of mercury, and they afford an example of the difficulty of nomenclature, with regard to different salts formed from the same acid, united with the same metal in different states of oxidation; for it is not easy to assign to them distinctive appellations altogether unexceptionable. As the one contains a larger portion of oxygen than the other, it has been proposed to name it oxy-muriate, and the other muriate of mercury; but this is incorrect, the term oxy-muriate implying, in chemical nomenclature, a compound of oxy-muriatic acid, which this is not, the larger quantity of oxygen it contains being in combination with the metal, and not with the acid. In another mode of nomenclature, the one compound, that at the higher degree of oxidation, has been named Muriate; the other Sub-muriate of Mercury; but this is equally incorrect: the epithet *sub* is appropriated to salts in which there is a deficiency of acid, and this nomenclature would imply that the two compounds differed merely in the proportion of acid, their bases being the same. This is not, however, the difference between them. Although the compound named Sub-muriate has less acid in its composition than the other, this is because its base requires less for its saturation; it is not a subsalt, and its base is altogether different from that of the other. No better distinctive appellation can perhaps be given to them, than that drawn from any important property in which

they differ; this, as has been already explained, affording on the whole the best mode of distinguishing salts formed from the same metal and the same acid. The one, therefore, may be named Corrosive Muriate of Mercury, the other Mild Muriate; and this also has the advantage of retaining the epithets by which they have long been distinguished, and of pointing out the difference between them, which it is most important to attend to in relation to their medical use.

Another mode of preparing mild muriate of mercury, besides that by sublimation, was introduced by Scheele. It consists in dissolving quicksilver in nitric acid, and adding to this a solution of muriate of soda; the muriatic acid combines with the mercurial oxide, while the nitric acid combines with the soda. The muriate is precipitated, it is thoroughly washed with water and dried. When this process is properly conducted, the product appears to be essentially the same with that formed by the other process. But from the theory of metallic solutions not being perfectly understood in the time of Scheele, he gave the improper direction of promoting the solution of the quicksilver in the acid by the application of heat. From this two effects arise, both giving rise to an alteration in the product; first, the decomposition of the acid being promoted, the metal passes to a higher state of oxidation than that in which it forms the base of the mild muriate, and hence a portion of corrosive muriate is also formed; and, secondly, the acid is so completely saturated with oxide, that water alone produces a partial decomposition of the solution, throwing down a sub-nitrate; and hence, on adding to it

the solution of muriate of soda, a portion of this sub-nitrate is formed, and mingles with the precipitated muriate. These sources of alteration may be avoided by dissolving the quicksilver in the nitric acid, diluted with more than an equal weight of water, and avoiding the application of heat; a solution being thus obtained, which contains the metal in the lowest state of oxidation, and which affords the mild muriate alone, when decomposed by muriate of soda. But the process has no real advantage over that by sublimation, and as, from not being always properly conducted, it may afford a less uniform product, ought to be discarded.

Mild muriate of mercury, obtained by sublimation, is in the form of a dense mass of crystalline structure, composed of short prisms; and when sublimed slowly, it is obtained in tetraedral prisms, or in octohedrons. In its dense state, it has a specific gravity of 7.1; it is somewhat ductile, and is semitransparent, with a slight tinge of yellow. It is volatile, as is obvious from its mode of formation; it is so sparingly soluble in water, as to require above 1000 parts for its solution. It is insipid, has no escharotic power, and is mild in its operation on the system.

This compound is decomposed by the alkalis and earths, which partially abstract its acid, and form a sub-muriate of a grey colour.

Mr Chenevix observed the formation of an oxymuriate or hyper-oxymuriate of mercury, on transmitting a current of oxymuriatic acid gas through water in which red oxide of mercury was diffused. Along with crystals of corrosive muriate, another crystallized salt was obtained,

more soluble in water, from which sulphuric acid expelled vapours of hyper-oxymuriatic acid.

Mercury is scarcely acted on by any of the other acids; its oxides, however, combine with the greater number of them, and form peculiar compounds. These combinations may be effected by digesting the oxide in the acid; but a more effectual mode is to add to the nitrous solution of mercury, either the acid designed to be combined with the oxide of mercury, or what is preferable, a solution of a neutral salt which contains this acid. Thus, if phosphoric acid be added to the nitrous solution of mercury, a phosphate of mercury is formed; or if, instead of the acid, a solution of phosphate of soda be added, the same compound is obtained,—the soda attracting the nitric acid, and the phosphoric acid combining with the oxide of mercury. In the same manner may be effected the combinations of the oxides of this metal with any other acid. None of these compounds are important, or applied to any use.

The oxides of mercury precipitated by the alkalis, especially by ammonia or lime, if dried with exposure to light, and triturated with 1–6th of their weight of sulphur, detonate on being heated. A more powerful fulminating preparation has been discovered by Mr Howard. It is obtained by dissolving 100 grains of mercury in one ounce and a half of nitric acid, with the assistance of heat; the solution, when cold, is *poured upon* two ounces of alkohol by measure; a moderate heat is applied, till an effervescence is excited, and a precipitate is formed; this, washed and dried, forms the fulminating mercury: 1½ or

2 grains of it, struck upon an anvil, explode violently; and the same effect is produced by a strong electrical discharge, by sudden friction, or exposure to heat. Mr Howard found this preparation to consist of oxide of mercury, oxalic acid, and nitrous etherised gas. Its detonation appears to be owing to the sudden combination of the oxygen with the carbon and hydrogen of these substances, forming aqueous vapour and carbonic acid, and disengaging nitrogen gas, while, at the same time, so much caloric is rendered sensible, that not only is the elasticity of these gases much increased, but even the metal, it has been proved by Mr Howard's experiments, is converted into vapour; and to the great elasticity of this mercurial vapour he ascribes its high explosive power.

Quicksilver combines with sulphur. By mere trituration the mercurial globules are extinguished, and a black powder is formed, the product of the combination of the two substances. It is the black sulphuret of mercury. When seven parts of the metal are triturated with one of sulphur, and the black powder they form is subjected to a moderate heat, the temperature rises, and light is evolved, apparently not from oxygenation, but from the combination of the sulphur and the metal. On subliming the residual mass, it acquires a very vivid red colour. This is the red sulphuret of mercury, the cinnabar or vermilion of commerce. Both the black and the red sulphurets have been supposed to contain oxygen, but this has not been established by any accurate analysis.

Mercury is acted on by the alkaline sulphurets when these are dissolved in water, a black powder being form-

ed. These compounds, especially that from the sulphuret of ammonia, on exposure to the air, assume a red colour, and form a compound similar to cinnabar.

Mercury does not unite with carbon; it combines with phosphorus, forming a tenacious concrete mass, fusible, and which is decomposed by heat.

Quicksilver combines with many of the metals; it has not been practicable to unite it with iron, cobalt, antimony, or nickel, and it unites with platina with great difficulty. These compounds are brittle and soft, and when the mercury is in large proportion, are even fluid. They are named Amalgams. The amalgam of it with tin is used in silvering glasses; that with gold, or silver, in gilding or silvering the other metals: and from its property of amalgamating so easily with these two metals, quicksilver is employed in extracting them from the foreign substances with which they are naturally mixed.

CHAP. IX.

OF COPPER.

Copper is of a red colour, with a shade of yellow, having considerable lustre, but liable to tarnish and rust from exposure to the air. It is moderately hard, and has considerable ductility and malleability. Its specific gravity is 7.8. It has a sensible odour, especially when heated or

rubbed, a styptic unpleasant taste, and is peculiarly noxious to health.

Copper occurs in nature native, and also mineralized by oxygen, by sulphur, united with other metals, and in the state of oxide combined with different acids. It is principally extracted from those ores in which it is associated with sulphur, these being most abundant. The ore is roasted by a low heat, the metal is reduced, melted, and, by repeated fusions, is obtained pure.

Copper melts at a full white heat, and by slow cooling may be crystallized. It suffers oxidation at a lower temperature from the action of the air, thin scales of oxide forming on its surface when it is heated to redness. At a higher heat it burns with a green flame. Its rusting from exposure to air and humidity at natural temperatures, probably likewise arises from oxidation, though some have regarded the green rust as a carbonate of copper. The degrees of oxidation of which this metal is susceptible, have not been determined with much precision. The brown oxide, formed in scales when it is ignited under exposure to the air, are supposed to be at the minimum of oxidation; and by exposing this to a red heat, or by oxidating the metal directly at a higher temperature, another oxide in a higher state of oxidation, containing about 25 of oxygen in 100 parts, is formed. Chenevix supposed that a still lower degree of oxidation than the former of these is established in some of the saline combinations of the metal, the proportion of oxygen being not more than 11.5 in 100 parts. The blue and green precipitates thrown down from the salts of copper by the al-

kalis and earths, are not pure oxides, as had been supposed, but sub-salts, containing, besides a small quantity of acid, a portion of combined water. None of the oxides of copper are entirely decomposed by heat.

Copper is oxidated and dissolved by the greater number of the acids, and forms with them in general soluble and crystallizable salts, of a green or blue colour.

Sulphuric acid, either concentrated or diluted, oxidates it, and combines with the oxide, especially when its action is promoted by heat. The solution is of a blue colour, and by evaporation affords crystals of the same colour in the form of rhomboidal prisms: they are soluble in four parts of water at 60, and in two parts at 212°, and are decomposed by heat, the acid being partially expelled. This salt is the blue vitriol of commerce, and is usually obtained either by evaporation of the solution of it formed by the infiltration of water through copper mines, or by exposure of sulphuret of copper to the action of air and humidity, until the sulphur is converted into sulphuric acid, and the metal is oxidated and combined with it.

Nitric acid acts on copper with much facility, the metal attracting a portion of its oxygen, nitric oxide gas being disengaged, and the oxide combining with the remaining acid. The solution is of a deep green or blue colour, probably according to the state of oxidation. When evaporated, it affords prismatic crystals of a deep green colour, deliquescent, and easily soluble in water. This salt, from the facility with which it parts with oxygen, acts with considerable energy on a number of substances. Thus it detonates when struck with phosphorus, and burns several of

the metals. If wrapt, for example, in tinfoil, the tin in a few moments is oxidated, and frequently with such rapidity as to produce appearances of inflammation. To succeed in this experiment, it has often been remarked, that the salt must not be in a perfectly dry state, but that a little water must be added to it; this has been supposed to operate simply by communicating that fluidity necessary to chemical action, and the experiment has often been produced as affording a proof of this. I have found, however, that it depends on a different cause—the concentration of the acid; for if the solution be strongly evaporated, and the salt employed while it is still a little warm, though it be perfectly soft, and even humid, it does not act on the tin, until a little water is added. It is therefore an example of the singular fact, established by more direct experiments, that nitric acid highly concentrated does not act on metals, but requires the presence of a portion of water.

Muriatic acid dissolves copper slowly when the atmospheric air is admitted; if it is excluded, the action is very inconsiderable unless heat is applied; the solution is of a green colour, and by evaporation slender prismatic crystals are obtained, deliquescent and very soluble in water. The salt is decomposed by heat, and the acid disengaged partly in the state of oxy-muriatic acid. The combination of copper with muriatic acid can be established in other states of oxidation. Thus, if a portion of copper-filings be included in a phial closely stopt, with a solution of green muriate of copper, the solution gradually becomes colourless, the metallic copper attracting a portion of the oxygen

of the dissolved copper; but that the solution still holds the metal dissolved at a lower degree of oxidation, is proved by the fact, that if the air be admitted, a blue tint is soon produced, and appears first at the surface of the liquid. By the addition too of muriate of tin, a substance which powerfully abstracts oxygen, to a solution of muriate of copper, a white muriate is precipitated, and this, by an addition of acid, forms a colourless solution. Oxy-muriatic acid dissolves copper, and when transmitted in its elastic form through water in which oxide of copper is suspended, the oxide disappears.

Copper is slowly oxidated by a number even of the weaker acids, as by sour vegetable juices, when submitted to their action in contact with the air and with humidity, while the acid alone does not appear to impart oxygen. The combinations of its oxide with phosphoric, carbonic, and other acids, are most easily effected by adding to a solution of nitrate or sulphate of copper, a solution of a neutral salt, containing the acid with which the copper is designed to be combined. The carbonate, phosphate, and borate of copper are thus obtained in the form of precipitates of a green colour, more or less deep. The fluate of copper can be obtained crystallized. Acetic acid or vinegar oxidates copper, forming on copper plates a crust of a green colour, the verdegris of commerce; and this, when dissolved in the acid, so that the oxide is neutralized, affords on evaporation prismatic crystals of acetate of copper, of a rich green colour.

All the saline combinations of copper are decomposed by the alkalis and earths. Potash, soda, and the alkaline

earths, throw down precipitates which are of various shades of green or blue, according to the quantity of alkali added, the colour being green if a small quantity has been employed, and becoming blue from a larger quantity. These precipitates are sub-salts, the alkali attracting the greater part of the acid, but the oxide precipitated retaining a small portion of the acid combined with it. The green contains more acid than the blue. The blue was even supposed to contain no acid, and was regarded by Proust as what he named a hydrate of copper, or combination of oxide of copper and water: but the experiments of the younger Berthollet have sufficiently shewn, that it always retains a portion of the acid of the salt from which it is obtained. These precipitates retain a considerable quantity of water in combination, frequently as much as 12 or 15 in 100 parts in a dried state, and the oxides of copper carry with them usually a large proportion of water into their saline combinations.

The action of ammonia on the salts of copper is more peculiar. It first abstracts a portion of the acid, and throws down a precipitate of a green or blue colour, which is a sub-salt. But if added in larger quantity, it re-dissolves this precipitate, and forms a transparent solution of a very deep blue colour. It forms a similar solution with the pure oxides of copper, if the degree of oxidation be sufficiently high, for in a lower state of oxidation the solution is colourless, as is well shewn in the experiment of inclosing a few copper filings with the blue solution in a phial closely stopped; the colour is gradually removed by the metallic copper abstracting a part of the oxygen of the dissolved

oxide; but that the oxide, in this lower degree of oxidation, is still in combination with the alkali, is shewn by the blue tint almost immediately appearing at the surface of the liquid when the atmospheric air is admitted. The ternary combinations of oxide of copper, acid, and ammonia, may be obtained in small crystals by evaporation of their solution, or by precipitation by alkohol. A similar compound, used in medicine under the name of Ammoniuret of Copper, is prepared by triturating two parts of sulphate of copper with one part of carbonate of ammonia, the mass becoming soft from the mutual action of the two salts, the carbonic acid being disengaged with effervescence, and the triple compound of sulphuric acid, oxide of copper, and ammonia, being obtained of a deep violet colour.

Copper is precipitated in its metallic state from its saline solutions by zinc and iron, these metals attracting the oxygen which serves as the medium of its union with the acid of the solution.

Copper and sulphur unite easily by fusion, the combination being attended with an elevation of temperature and an extrication of light. The compound is of a dark-grey colour, with a degree of metallic lustre, brittle and fusible. Sulphuret of potash combines with copper by fusion, and even by the intermedium of water. Sulphuretted hydrogen and the hydro-sulphurets throw down dark-coloured precipitates from its salts.

Copper appears to form a combination with carbon. This is not indeed obtained directly; but when the vapour of alkohol is transmitted through a red-hot copper tube, or over copper-filings placed in an ignited earthen tube, a

substance is obtained, black and friable, which burns in oxygen gas, affording carbonic acid, and a residuum of oxide of copper.

Phosphorus may be combined with copper, by exposing to heat the metal in mixture with phosphoric acid and charcoal. The phosphuret is of a white or grey colour, with metallic lustre; it is hard and brittle, tarnishes on exposure to the air, and is decomposed by heat.

Copper combines with the greater number of the metals by fusion. It communicates hardness to gold and silver, without much diminishing their ductility, or debasing their colour, when in small proportion; hence it is employed in the standard alloys of these metals. With platina it forms an alloy ductile, and susceptible of a fine polish. Quicksilver easily amalgamates with it, and in small quantity renders it brittle. With zinc it forms brass and pinchbeck; with tin, bell-metal and bronze.

Copper, from its comparative fusibility, its ductility, the facility with which it can be extended in sheets, and with which it can be united by solder, is capable of being applied to many purposes of utility; and it is accordingly employed in the construction of boilers, stills, and various household utensils. Its utility is much limited by its poisonous quality; and though this has been attempted to be obviated, by coating its surface with a thin layer of zinc or tin, the precaution is scarcely effectual. In thin sheets, it is applied to sheath the bottoms of ships, and for this purpose is preferable to any other metal. Several of its combinations are used as pigments, and some are employed in the practice of medicine.

CHAP. X.

OF IRON.

This metal is extensively diffused. It exists in the mineral kingdom in immense quantity, and under numerous forms; there are even few fossils entirely free from it; it is a constituent principle of vegetable matter, and is obtained from the ashes of every plant; it exists in the composition of the blood, and of other animal products; and the singular fact has even been established, that it is an atmospheric or meteoric production, those stoney masses which at different times, and in different countries, have fallen from the atmosphere, containing iron as their principal ingredient.

The ores from which iron is extracted, are those in which it is mineralized by oxygen; of which there are many varieties, consisting of the oxide more or less pure, intermixed with argillaceous, calcareous, and siliceous earths. It is principally from the argillaceous ores that iron is extracted in this country. The ore is roasted to expel any foreign volatile matter; it is then put into a furnace with layers of coaked coal, and with a quantity of lime, and is exposed to an intense heat excited by a blast of compressed air. The lime combining with the other

earthy substances in the ore, they vitrify more easily, so as to admit of the action of the carbonaceous matter of the coal on the oxide, and the separation of the metal reduced by the abstraction of the oxygen. The charge of fresh materials is renewed at the upper part of the furnace, and the process carried on without interruption, the vitrified matter being withdrawn by an opening in the side, and the melted metal run out at the bottom. It forms what is named crude iron, pig iron, or cast iron.

In this state it is not the pure metal; it always contains a portion of carbon and of oxygen; and frequently smaller portions of other ingredients, manganese, silex, argil, phosphorus, and chrome. The oxygen, carbon, and phosphorus, appear to be diffused through the metal in the state of oxide, carburet, and phosphuret of iron. According to the nature and proportions of the foreign substances, the qualities of the iron are modified. Three principal varieties have been distinguished;—white crude iron, in which the colour approaches to white, the fracture exhibits a striated appearance, and the mass is extremely brittle; the grey crude iron, in which the colour is grey and dull, the fracture granular, and which is less brittle than the other; and, lastly, the black crude iron, which is of a dark grey colour, approaching to blue, and the fracture of which presents larger granular concretions; it is also softer and more fusible than the others. The peculiar qualities of the first variety have been supposed to depend principally on the presence of oxygen, or perhaps rather oxide of iron; of the second, on the presence of this, with a portion of carbonaceous matter; and of the third, on the

predominance of carbon, or rather perhaps carburet of iron. The production of them depends on the proportion of fuel to the ore in the process of reduction, and partly on the nature of the ore itself. The metal in all these states is much more fusible than when it is pure; hence it can be cast in a variety of forms; it is at the same time, however, more hard and brittle, and is therefore unfit for many of the purposes to which pure iron is applied.

To obtain pure iron, crude iron is submitted to two operations, fusion and forging. In melting it, part of the foreign matter separates and collects on the surface; and if kept in fusion for some time, the separation is rendered more perfect, a blue lambent flame appears on the surface, apparently from the disengagement of carbonic oxide, or carburetted hydrogen; and the metal, at first quite liquid, gradually becomes thick and viscid from its fusibility diminishing, and at length assumes the consistence of a paste; it is then submitted to the action of the forge-hammer, or to the pressure of steel rollers, by which a quantity of oxide of iron and other impurities is forced out. In this state it forms forged or bar iron, which is no longer granular, but fibrous in its texture; is soft, ductile, and malleable, and much less fusible; it is the metal in its pure form.

Still there are some peculiarities in forged iron, giving rise to different varieties. Apart from these peculiarities, iron is distinguished by its infusibility, softening when heated, and being ductile and malleable at all temperatures. One kind of forged iron has this ductility when cold, but is brittle at a high temperature; this is named hot

short iron: another, named cold short iron, has precisely the opposite property, being ductile and malleable when heated, but brittle when cold. The causes of these peculiarities are not very well determined. The cold short property appeared, from Bergman's experiments, to depend on the presence of a substance which he regarded as a new metal, and named Siderite, but which has been ascertained to be phosphuret of iron. The hot short property has been ascribed to the presence of sulphur, arsenic, manganese, or chrome.

Forged iron, free from these peculiarities, is the metal in its pure state; it is ductile and malleable at every temperature; its texture is fibrous; its colour a light grey, accompanied in the fresh fracture with considerable lustre; its specific gravity is 7.7; in hardness it is superior to the greater number of the metals; it also exceeds them in ductility, being capable of being drawn into finer wire, and having such tenacity that a wire 0.078 of an inch in diameter supports without breaking above 500 pounds. It is also highly elastic.

Iron is peculiarly distinguished by the property of magnetism; it has even been supposed to be the only substance which possesses it; some other metals, however, particularly nickel and cobalt, appear also to be magnetic. The magnetic power remains within a certain degree of oxidation, but beyond this is impaired; it also remains when the iron is combined with a certain proportion of carbon, sulphur, or phosphorus, but beyond this it is weakened, and at length destroyed.

Iron is extremely infusible, and was supposed to be even incapable of being melted by any heat that can be excited in a furnace. Its fusion has been accomplished, however, at a temperature calculated to be between 155° and 160° of Wedgwood's scale. Crude iron melts at 130. At a temperature far below that which is necessary to its fusion, forged iron softens until its surface appears as if it were covered with a thick tenacious fluid; and this softening extends so far through the whole mass, that two pieces in this state hammered together unite firmly. This is the property of welding, so valuable with regard to iron, as rendering it capable of being worked; it is possessed besides only by platina, and by it in a very inferior degree. The temperature at which it takes place is about a white heat; if the temperature be raised much beyond it, the iron becomes brittle, and falls to pieces under the hammer.

Iron is oxidated by atmospheric air. Even at a common temperature, it undergoes the operation of rusting, in which it is oxidated. The change in this case, however, depends partly on the agency of water, as it is accelerated by humidity; and if the air is perfectly dry, it scarcely takes place. The rust, too, is not a pure oxide, but contains a portion of carbonic acid, absorbed from the atmosphere, or formed perhaps from the oxygenation of a little carbon contained in the iron.

At a high temperature, the oxidation of iron takes place more rapidly. When raised to a red heat, its surface assumes various tints of colour, and at length scales form upon it, consisting of the oxide. In the state of filings,

it even burns brilliantly when projected across the flame of a burning body, and ignited iron-wire burns with splendour in oxygen gas. In these cases, what is named the black oxide of iron is formed, containing, according to Lavoisier's estimate, 27 of oxygen in 100 parts. If it be exposed to a continued heat, with the access of the air, it changes its colour and becomes red, from farther oxygenation. This red oxide contains 48 of oxygen in 100 parts. These oxides are obtained also by other processes. The black oxide is produced by the slow action of water on iron, when the iron is entirely immersed in it, and also in the more rapid decomposition of water, when it is transmitted over the metal at the temperature of ignition; it exists, too, in several of the saline combinations of iron. The red oxide is the base of those at a higher state of oxidation, and is obtained from their decomposition. And other oxides, in intermediate degrees of oxidation, probably exist. One of a white colour is obtained from muriate of iron, formed by boiling a large quantity of muriatic acid on iron-filings, and decomposed by an alkali, which has been supposed to be iron at a lower degree of oxidation than the black oxide. None of these oxides can be reduced by heat; but their reduction is accomplished by the action of carbonaceous matter at a temperature sufficiently elevated.

Iron, from the strength of its affinity to oxygen, is oxidated and dissolved by the acids with facility; its saline compounds, when neutral, are in general soluble and crystallizable.

Sulphate of iron is a salt which has long been known

under the name of Green Vitriol. It is economically prepared from the native sulphuret of iron, which, when calcined, and exposed for some time to air and humidity, absorbs oxygen, so that the sulphur is converted into sulphuric acid, and the iron is oxidated; the sulphate of iron, thus formed, is extracted by lixiviation and crystallization. It is obtained more pure by the direct solution of iron in diluted sulphuric acid, the acid enabling the iron to decompose the water, by attracting its oxygen, and combining with the oxide, hydrogen gas being disengaged. The solution is of a pale green colour, and, if concentrated, affords, after filtration, crystals of the same colour, in the form of rhomboidal prisms. They consist of 28 of oxide of iron, 26 of sulphuric acid, and 46 of water. This salt is soluble in six parts of cold water. Exposed to heat, it first liquifies; when the water of crystallization is dissipated, it forms a dry mass of a greenish colour; when urged by a strong heat, the greater part of its acid is expelled, partially decomposed, and a red oxide remains. Exposed to the air, it loses its transparency, and is covered with a yellowish crust; a change owing not merely to the dissipation of the water of crystallization, but to the absorption of oxygen. This absorption takes place to a greater extent when the salt is in solution, and continues until the oxide pass to the maximum of oxidation. In this state it requires a larger quantity of acid for its saturation than the oxide in the green sulphate does; hence a portion of this more perfect oxide is precipitated, while the remaining quantity is retained in combination with the acid. The one of these salts is named the Green Sulphate

of Iron, the other the Red Sulphate. The latter is not crystallizable, but when its solution is evaporated it forms merely a mass of a yellowish-red colour. It is soluble in alkohol, and this affords a mode of separating it from the other. With re-agents, these salts afford different phenomena. The green sulphate, decomposed by the alkalis, gives precipitates of a green colour; the red sulphate affords precipitates of a yellow colour, approaching more or less to red; the former, with prussiate of potash, gives a white precipitate, the other, with the same test, a precipitate of a rich blue colour; the one is little altered by the infusion of galls, the other strikes immediately a deep purple colour.

From the strong tendency of iron to pass to a highly oxidated state, it is difficult to obtain the green sulphate perfectly pure, so as to exhibit these phenomena. The solution of iron is usually in an intermediate state of oxidation; and though Proust and some other chemists have supposed that there are only two sulphates of iron of determinate composition, one having for its base the metal at the *minimum*, the other at the *maximum* of oxidation, and that any apparent intermediate compound is merely a mixture of these, it is more probable that there is a series of these compounds in indefinite degrees of oxidation; and accordingly crystals of numerous shades of colour can be obtained. The different precipitates which the compounds at the extremes of the series form with the different re-agents, the prussiate of potash, and infusion of galls, have been supposed to depend on the peculiar properties of the oxides which are their bases: this may be partly

the cause, but they appear also to arise in part from the different forces of affinity with which the oxide is retained in combination with the sulphuric acid, the force being greater as exerted towards the metal at a low than at a high degree of oxidation, so that the salt in the former state does not so easily form a precipitate with these reagents. But if the affinity be weakened by causes which do not change the state of oxidation, as by mere dilution with water, or the addition of an alkali in small proportion, the precipitation is produced by their action on the salt in even the least oxidated state.

Sulphate of iron is a salt applied to numerous uses in the arts, more particularly in dyeing, as forming, with vegetable astringents, the bases of black dyes, and, with other colouring substances, different shades of colour. Its combination with these astringents is also the basis of writing-ink.

Sulphurous acid dissolves iron, being partly decomposed, so that the combination is a sulphuretted sulphite of iron. The pure sulphite is obtained by the direct combination of the acid with oxide of iron; it is soluble in water, not soluble in alkohol, and is not coloured by infusion of galls.

Nitric acid is decomposed by iron with great rapidity, and the metal passes to the highest state of oxidation. When the acid is diluted, the action is more moderate, and a more perfect solution is obtained, which, however, cannot be evaporated so as to afford the nitrate crystallized, the heat that is required causing a farther decomposition of the acid, and the precipitation of a sub-nitrate of iron.

A similar change is produced in the solution from exposure to the air, oxygen being absorbed.

Muriatic acid dissolves iron with facility, the iron receiving oxygen from the water, and the solution being therefore attended with a disengagement of hydrogen gas. The solution is of a pale green colour, and affords crystals on evaporation of the same colour. If oxide or rust of iron is dissolved in muriatic acid, a solution is obtained of a yellow colour, more or less deep, which does not crystallize on evaporation, but affords merely a soft deliquescent mass. In the one of these salts, the iron is in a low, in the other in a high state of oxidation, and they differ considerably in their chemical properties; the former, the green muriate, is insoluble in alkohol, is little altered in its colour by infusion of galls, and, when decomposed by the alkalis, gives a green precipitate; the latter, the red muriate, is soluble in alkohol, gives a deep purple colour with galls, and a blue with prussiate of potash, and affords a yellow precipitate when decomposed by the alkalis. The green is converted into the red muriate by exposure to the air, passing through various intermediate states of oxidation, by absorption of oxygen.

The solution of the green muriate, as well as of the green sulphate of iron, absorbs nitric oxide gas; a property, the application of which to eudiometry has been already stated.

Iron is acted on by water strongly impregnated with carbonic acid, and a portion of it is dissolved. The common rust of iron contains a portion of this acid; and a carbonate is formed by decomposing sulphate of iron by

carbonate of potash or soda; it is precipitated of a greenish colour, but in drying becomes brown from absorption of oxygen from the air. In the natural chalybeate waters, the iron is usually held dissolved by carbonic acid.

Phosphoric acid acts weakly on iron; but the phosphate may be formed by adding phosphate of soda to a solution of sulphate of iron; it is of a white colour, insoluble in water, and fuses into a brilliant globule by an intense heat. The borate, formed by a similar process, is likewise insoluble. The fluate is soluble, does not crystallize, but by evaporation forms a gelatinous mass. Prussic acid has a powerful affinity to oxide of iron; it forms with it the pigment of a rich blue colour, known by the name of Prussian Blue; and from the deepness of the colour of this combination, and the strength of affinity which the acid exerts, it affords one of the most delicate tests of iron. Gallic acid produces with the salts of iron a deep violet tinge, and in the state in which it is combined with tannin in the infusions of vegetable astringents, particularly of galls, is a test still more delicate and more accurate.

The alkalis scarcely act on iron or its oxides; in decomposing its salts, they in some cases form, when added in excess, soluble ternary compounds. The earths form coloured enamels, when melted with oxide of iron.

Iron appears to exert a strong attraction to carbon. When melted from its ores in contact with the fuel, a portion of carbonaceous matter combines with it, and this, with oxygen and other ingredients, forms cast iron. The combination of iron with carbon alone constitutes Steel, one of the most useful forms of this valuable metal.

The usual process for forming steel is that of Cementation, bars of malleable iron being imbedded in layers in charcoal powder in a close furnace, through which flues are carried to distribute the heat. A strong fire is applied for six or eight days; the progress of the cementation is known by withdrawing a bar from the furnace; if this is sufficiently changed, the fire is extinguished, and the metal is left to cool for six or eight days. This forms Blistered Steel; it is rendered more perfect by subjecting it to the operation of the forge-hammer, as in forging iron; or by welding it; or it is fused and cast into small bars, forming what is named Cast Steel. These operations are performed on malleable iron; but some kinds of cast iron, particularly of the grey crude iron, can be converted into steel of an inferior quality by a similar process. Steel is also formed by fusing forged iron with charcoal.

In this operation, an increase of weight from $\frac{1}{180}$th to $\frac{1}{140}$th is gained. The more carbon is introduced, the more brittle is the steel. Bergman first clearly shewed the presence of this carbonaceous matter, by ascertaining by experiment, that less hydrogen is disengaged during the solution of steel in diluted sulphuric acid, than during the solution of iron in the same acid; and that, during the solution of the steel, carbon is precipitated in the form of a black shining powder, similar to plumbago. Guyton has observed, that it is probably pure carbon, not charcoal, that is present in steel; and to this its great hardness may be ascribed. This has been confirmed by the interesting experiment of converting iron into steel, by exposing it to heat with diamond. If the ultimate base of car-

bon be metallic, as is not improbable, it may be this metallic matter that combines with iron to form steel. Bergman further found, that some specimens of steel contain manganese and siliceous earth; and Vauquelin has likewise discovered the existence of this earth and of phosphorus in several kinds of steel which he analyzed.

Steel is of a grey colour; its fracture is granular and brilliant, and it is susceptible of a very high polish. It is more fusible than iron. It is both ductile and malleable, and when hammered, its ductility and also its elasticity are increased. The property by which it is eminently distinguished is, that of acquiring a great degree of hardness by being immersed in cold water when previously heated, the hardness being greater as the steel has been hotter and the water colder; it at the same time becomes more brittle and elastic, effects which evidently arise from the irregular aggregation produced by the sudden cooling. Steel, thus hardened, may have its softness and ductility restored, by again heating it, and allowing it to cool slowly. This is what is termed *tempering* of it, the requisite degree of hardness being given by heating the metal more or less, previous to the slow cooling. The harder it is, it is also the more elastic, and at the same time more brittle, and hence, for different purposes, different degrees of *temper* are required.

Steel possesses a degree of hardness superior to any other metal; it is also possessed of the highest elasticity: and from these properties it acquires its high value.

The mineral substance known by the name of Plumbago, or Graphite, is a native combination of iron and car-

bon. The proportion of iron is variable, but in general it does not exceed from 5 to 10 in 100 parts; it is in combination, as Mr Davy has supposed, with the pure carbonaceous base.

Iron has a strong attraction to sulphur, and combines with it with facility by fusion, the combination being attended with the evolution of heat and light. They also exist combined in nature, the mineral named Pyrites being a combination of this kind. The proportions of the ingredients in the native sulphurets, are usually different from those in the artificial sulphuret; in the former they are about 53 of sulphur, and 47 of iron; in the latter the proportion of sulphur does not exceed 37; but the artificial sulphuret may be combined by fusion with an additional proportion of sulphur, and sulphurets formed in various intermediate proportions. When the proportion does not exceed 37 of sulphur in 100 parts of the compound, the magnetic property remains; but when it is so high as 53, it is entirely destroyed. These compounds are of a grey or yellow colour frequently variegated, with a degree of lustre, the colour approaching more to yellow, and the lustre being more perfect, as the proportion of sulphur is large. They are of a crystalline texture, brittle, fusible, and are partially decomposed by heat; the compound in which the iron predominates, when moistened and exposed to the air, absorbs oxygen, and is gradually converted into sulphate of iron. A mere mixture of iron filings and sulphur moistened acts on atmospheric air in a similar manner, and suffers the same change. The alkaline sulphurets combine with iron by fusion, and also

by boiling with water. Sulphuretted hydrogen, and the hydro-sulphurets, form precipitates from the salts of iron.

With phosphorus iron forms a compound, white, brittle, and of a granular fracture.—A compound of this kind, obtained from cast iron, was once regarded as a peculiar metal, and named Siderite. It has been considered as the cause of the cold short property of iron.

Iron combines with a number of the metals, but few of its alloys are applied to use. That with gold is hard, ductile, and malleable, but of a dull grey colour. With silver it forms an imperfect combination. With platina the combination is not easily effected, from the infusibility of both metals. It does not easily amalgamate with quicksilver; the combination can only be produced by indirect methods, and is imperfect. The alloy with copper is brittle, and of a grey colour. The principal alloy of any use is that with tin, this forming what is named Tinned Iron.

Iron is perhaps the most useful of the metals, possessing in its pure form the highest degree of tenacity, ductility, elasticity, and hardness, combined, whence it is applied to all purposes where strength is required; and though infusible, it is capable, by the singular operation of welding, of being easily fashioned and worked. Cast iron, being fusible, can be adapted to other purposes, and derives value from its hardness, and from being less liable than forged iron to be acted on by the air. And the great elasticity and hardness of steel adapt it to numerous uses, for which other metals would afford very imperfect substitutes.

CHAP. XI.

OF LEAD.

Lead is the softest and least elastic of the metals; it has little ductility, but considerable malleability; its lustre tarnishes speedily; its specific gravity is 11.3; when rubbed it has a peculiar smell; it has also a perceptible taste, and is one of those metals which prove most noxious to animal life. Its action too, as a poison, is very insidious, being liable to accumulate in the system, without immediately producing any sensible effect.

Lead occurs mineralized by carbonic, sulphuric, phosphoric, and molybdic acids, and by sulphur. It is from the last of these ores, the Galena of mineralogists, that the greater part of the lead of commerce is extracted; the ore reduced to powder being mixed with lime, and exposed to a sufficient heat; the lime combines with the sulphur, and the lead is run out. The other ores are previously roasted, and are treated in a similar manner.

Lead melts at a temperature a little inferior to ignition, or about 594° of Fahrenheit. When cooled slowly, it crystallizes in aggregated pyramids. By an intense heat it is volatilized.

When in fusion it is oxidated with great facility by the atmospheric air; its surface is quickly covered with a film

which increases, and a grey powder accumulates, consisting of the metal in the first stage of oxidation. This, by exposure to a higher heat, acquires a lively yellow colour, forming what is named Massicot, a change probably owing to farther oxygenation. If the flame be made to reverberate on its surface, and it be constantly stirred, the colour changes to a bright red, and the substance named Minium, or Red Lead, is formed. By applying heat quickly to the oxide, directing at the same time a current of air over its surface, it is semi-vitrified, and forms a substance in thin scales, named Litharge. This, by a more powerful heat, may be completely vitrified, when it forms what is named the glass of lead. It is probable that the degrees of oxidation of lead are nearly indefinite, there being no external circumstance connected with their formation to render them determinate. The proportion of oxygen in the grey oxide has not been determined. In the yellow oxide obtained by decomposing the nitrate of lead, the proportion of oxygen, according to Proust, amounts to 9 in 100 parts, according to Dr Thomson 10.3. In minium, the quantity of oxygen is equal to 12 parts. Litharge, Dr Thomson found to contain about 4 parts of carbonic acid in 100, united with the yellow oxide. The existence of a brown oxide, formed by the action of nitric acid, or oxy-muriatic acid on the red oxide, has also been supposed containing a larger proportion of oxygen than any of the others. All the oxides of lead have a considerable specific gravity; they are fusible, and act as powerful fluxes on earthy matter. The red oxide is partially decomposed by heat, giving out a portion of oxygen

gas. It and the other oxides are easily reduced by heating them with carbonaceous matter.

Lead does not decompose water, so as to produce any sensible disengagement of hydrogen gas; but when kept immersed in water for some time, it is encrusted with a white substance, formed probably from the action of the oxygen which water holds loosely dissolved.

Lead is oxidated by a number of the acids, and its oxides combine with them easily. Its salts, those of them at least which are soluble, are distinguished by a peculiar sweet and styptic taste.

Sulphuric acid has little sensible effect on it, unless its action is aided by a high temperature, and even then the action is imperfect. The neutral sulphate of lead, formed by decomposing any of the soluble salts of lead by an alkaline sulphate, is very sparingly soluble, so as to be instantly precipitated. With an excess of acid it becomes more soluble, and by evaporation of its solution, is obtained in needle-like crystals.

Nitric acid acts more readily on lead, oxidating and dissolving it; the solution by evaporation affords small pyramidal crystals, white and semi-transparent, with adamantine lustre. They are decomposed by heat, and deflagrate when thrown on burning fuel. Muriatic acid exerts but a feeble action on metallic lead; it combines, however, with its oxides, forming a compound not easily obtained without an excess of acid. The neutral muriate is best formed by decomposing any of the soluble salts of lead by muriate of soda; being very sparingly soluble in water, it is immediately precipitated: it can be so far dissolved,

however, by the aid of heat, as to afford, by evaporation of its solution, slender prismatic crystals. It melts at a moderate heat, and forms, on congealing, a solid semi-transparent mass, which, from its appearance, has been named Horn Lead. By urging it with a stronger heat, it is partially decomposed. Oxy-muriatic acid, by its action on metallic lead, forms nearly the same compound. When transmitted through water in which the red oxide is diffused, it brings it to a higher state of oxidation, and combines with this oxide, forming a salt more soluble than the muriate.

Phosphoric acid has scarcely any sensible action on lead, but combines with its oxide, forming, when the combination is established by the exertion of a double attraction, a compound of very sparing solubility. Nearly the same relations are displayed by fluoric and boracic acids. Carbonate of lead, when it is formed by a similar process, is likewise insoluble. Cerusse, or white lead, is a sub-carbonate. It is prepared by exposing plates of lead to the vapour of vinegar; a white crust forms on their surface from the oxidation of the metal, and the oxide either absorbs carbonic acid from the atmosphere, or the portion of this acid combined with it, is formed from the partial decomposition of the vinegar. When cerusse is boiled with vinegar, it is dissolved, and by evaporation, a salt is obtained in slender prisms aggregated, the sugar of lead of commerce, the super-acetate of lead.

The salts of lead are decomposed by the alkalis and earths. If an excess of the decomposing substance is added, part of the precipitate is redissolved, and the fixed

alkalis and lime, when boiled in solution on the oxides of lead, dissolve a minute portion of them. The earths vitrify with them with great facility, and oxide of lead is powerful in promoting the vitrifaction of all earthy mixtures.

Oxide of lead can, on the other hand, decompose a number of the alkaline and earthy salts, particularly the muriates and sulphates. When triturated with muriate of ammonia and a little water, the mixture soon disengages an ammoniacal odour from the oxide combining with the acid. When triturated in a similar manner with muriate of soda, on continuing the trituration, and allowing the mixture to stand in a humid state, the decomposition of the salt is complete, the soda being dissolved by the water, while the oxide and acid remain in combination. These decompositions appear to be owing to the affinity of the oxide of lead to the acid being aided by its quantity; and accordingly a large quantity of oxide, four parts to one of the salt, are necessary to the decomposition; and the residual matter is sub-muriate of lead with a great excess of oxide. The process has been carried on on a large scale to obtain soda from muriate of soda, the sub-muriate of lead forming, when exposed to heat, a substance of a yellow colour, the sale of which as a pigment rendered it more economical.

Lead does not unite with carbon. With sulphur it combines by fusion, forming a compound of a dark-grey colour and metallic lustre. Sulphuretted hydrogen tarnishes the lustre of lead, and it decomposes its saline compounds, forming a precipitate of a very dark colour, which appears

to be a sulphuret of lead, the hydrogen of the sulphuretted hydrogen combining with the oxygen of the oxide, while the sulphur unites with the lead. The action of the sulphuretted hydrogen combined with the alkalis or earths, is similar. It affords the most delicate test to discover the presence of lead, and is sometimes employed to detect it where it is suspected to be present in wines or other liquors, the solution of the sulphuretted hydrogen, or what is more frequently employed, of the sulphuretted hydro-sulphuret of potash, being added to the liquor. It is liable to some fallacies, however, from precipitating other metals, as iron, likewise of a dark colour; and this is only imperfectly obviated by different additions which have been made to what are named the wine tests; to render it certain, therefore, the precipitate ought always to be reduced to the metallic state. From the deepness of the colour produced by the action of sulphuretted hydrogen on the salts of lead, solutions of these form a well-known sympathetic ink, lines traced with any of them on paper becoming visible when exposed to the gas.

Lead forms with phosphorus a compound of a greyish-white colour, and metallic lustre, soft so as to be easily cut by a knife, flexible, and of a lamellated texture.

With the greater number of the metals lead combines easily by fusion, but few of its alloys are applied to any useful purpose. It diminishes greatly the ductility of gold, silver, and platina. It amalgamates readily with quicksilver, forming alloys more or less solid, according to the proportions. With copper it forms an alloy of a grey colour; with iron it can scarcely be combined.

Lead is adapted to many purposes of utility, from its flexibility, the facility with which it is cast into different forms, and with which, when in sheets, it is united by solder. In thin sheets, it is employed for covering the roofs of buildings. It forms evaporating vessels and boilers, to which the fire may be directly applied. And pipes formed of it are in common use for conveying water; an application which has not been supposed to be altogether without danger, as lead suffers a slight oxidation at its surface when immersed in water; in water conveyed through leaden pipes, however, no indication of the presence of lead can be discovered by the action of sulphuretted hydrogen; and from the perfect exclusion of the atmospheric air, the metal is probably little acted on by the water. The use of cisterns of lead for containing water must be more hazardous, as in these the metal is exposed to the action both of air and water; and they are probably rendered safe only from the deposite of the earthy matter contained in spring water, which forms a crust covering the surface of the metal. The oxides of lead are employed as pigments, and in the manufacture of the finer kinds of glass, to which they communicate greater density, and a higher refractive power. They are also used in glazing the coarser kinds of earthen ware, another practice which is not without hazard, as the glazing is easily acted on by liquors slightly acid. Several preparations of lead are employed in medicine, from their styptic power.

CHAP. XII.

OF TIN.

Tin has a white colour, with a slight shade of grey; it has little ductility, but so much malleability as to be capable of extension into thin leaves; it is soft and flexible, and in bending gives a peculiar crackling noise. It is one of the lightest of the metals, its specific gravity being not more than 7,3. It occurs in nature in the state of oxide, and in smaller quantity in that of sulphuret, and is one of the metals of least extensive distribution, being found in comparatively few countries. It is extracted from the native oxide by fusion in contact with the fuel, the oxygen being abstracted by the carbonaceous matter.

Tin is one of the most fusible of the metals, its melting point being not higher than 442°. When in fusion, if it is exposed to the atmospheric air, a film quickly forms on its surface, and a grey oxide accumulates. If this be longer exposed to heat, and stirred, it becomes of a yellowish-white colour, from passing to a higher state of oxidation. When tin is exposed to a high heat, it burns with a weak flame; and it is also oxidated with the phenomena of combustion, when exposed to a full red heat in mixture with nitre. The grey oxide has been supposed to contain from 8 to 10 of oxygen in 100 parts; the oxide at the *maximum*

formed by the action of nitric acid on tin, contains, according to Proust, 30 or even 40 in 100 parts. These oxides are reduced with facility by exposure to a sufficient degree of heat in mixture with carbonaceous matter. They are extremely infusible, but vitrify with earthy substances.

Tin loses its lustre from exposure to the air, but is not liable to rust. It suffers little change from the action of water at any temperature.

Tin is oxidated and dissolved by the acids, and in these combinations is displayed one of the most characteristic properties of this metal, the avidity with which it combines with oxygen, and its tendency to pass to a highly oxidated state, so that the compounds at the *minimum* of oxidation are not easily obtained.

When heat is applied to favour its action on sulphuric acid, the acid is decomposed, and the decomposition proceeds to that extent, that not only is sulphurous acid disengaged from the partial abstraction of oxygen, but from its entire abstraction sulphur is separated. The solution deposites slender crystals; it is decomposed by the affusion of water, and suffers even spontaneous decomposition when kept for some time, the oxide passing gradually to so highly an oxidated state, that it exerts a less energetic action on the acid. Sulphurous acid is also decomposed by tin; a portion of sulphuret of tin appears to be formed, and sulphite of tin is partly precipitated, partly retained in solution.

Nitric acid, in its most concentrated state, exhibits the same singular phenomenon with tin that it does with some other metals; it is not decomposed by the metal, nor does

it produce on it any change. But if somewhat weaker, or if a little water is added, the mutual action is rapid and violent, dense vapours of nitrous acid are disengaged, and the tin is so highly oxidated, that it is not dissolved, and appears scarcely to be combined with any of the acid. If the acid is more largely diluted, a more perfect solution is obtained, though still attended with the abundant disengagement of nitric and nitrous oxides. Such is the avidity even of this metal to oxygen, that the decomposition of part of the acid is complete; the water is at the same time decomposed by the abstraction of its oxygen, and the nitrogen of the one and hydrogen of the other being evolved, are presented to each other in their nascent state, unite and form ammonia, with which a portion of the acid combines. In the solution formed with the concentrated acid, the metal is oxidated to the *maximum*; when a dilute acid has been employed, it is less highly oxidated; it is not, however, permanent, but continues to attract oxygen from the acid, so as to become at length insoluble.

Muriatic acid dissolves tin slowly in the cold, and more rapidly when heat is applied, hydrogen gas being disengaged: this gas, it has often been remarked, has a peculiar fœtid odour, somewhat approaching to the arsenical odour, and it has hence been supposed to hold arsenic dissolved derived from the tin; it is more probably owing to the solution of a portion of tin itself. The solution of muriate of tin deposites, when concentrated, needle-like crystals, which are somewhat deliquescent; they are not dissolved in water without being partially decomposed, and sub-muriate of tin precipitated. In this combination, the

tin is at a low degree of oxidation, but it has a great tendency to pass to a more highly oxidated state, and in consequence of this, this solution acts with energy on a number of the compounds of oxygen, particularly the metallic salts, decomposing them partially, or even in some cases completely, by attracting oxygen. It attracts oxygen, too, from several of the acids, and absorbs it from the air.

The muriate of tin, at the *maximum* of oxidation, is possessed, when in its concentrated state, of some very peculiar properties. The process long known to chemists, by which it is obtained in this state, consists in exposing to heat a mixture of an amalgam of tin and quicksilver with corrosive muriate of mercury; the oxygen and muriatic acid being transferred from the quicksilver to the tin, and the muriate of tin obtained by distillation. It forms a dense liquid, which exhales vapours when exposed to the atmosphere; these consisting of the muriate, which, in this concentrated state, is highly volatile, combining with the watery vapour of atmospheric air; their odour is acrid; the liquid, on being presented to water, combines with it with a hissing noise, and the disengagement of an elastic fluid. When combined with about one-third its weight of water, it forms a solid mass, which melts on the application of heat, and congeals by cold.

Nitro-muriatic acid dissolves tin with great rapidity; to obtain a proper solution, it is even necessary that the action should be moderated by dilution with water, and by adding the metal in successive portions; otherwise it is so highly oxidated, as scarcely to enter into combination with the acid. The solution, when concentrated, soon acquires

a gelatinous consistence, and at length becomes firm. It is also at once rendered gelatinous by the affusion of water, which decomposes it, and precipitates the oxide, this remaining diffused through the liquor, and rendering it white and opaque. This solution is an important mordant in the art of dyeing, rendering several colours, particularly scarlet, more brilliant and permanent.

The phosphoric, fluoric, and boracic acids, form with the oxides of tin insoluble compounds.

The alkalis unite with oxidated tin; when employed to decompose the salts of tin, they re-dissolve the precipitate when added in excess; and after some time a partial decomposition is produced in the solution, one portion of the oxide of tin passing to a more highly oxidated state, while the portion losing this oxygen is reduced, and appears in the form of metallic arborescence. The ternary compounds of oxide of tin, with portions of acid and of alkali, are even capable of crystallizing. The alkalis dissolve likewise the oxide, independent of the presence of any acid,—exerting, in conformity to the law already stated, the strongest attraction to the metal in its more highly oxidated state. Some of these combinations likewise crystallize.

Tin and its oxides decompose several of the neutral salts, especially those having ammonia for their base.

Tin and sulphur unite easily by fusion; the compound is of a grey colour with metallic lustre, and may be obtained crystallized in cubes; with oxide of tin sulphur unites, forming a compound of a golden colour and lustre, and flaky appearance, named *aurum musivum*, and sometimes used for ornamental purposes. It may be formed

by various processes, but the one usually followed is to melt twelve parts of tin in a crucible; and as it cools, add three parts of quicksilver, completing the amalgamation by trituration. It is then intimately mixed with seven parts of sulphur and three parts of muriate of ammonia: the mixture is exposed to heat in a matrass as long as any white vapours are disengaged: the heat is then moderately increased, a little sulphuret of mercury and muriate of tin sublime, and the *aurum musivum* remains at the bottom of the matrass.

The theory of the formation of this compound is intricate, but it appears to have been sufficiently ascertained by the researches of Pelletier. In the first amalgamation and trituration of the mercury and tin, the latter is divided, and in some degree oxidated; when the mixture of this amalgam with the sulphur and muriate of ammonia is heated, the muriatic acid, by a resulting affinity, enables the tin to be oxidated by decomposing the water, and this oxide combines with the muriatic acid; the hydrogen of the water is disengaged, with the ammonia of the muriate of ammonia, this ammonia uniting with a portion of the sulphur, and forming sulphuret of ammonia, which being disengaged, causes the white fumes. The heat being now augmented, the muriate of tin is again decomposed, the oxide of the metal attracts a portion of sulphur, and forms the *aurum musivum*. In conformity to this theory, Pelletier found that, by combining oxide of tin and sulphur by several more simple processes, the same compound is formed.

Sulphuret of potash combines with tin by fusion; the compound is partly soluble in water: if an acid is added to

the solution, the tin is precipitated in combination with sulphuretted hydrogen. The metal is tarnished by sulphuretted hydrogen gas, and the alkaline hydro-sulphurets form coloured precipitates with its saline compounds.

Tin combines with phosphorus; the compound has the metallic brilliancy, is of a white colour and foliated texture, and so soft that it can be cut with a knife.

With the greater number of the metals tin combines with facility, and several of its alloys are in common use. It had always been believed, that in combining with gold it destroys its ductility, though present even in the most minute quantity. From the experiments of Alchorne, this appears however to be a mistake, and it had probably originated from the operation of some of the other metals, which the tin of commerce contains in small quantity. It has also been supposed to destroy the ductility of silver, an opinion probably resting on the same foundation. It combines with platina, and amalgamates easily with quicksilver; when the proportion of quicksilver is only one fifth, the alloy is solid and capable of crystallizing. With copper a series of valuable alloys are formed, bronze, bell-metal, and others. Bronze is the one in which the proportion of tin is smallest; it does not exceed 10 or 12 parts in 100; it is harder than copper, less liable to rust, and when melted, runs thinner, and therefore takes a more delicate impression from a mold; hence its adaptation to the fabrication of statues and ornamental vessels. The metal of which pieces of artillery are cast is of similar composition. An alloy nearly of the same composition was in use among the ancients, for the fabrication of

swords, darts, and other warlike instruments, Dr Pearson having analyzed different ancient instruments of this kind, and found the composition to be eight or nine parts of copper with one of tin, and from its hardness it affords, as he remarks, the best substitute for iron or steel. Of the same alloy ancient medals and coins appear to have been often formed. When the proportion of tin is larger, the alloy becomes more brittle; it is also highly sonorous; it then forms bell-metal. With the tin considerably increased in quantity an alloy is formed nearly white, of a close texture, susceptible of a fine polish, and not liable to tarnish, and, from these qualities, well adapted to the purpose to which it has been applied, that of forming the speculum of reflecting telescopes; the addition of a small portion of arsenic and zinc adds to the density and whiteness. The composition recommended from the latest experiments, those by Mr Little, is 32 of copper, 4 of brass, $16\frac{1}{2}$ of tin, and $1\frac{1}{4}$ of arsenic. Lastly, from the affinity between tin and copper, the latter metal can be covered with a thin layer of the former; this tinning of copper is executed by applying melted tin to the surface of the copper, perfectly clean and preserved from oxidation at the temperature to which it is raised by the application of muriate of ammonia, or sometimes of pitch; by this covering the noxious impregnation which might be communicated from copper-vessels to liquors boiled or preserved in them, is supposed to be prevented, though, as the coating is thin and easily eroded, it may be doubted if it affords any security.

Tin and iron unite by fusion, forming alloys with pro-

perties in some measure intermediate according to the proportions. Plates of iron immersed in melted tin unite with it at both surfaces, forming tinned iron, which, in the fabrication of small vessels, has the advantages over iron of being more flexible, less liable to rust, and easily united by solder. Tin and lead, differing little in their fusibilities, can be united in all proportions, and the compounds are nearly intermediate in physical properties, but more fusible. Pewter is an alloy of this kind, with the addition sometimes of a little copper and zinc. Equal parts of tin and lead form soft solder.

The amalgam of tin is used as a covering to glass mirrors, to enable them to reflect the light, and glass globes are sometimes coated internally by a similar amalgam.

It is in the formation of these alloys that tin is principally employed. Its oxides are used in enamelling, and to polish the metals; and its solution in nitro-muriatic acid is a valuable mordant in the processes of dyeing.

CHAP. XIII.

OF ZINC.

Zinc is a metal which appears to have been discovered during the researches of alchemy. It exists in nature mineralized by oxygen, with or without carbonic acid, and by sulphur. From the first of these ores, the calamine of

mineralogists, it is extracted by a process founded on its volatility. The calamine, calcined with a low heat, is mixed with charcoal powder; the mixture is put into conical pots closed at the head, a tube which rises nearly to the top within descending through the bottom, and terminating in a vessel of water beneath. A sufficient degree of heat is applied around the pot, the oxide of zinc is reduced, and the metal volatilized is condensed at the termination of the tube.

Zinc is of a bluish-white colour, accompanied in the fresh fracture with considerable lustre, but liable to tarnish from exposure to the air; its texture is striated, it is hard, and has a specific gravity of 7.2. It was usually placed among the semi-metals, as having little ductility or malleability; it was always known, however, to have these properties to a certain extent; and more lately it has been shewn by Mr Silvester, that at a certain temperature, it can both be drawn into wire, and extended in thin plates, so as to be applied to purposes of utility founded on these properties. The temperature at which this can be effected is between 210 and 300 of Fahrenheit; and by annealing, it retains its tenacity when cold, so as to admit of being easily bent. At a higher temperature it is brittle.

Zinc melts nearly at ignition, and, when heated to a higher point, is volatilized unchanged. If the air is admitted to it when in fusion, its surface is covered with a grey oxide, and, if heated fully to ignition, the oxidation becomes more rapid, and is attended with a vivid light, and considerable heat; an oxide is formed in light white flocculi, which are in part carried off by the rapid current

of heated air arising from the surface of the burning metal. The oxide itself is not volatile, but vitrifies when urged by an intense heat, forming a transparent glass of a yellow colour. The oxide formed by the rapid oxidation consists of 80 of zinc and 20 of oxygen; in its vitrification it loses a little oxygen, so as to contain not more than 11 of oxygen in 100 parts.

Zinc is scarcely sensibly acted on by water at a low temperature, but at a temperature approaching to ignition, decomposes it, attracting oxygen.

It is oxidated and dissolved with facility by the greater number of the acids. Sulphuric acid, in its concentrated state, requires the aid of heat. When diluted, it acts on the metal rapidly in the cold, enabling it to decompose the water, and hence the solution is attended with a copious production of hydrogen gas. The solution, when concentrated, is of a thick consistence, and affords in a short time slender prismatic crystals of sulphate of zinc. This crystallized salt consists of 40 of oxide, 20.5 of acid, and 39 of water. It is soluble in three times its weight of water at 60°, and in its own weight at 212°. The white vitriol of the shops is a sulphate of zinc not crystallized. It is prepared on a large scale from sulphuret of zinc, calcined, moistened, and exposed to the action of the air; the zinc is oxidated, the sulphur is converted into sulphuric acid, and the materials, by lixiviation, afford the sulphate which, by evaporation, is obtained in the state of a white granular mass; it generally has a sensible impregnation of iron.

Nitric acid is decomposed by zinc with great rapidity;

by using a dilute acid, a solution is obtained, which, by evaporation and cooling, crystallizes in slender prisms, deliquescent, and readily soluble both in water and alkohol.

Muriatic acid likewise dissolves this metal rapidly, by enabling it to attract oxygen from the water, and combining with the oxide. The solution becomes gelatinous on evaporation, without affording crystals; and when the dry mass is urged by heat, it is partly sublimed, partly decomposed. Phosphoric acid likewise dissolves zinc, by enabling it to decompose water so as to be oxidated; and this solution does not crystallize, but rather becomes gelatinous on evaporation. Even fluoric acid, which acts on few of the metals, causes the oxidation of zinc by water, and dissolves the oxide. Boracic acid, combined with the oxide by a double affinity, forms an insoluble compound. Carbonic acid, combined with water, dissolves it in small quantity.

The salts of zinc are decomposed by the alkalis and earths. If an excess of alkali be added, the precipitate is re-dissolved, and on this is founded a method of analyzing brass, which is an alloy of zinc and copper, the brass being dissolved in diluted nitric acid, the solution being decomposed by an alkali, and the precipitate, which consists of the oxides of zinc and copper, after being dried and weighed, being submitted to the action of solution of potash, by which the oxide of zinc is dissolved, while the oxide of copper remains undissolved. The fixed alkalis even act on metallic zinc, promote its oxidation by water or atmospheric air, and dissolve the oxide.

This metal, having so strong an attraction to oxygen,

decomposes the greater number of the metallic salts, precipitating the metal which is their base in its metallic form.

It is soluble in small proportion in hydrogen gas. With carbon it does not combine in any considerable quantity; but the zinc of commerce, during its solution in diluted sulphuric acid, deposites a black powder, which has been supposed to consist chiefly of carbonaceous matter. Neither can zinc be united with sulphur, though the compound exists in nature. When oxidated, however, it unites with sulphur, forming a compound of a brown colour, and volatile. The alkaline sulphurets do not dissolve it. Sulphuretted hydrogen throws down a white precipitate from the solutions of its salts. With phosphorus it combines, forming a compound of a white colour, with metallic lustre, malleable, and which burns when heated with the admission of the air. Phosphorus unites too with oxide of zinc, the compound being volatile, and being capable of being obtained by sublimation in needle-like crystals of a white or bluish colour, with metallic lustre, and highly inflammable.

Zinc combines in general with the other metals. It impairs, even when added in very minute quantity, the ductility of gold and silver, rendering them also more hard. With quicksilver it forms a granular mass, which, when solid, can be crystallized. With copper, a series of alloys are formed, the most extensively used of any of the compound metals. The combination is not easily formed directly, owing to the volatility of the zinc; it is therefore usually effected by the process named cementation, copper-plates being stratified with calamine in powder mixed

with charcoal, and exposed to the necessary heat; the zinc of the calamine is reduced by the charcoal abstracting the oxygen with which it is united, and unites with the copper; and this alloy being fusible, can be combined easily with additional proportions of copper or zinc. Brass is of these alloys the one which contains the largest quantity of zinc, the proportion being one to three of copper; it has the advantage, from being more fusible than copper, of being more easily cast, and it is less liable to tarnish or rust. With a larger proportion of copper, the colour approaches more to red; pinchbeck, tombac, and princes metal, are alloys of this kind. Zinc does not easily combine with iron, from the very high temperature required to melt the iron; but when iron plates are immersed in melted zinc, the metals enter into combination at the surface. It combines easily with lead and with tin, forming alloys harder than these metals.

It is principally in the formation of the alloys with copper that zinc is employed; since the discovery of the practicability of extending it in thin sheets, it has also been proposed to substitute it for some of the purposes to which lead is applied. Some of its preparations are employed in medicine.

CHAP. XIV.

OF NICKEL.

Cronstedt discovered this metal, having extracted it from its principal ore, the kupfer-nickel of mineralogists, in which it exists combined with arsenic, and a small portion of sulphur. It had usually been ranked, from its brittleness, among the semi-metals; but more recent researches, particularly those of Richter, have shewn that this brittleness is generally owing to the presence of arsenic, and that when obtained free from alloy, it is both ductile and malleable. It is extracted from the kupfer-nickel by calcining the ore to expel the volatile matter; the residual substance is mixed with twice its weight of black flux, and is melted by applying the intense heat of a forge; a metallic button is thus obtained, composed of the nickel alloyed with small portions of other metals. These it is difficult to abstract entirely, and complicated processes are therefore required to obtain nickel perfectly pure.

When obtained in a state of purity, it is of a white colour intermediate between that of silver and tin, with considerable lustre; in its usual state the colour has a reddish tint; it is hard, but has so much malleability as to be capable of being forged into very thin plates: its specific gravity is 8.6. It is very sensibly magnetic, a pro-

perty which had been supposed to depend on the presence of iron. But it appears to be sufficiently established that it belongs to nickel itself, for instead of becoming weaker as the metal is purified, it becomes stronger, and at length is so strong, that if it arose from the presence of iron, it would be necessary to suppose that the iron amounts to one half its weight, though at the same time no traces of it are discoverable by chemical tests. The effect of the magnet on pure nickel is little inferior to that on iron; it can also be rendered magnetic, and magnetic needles have been constructed of it, which have the advantage of not being liable to rust.

Nickel is extremely infusible; it is imperfectly agglutinated even in the heat which melts malleable iron. When submitted to a high temperature under exposure to atmospheric air, it is oxidated, though with difficulty; by submitting it to heat mixed with nitre, its oxidation is effected with more facility. Its oxide is of an apple-green colour, and is obtained of the same colour by precipitation from some of its saline combinations. This is the oxide at the *minimum* of oxidation; when exposed to a continued red heat, or to the action of oxy-muriatic acid, it passes to a higher state of oxidation, becomes of a black colour, and when acted on by acids, is reduced again to a lower state of oxidation, a portion of oxygen being expelled.

Nickel is oxidated and dissolved by the acids; its salts are usually of a green colour. Sulphuric acid requires the aid of heat; and by evaporation of the solution, crystals of a pale green colour are obtained. Nitric acid forms a solu-

tion of a rich green colour, and rhomboidal crystals of the same colour are formed on evaporation. Muriatic acid acts more weakly on the metal, but dissolves its oxide, and likewise affords crystals of the same colour. Nitro-muriatic forms the same salt with more facility. Phosphoric acid scarcely combines even with the oxide. Fluoric acid dissolves it. Boracic acid does not directly combine with it, but the combination may be effected by the exertion of a double affinity. Carbonic acid is united with the oxide by a similar method; the carbonate, of an apple-green colour, is decomposed by heat.

The salts of nickel are decomposed by the alkalis and earths, and precipitates of a green colour thrown down. When the alkali is added in excess, the precipitate is redissolved. The pure oxide is likewise soluble in the alkaline solutions; the solution in liquid ammonia is of a rich blue colour, similar to that of copper in the same alkali; but what has been pointed out as very characteristic of nickel, is that the colour gradually changes to a purple, and lastly to a violet; the violet, by the addition of an acid, is changed to a green; but by again adding ammonia, the blue colour is restored. An effect rather singular, is the precipitation of the oxide of nickel from liquid ammonia by potash or soda.

Nickel combines with sulphur by fusion, forming a compound of a yellow colour, hard and brittle; with phosphorus it unites; the compound is of a white colour, with metallic lustre, and has a crystalline texture.

With the other metals it forms alloys, but as the nickel has been employed in their formation in its usual impure

state, their properties are scarcely be considered as known. Its oxide combines by fusion with the vitrifiable earths, and forms glasses of a hyacinthine colour.

CHAP. XV.

OF COBALT.

The ores of this metal had been long employed, from a property belonging to it, of giving a blue colour to glass. The metal itself was first extracted by Brandt, and its properties were examined by Bergman. It occurs in nature alloyed with arsenic, nickel, and other metals, and mineralized likewise by oxygen, and by arsénic acid. It is obtained after the ore has been roasted and calcined, in the state of an oxide impure from the presence of other metallic oxides. This, with an intermixture of siliceous earth, forms the zaffre of commerce. When mixed with thrice its weight of black flux, a little sea salt and oil, and urged with an intense heat, it is reduced, and affords metallic cobalt, alloyed, however, with portions of arsenic, nickel, and generally of iron. To free it from these is difficult, and very complicated processes are required.

When cobalt is obtained in a state of purity, it is of a white colour inclining to grey, and if tarnished to red, with moderate lustre; its fracture is compact; it is hard and brittle; its specific gravity is 7.8. Like nickel, it is

sensibly magnetic; and this even as powerfully as iron, and when it has been purified, so that no traces of that metal are discoverable by tests, by which a minute portion of it intentionally added was detected.

Cobalt requires a very intense heat to melt it; its fusing point has been estimated at 130 of Wedgwood's scale. At a temperature much inferior to this, it suffers oxidation from the action of the air: the oxide is of a deep blue colour; a precipitate of a similar colour is thrown down from its saline compounds by the alkalis. This, when exposed to the air in a humid state, appears to absorb oxygen; it assumes an olive colour, and when heated in contact with the air, it becomes brown, and at length nearly black. The oxide at the *minimum* has been stated by Proust to contain 19 of oxygen, that at the *maximum* 24 of oxygen in 100 parts.

The acids oxidate cobalt, or combine with its oxides. When sulphuric acid is boiled on it, sulphurous acid is disengaged, and a saline matter obtained of a reddish colour, which is sulphate of cobalt. This, when dissolved, affords, by evaporation, acicular crystals of a reddish tinge. Nitric acid oxidates and dissolves the metal in the cold; the solution is of a red colour, and affords on evaporation minute prismatic crystals, which are deliquescent. Muriatic acid, to act on cobalt, requires the application of heat; it dissolves the oxide more readily, forming a solution of a reddish tinge, and which by evaporation affords needle-like crystals of the same colour. Phosphoric acid forms with its oxide a red-coloured solution, which, when saturated, is turbid. Fluoric acid gives a gelatinous

solution. Boracic and carbonic acids are combined with it by the process of double affinity, and form compounds of sparing solubility.

The solutions of the salts of cobalt afford a sympathetic ink, lines traced with them on paper being invisible when cold, but becoming green when heated, the green colour disappearing again as the paper cools. The solution usually employed for this purpose, is prepared by dissolving one part of zaffre in two of diluted nitric acid, with the aid of heat, adding to it muriate of soda one part, and diluting it with twenty parts of water. A red sympathetic ink is said to be formed by dissolving pure oxide of cobalt in pure acetic acid; and a purple one by dissolving it in distilled vinegar, and adding to the solution muriate of soda.

The salts of cobalt are decomposed by the alkalis and earths, precipitates being thrown down of a red tinge; or, according to Thenard, if the cobalt is perfectly pure, of a blue colour. By an excess of alkali, they are re-dissolved, particularly when ammonia is employed, and the oxide is at the minimum of oxidation. It vitrifies with siliceous earth, forming a substance of a deep blue colour, the smalt of commerce.

Cobalt does not combine with sulphur by fusion, but is dissolved by the alkaline sulphurets. With phosphorus it unites, forming a compound of a white colour and metallic lustre, brittle, and of a striated texture.

It forms alloys with a number of the metals, but none applied to any use. Gold and silver it renders quite brittle. It does not amalgamate with quicksilver. With cop-

per it forms an alloy, white, hard, and brittle; with iron, one of a close grain, and very hard. It combines with lead in different proportions, the alloy, when the proportion of cobalt is considerable, being brittle and hard: with tin it forms a compound metal, of a violet colour, and close grain. It does not combine with zinc.

Cobalt is principally employed to give a blue colour to glass, a portion of its oxide being fused with the glass. Its oxide is applied by the proper flux to give the blue colour in painting on porcelain.

CHAP. XVI.

OF MANGANESE.

This metal occurs in nature in the state of oxide, and this oxide had been used in some arts, particularly in the manufacture of glass, to render it free from colour, before its nature was known. Scheele and Bergman, from an examination of it, inferred that it is the oxide of a peculiar metal, and this metal has since been procured in its pure form. The process, however, is extremely difficult, from the intense heat that is required. The oxide reduced to powder, is made into a paste with a small quantity of oil and charcoal, and being imbedded in charcoal powder, is exposed to the most intense heat which the most powerful furnace can raise. To obtain it more free from iron,

the oxide may be previously dissolved in diluted nitric acid, adding a little sugar, which is necessary to promote the solution; this solution is decomposed by carbonate of soda; the white precipitate of carbonate of manganese being dried, is decomposed in the manner above described. The metal can scarcely be obtained but in small globules. In this state it is of a greyish-white colour, with moderate lustre, which tarnishes, however, on exposure to the air; its texture is granular, it is brittle and hard, its specific gravity is 6.8. Some of the globules split and fall to powder on exposure to the air, while others retain their metallic form; the change in the former has been ascribed to the presence of a portion of carbon, which absorbing oxygen, the cohesion is subverted.

When metallic manganese is exposed to heat in contact with the air, it passes rapidly through different stages of oxidation, becoming grey, yellow, red, brown, and at length black; this black oxide being the metal at the *maximum* of oxidation, and the same with the native oxide. By precipitation from some of its saline compounds, an oxide nearly white is obtained, in which the metal appears to be at the *minimum* of oxidation; the white oxide, according to Bergman, consists of 80 of manganese, and 20 of oxygen; the black oxide, according to Fourcroy, of 60 of manganese, and 40 of oxygen, and the series between these is probably indefinite. The white oxide absorbs oxygen when exposed to the air, especially when heated a little; the black oxide, on the contrary, at a temperature above ignition, gives out a portion of oxygen gas, the quantity being larger as the heat is more intense;

it is thus converted into oxides of different shades of brown and grey. The affinity of the metal to oxygen becoming more powerful as the decomposition proceeds, from the increase in its relative quantity, it is at length capable of counteracting the effect of the elevated temperature, and it is scarcely possible, by any intensity of heat, to reduce it to the state of the white oxide.

Manganese being not easily procured in its metallic form, its relations to the acids have been examined principally in their actions on its oxides; and these display extremely well the effects of particular degrees of oxidation on these relations. In general it appears, that the black oxide is too highly oxidated to combine with the acids; and hence the necessity of its de-oxidation in establishing these combinations.

Thus, when sulphuric acid is brought to act on the black oxide, by applying a moderate heat, it does not directly combine with the oxide, but decomposes it, a considerable portion of its oxygen is separated, and assumes the elastic form, and with the oxide thus reduced in its degree of oxidation, the acid combines. This sulphate of manganese is soluble in water; when obtained neutral, it becomes gelatinous, forming at the same time small crystals. The alkalis throw down from it a reddish-yellow precipitate. The oxide existing in it appears to be not altogether at the minimum of oxidation. The salt formed by the action of sulphuric acid on metallic manganese, is rather in that state; it is colourless, affords by evaporation rhomboidal crystals, and gives a white precipitate when decomposed by the alkalis. It is obtained in a similar

state, by digesting the black oxide with sulphuric acid, and a portion of carbonaceous matter, as sugar, which attracts the excess of oxygen from the salt. Sulphurous acid forms a similar combination.

Nitric acid does not dissolve the black oxide of manganese, but if any substance is added which attracts oxygen from the acid, this enables it to re-act on the oxide, and reduce its state of oxidation, and then the solution is effected. A little alkohol or sugar has this effect, or, as Scheele shewed, exposing the acid with the oxide to the solar rays. The solution formed in these cases is colourless, and when decomposed by the alkalis, gives a white precipitate.

Muriatic acid is equally incapable of combining directly with the black oxide, but, according to the theory usually given of its action, it de-oxidates it, one portion of the acid passes to the state of oxy-muriatic acid, which escapes in the elastic form, while another portion of the acid combines with the oxide thus reduced in the degree of oxidation. On this depends, indeed, the conversion of muriatic into oxy-muriatic acid, by the black oxide of manganese. The muriate of manganese is colourless, and affords by evaporation a soft deliquescent mass; when decomposed by the alkalis, it gives a yellowish-white precipitate.

The phosphate, fluate, and borate of manganese, are most easily formed, by adding to the solution of the muriate or nitrate of the metal, a solution of any neutral salt containing any of these acids; being insoluble, they are precipitated. Carbonate of manganese may be formed by

a similar process; and a portion of the oxide is even dissolved by water impregnated with carbonic acid.

The salts of manganese suffer decomposition from the alkalis, which precipitate the oxide retaining perhaps a little of the acid with which it is combined. They are not decomposed by the inflammables or the other metals, a proof of the strength of affinity of manganese to oxygen.

The fixed alkalis combine with black oxide of manganese, when their mutual action is promoted by heat. The compound is soluble in water, and during its solution exhibits rapid changes of colour, the liquor being first green, then changing to a purple and violet, and becoming after some time colourless: it is also rendered colourless at once by a few drops of nitric acid. These changes are probably owing to rapid changes of oxidation; the compound to produce them is best obtained by calcining a mixture of one part of the black oxide with three parts of nitre.

Oxide of manganese combines with those earths capable of vitrification, and with their vitrifiable compounds, and communicates to the glasses they form a violet tinge: it communicates the same colour to borax, and other vitrifiable salts.

Manganese cannot be combined with sulphur; the oxide, heated with sulphur, forms a yellowish-green mass, which, when acted on by acids, produces sulphuretted hydrogen. It unites with phosphorus, and forms a compound of a white colour and metallic lustre, of a granular texture, brittle and fusible.

Manganese, from its infusibility, cannot be combined with many of the metals. It shews a considerable affinity

to iron, occurring frequently combined with it in nature, and being capable of being combined with it artificially, when it forms an alloy white and brittle: it is contained too in those ores of iron best adapted to the fabrication of steel, and is supposed to improve the quality of steel.

The metal is applied to no use in its metallic form. The black oxide is employed by the chemist, as affording by the most economical process oxygen; and in the formation of some chemical compounds, particularly the oxy-muriatic acid, it is used with the same view. It has long been used in the art of glass-making, to counteract the green tinge communicated by the iron contained in the materials, an effect it produces by yielding oxygen to the oxide of iron, and bringing it to a high degree of oxidation; in a larger quantity added to glass, it gives a purple colour. It is also used to give a black colour to earthen ware.

CHAP. XVII.

OF ARSENIC.

The name Arsenic is in common language applied to the oxide of a metal, to which in the chemical nomenclature it is appropriated. This oxide, obtained by sublimation from certain metallic ores, particularly those of cobalt, was known long before the method of obtaining the metal from it had been discovered. This was made known by Lemery

and Schroeder. It is sufficiently simple, consisting merely in mixing the oxide with twice or thrice its weight of the black flux, and exposing the mixture in a retort or glass tube, or in a crucible to which another is adapted, to a heat gradually raised to ignition; the oxygen of the oxide is abstracted by the carbonaceous matter, and the metallic arsenic is sublimed.

This metal is of a bluish-grey colour, with considerable lustre, which, however, is soon tarnished from exposure to the air. Its texture is distinctly broad striated, and it is extremely brittle, so as to be easily reduced to powder. Its specific gravity has been stated at 5.763, and also at 8.310.

It is so volatile that its fusion cannot easily be accomplished. It passes into vapour when heated to about 388° of Fahrenheit. When condensed slowly, it forms octohedral crystals. In the state of vapour it has a strong and peculiar smell, which has often been compared to that of garlic.

In volatilizing, if the atmospheric air is admitted, it is oxidated rapidly, a white vapour being produced consisting of the oxide; if the heat is raised somewhat higher, the metal burns with a dull blue flame, and the production of the same oxide. This oxide has peculiar properties. It is not, like the greater number of oxides, insipid, and insoluble in water; its taste is on the contrary sharp and acrid, and it is so soluble that it requires not more than 80 parts of cold and 15 of boiling water for its solution; the latter solution affording on cooling, crystals in the form of four-sided prisms or octohedrons. It combines

too with the alkalis, and even reddens the infusion of litmus. Hence it has been regarded rather as an acid than an oxide, and has received the name of arsenious acid. Yet it is on the whole more analogous to oxides in a high state of oxidation, for it is incapable of neutralizing the alkaline properties, while it combines with the acids, and produces with them neutral compounds. It is this substance which is the most virulent of the metallic poisons. It consists of 75.2 of arsenic, and 24.8 of oxygen. As obtained by sublimation, it is in the form of a dense cake, but it is reduced to powder for the purposes to which it is applied in some of the arts.

Arsenic is capable of acquiring unequivocal acid powers by a higher degree of oxygenation. This is effected by distilling nitrous acid from the white oxide, the acid yielding the requisite proportion of oxygen; or with more facility, by dissolving the oxide in muriatic acid with the assistance of heat, adding to this nitric acid, and distilling until the production of nitrous vapours cease. By continuing the application of the heat, and raising it at the end of the process to redness, the arsenical acid is obtained in a concrete form. The oxide, in its conversion to the acid, increases nearly one-seventh in weight. The acid consists of 64 of arsenic, and 36 of oxygen.

The oxide of arsenic combines with the different acids, forming compounds which are not easily obtained in the neutral state. The same compounds are in general produced by the action of the acids on metallic arsenic, the acid first yielding oxygen, and then combining with the oxide.

Sulphuric acid oxidates the metal when its action is promoted by heat; it also dissolves the oxide when boiled on it, forming a compound which, as the solution cools, is deposited in crystalline grains.

Nitric acid oxidates metallic arsenic. When much diluted, it dissolves the oxide, and the compound being of sparing solubility, is deposited. When concentrated, it yields oxygen to it, and partially converts it into arsénic acid.

Muriatic acid, digested with heat on metallic arsenic, causes its oxidation by the decomposition of water; the hydrogen disengaged has a very fœtid odour, from a portion of oxide which it holds dissolved. The acid boiled on oxide of arsenic dissolves one-third of its weight nearly, forming a salt of sparing solubility. A muriate of arsenic is obtained still more concentrated, by distillation from a mixture of corrosive muriate of mercury and metallic arsenic, the oxygen and acid being transferred from the quicksilver to the arsenic; the product is partly liquid, partly congealed; it emits acrid vapours, is deliquescent, but, by the affusion of water, is decomposed. By spontaneous evaporation, it deposites pellucid crystals, which are sparingly soluble in water. Oxy-muriatic acid gas inflames metallic arsenic, and converts it into the oxide or acid.

The other acids scarcely act on metallic arsenic, but combine with its oxide, and form compounds of sparing solubility.

Oxide of arsenic combines with the alkalis. The combinations with the fixed alkalis are formed by fusion; and

even the solution of the alkali, boiled on the oxide, dissolves a large portion of it, the solution, when concentrated, being viscid, of a brown colour, and unpleasant odour. Ammonia likewise dissolves a quantity of the oxide; and it combines in the dry way, by the application of heat, with lime and some of the other earths.

Arsénic Acid has all the most important acid properties. It is abundantly soluble in water, requiring only six parts for its solution at 60°, and not more than two parts at 212°; its taste is sour; it reddens the vegetable colours, and combines with the alkalis, earths, and metallic oxides, forming in the due proportion neutral compounds. By slow evaporation, it may be obtained in small irregular crystals. When evaporated to dryness, it forms a white solid mass, which, by raising the heat to ignition, is melted, and forms a translucent glass. By a continuance of the heat, it is partially decomposed, oxygen being expelled; and it is decomposed with facility by heating it with inflammable substances, being reduced to the metallic state.

Arsénic acid combines with the alkalis, forming salts soluble and crystallizable. They may be formed by direct combination, and also by an indirect method which has been generally followed, exposing a mixture of the white oxide of arsenic with any of the alkaline nitrates, to heat, continuing this as long as any red vapours are disengaged. The nitric acid is decomposed, yielding oxygen to the oxide, so as to convert it into arsénic acid, with which the alkaline base of the nitrate combines. The arseniate thus formed is obtained pure by solution and crystallization. The arseniate of potash, formed by this process, forms

large regular crystals, tetraedral prisms, having generally an excess of acid, to which the regularity of its crystallization is owing, the perfectly neutral salt not crystallizing so regularly, and being deliquescent. The arseniate of soda crystallizes in hexaedral prisms, arseniate of ammonia in rhomboidal prisms.

Arsénic acid combines with the earths, forming compounds of very sparing solubility, but which are rendered more soluble by an excess of acid.

It acts on several of the metals, yielding oxygen to the metal, and being thus reduced to the state of oxide. When the metal is previously oxidated, the arsénic acid enters into direct union with the oxide; but these combinations, presenting no important results, scarcely require to be individually noticed.

Metallic arsenic is dissolved by hydrogen gas. This compound is formed when zinc is acted on by arsénic acid, or from the mutual action of diluted sulphuric acid, zinc, and oxide of arsenic. It has the peculiar odour which arsenic has when in the state of vapour, and is heavier than pure hydrogen gas. When detonated with atmospheric air, it deposites a film of metallic arsenic; when detonated with oxygen gas, the arsenic is deposited in the state of oxide. It is also decomposed by nitric oxide gas and oxy-muriatic acid gas, the arsenic being precipitated either in its metallic or oxidated state, according to the proportions in which the gases are mixed. Even nitrous acid decomposes it with detonation; and sulphuric and nitro-muriatic acid precipitate from it a metallic film.

From its decomposition by nitric acid, it is inferred to consist of 10.600 of arsenic, and 0.219 of hydrogen.

Arsenic unites with sulphur by fusion or by sublimation, forming compounds of a red or yellow colour, according to the proportions. Its oxide, heated with sulphur, suffers decomposition, and similar compounds are produced. With phosphorus arsenic forms a compound of a black colour and metallic lustre, which tarnishes and oxidates on exposure to the air.

Arsenic combines with nearly all the metals, the combination being effected with most facility by exposing to heat a mixture of oxide of arsenic and the black flux, with the metal with which it is designed to be combined. The ductile metals it in general renders brittle, and to those that are refractory in the fire it communicates fusibility. Few of its alloys are applied to use. That with copper is of a white colour, and receives a fine polish; and hence it has been used instead of pure copper in forming silver-plating, but it has the disadvantage of tarnishing on exposure to the air. Oxide of arsenic exerts affinities to some of the other metallic oxides, and hence decomposes some of the metallic salts. The precipitate which its solution in potash throws down from a solution of sulphate of copper, is a combination of this nature; it is of a bright green colour, and is used as a pigment.

A part of the chemical history of arsenic is that relating to the tests by which it is detected, as, from being so active a poison, this is occasionally the subject of judicial investigation. The most decisive is, reducing a little of the oxide, by exposing it mixed with twice its weight of

the black flux, or of charcoal powder, in a coated glass tube lightly stopped, to a low red heat cautiously raised; a metallic crust of a grey colour and great brilliancy is obtained on the sides of the tube. The only disadvantage of this test is, that it cannot well be performed on a smaller quantity than several grains. *2d*, A little of this reduced metal, when put on a red-hot iron, is volatilized, and the vapour, in exhaling, has a peculiar odour, approaching to that of garlic. The oxide is also volatilized by the same degree of heat, forming a white smoke; and if it has been previously mixed with a minute quantity of oil, it will, in evaporating, give the garlic odour: this odour, it is to be remarked, however, is not very evident where a small quantity is employed, and is disguised by the intermixture of vegetable and animal substances. *3d*, If a little of the reduced metal, or a small quantity of the oxide made into a paste with charcoal and oil, be placed between two copper pieces, if these are pressed together, secured by wire, and exposed to a red heat in a charcoal fire for a quarter of an hour, the surface of the copper will be permanently whitened, so that, on removing the adhering matter, and rubbing it with a little chalk, it will have nearly the appearance of silver, owing to the alloy of the copper and arsenic. *4th*, If a little of the oxide be dissolved in warm water, with three times its weight of carbonate of potash, the solution, on being added to a solution of sulphate of copper, throws down a precipitate of a lively grass-green colour. To render this more evident and certain by contrast, a little of a solution of carbonate of potash alone ought to be added to the solution of sulphate of copper;

the precipitate it forms is of a bluish-green, and the difference is sufficiently evident when they are compared as they ought to be in the light of day. The same experiment may be made with any remaining portion of the liquid that has been the vehicle of the poison, or on the liquid found in the stomach, and freed by filtration from the substances diffused through it.

5th, Mr Hume has lately given another test,—that of nitrate of silver, which, added to a solution of so small a quantity of white oxide of arsenic as one grain, with an equal weight of carbonate of soda in ten or twelve ounces of boiling distilled water, produces instantly a bright yellow precipitate.

CHAP. XVIII.

OF BISMUTH.

Bismuth is a metal of a white colour, with a yellowish tinge, liable to tarnish and become iridescent from exposure to the air; its texture is distinctly foliated; it is not very hard, is quite brittle, and has a specific gravity of 9.8.

It is very fusible, melting at 460° or 480°. It crystallizes easily by slow cooling. When in fusion, if the air is admitted, its surface is soon covered with a greenish-grey powder from oxidation. If it be exposed to a stronger

heat, it burns with a small flame, and forms a yellow powder more highly oxidated. These oxides, by a powerful heat, are fused into transparent glasses.

Bismuth is oxidated and dissolved by the acids; its salts are in general decomposed by the affusion of water.

Sulphuric acid boiled on it is decomposed, sulphurous acid gas being disengaged, and oxide of bismuth remaining combined with a portion of sulphuric acid. By the action of water this is resolved into a sub-sulphate and super-sulphate, the latter affording acicular crystals on evaporation.

Nitric acid is rapidly decomposed by bismuth, the temperature rises, and dense red vapours are disengaged; the metal being so highly oxidated that it retains combined with it little of the acid. By using a diluted acid, a more perfect solution is obtained, which by evaporation affords rhomboidal crystals. By the affusion of water a white precipitate is thrown down, the Magistery of Bismuth, as it has been named, which is a sub-nitrate. When the solution is decomposed by a solution of tartrate of potash, a very white precipitate is obtained, which forms the paint sometimes used for the complexion, known by the name of Pearl-white.

Muriatic acid scarcely acts on metallic bismuth, but it combines with its oxides; and the solution, when concentrated by evaporation, forms a thick soft mass, which is liquified by heat, and congealed by cold. The metal in filings inflames when projected into oxy-muriatic acid gas.

Phosphoric acid forms with oxide of bismuth a com-

pound which is insoluble, and which melts before the flame of the blow-pipe into a glass. Fluoric acid forms with it a solution of a sweetish taste. Boracic and carbonic acids, in combining with it by double affinity, form insoluble compounds.

All the salts of bismuth are decomposed by the alkalis, and the precipitate which is thrown down is dissolved by boiling in a solution of potash or soda, or by digestion in liquid ammonia.

Bismuth combines with sulphur by fusion, and forms a compound of a grey colour and metallic lustre, which is easily melted, and when allowed to cool slowly, forms a mass composed of tetraedral prisms. Sulphuretted hydrogen tarnishes the metal, and either pure or in the state of hydro-sulphurets or sulphuretted hydro-sulphurets, throws down from solutions of its salts very dark-coloured precipitates; by this action it forms with these solutions a subtile sympathetic ink.

Bismuth does not unite either with phosphorus, carbon, or hydrogen.

It combines by fusion with the greater number of the metals, and in general communicates brittleness and fusibility. This property, with regard to fusibility, is well displayed in the formation of what is named the fusible metal, which consists of eight parts of bismuth, five of lead, and three of tin, and which melts at 212°, a degree of fusibility much greater than that of any of the metals of which it is composed. The addition of a little quicksilver renders it still more fusible, and a composition of this kind is used to coat the internal surface of glass globes. To quicksilver

alloyed with lead, bismuth added in small quantity, by increasing the fusibility, communicates a mobility equal to that of pure quicksilver, and hence it is used in adulterating that metal. It adds too to the fusibility of tin, the alloy of equal parts melting at 280. In a smaller proportion it adds to the hardness of tin, and hence it is used in the formation of pewter. An alloy of equal parts of tin, bismuth, and quicksilver, forms a compound of a flaky brilliant appearance, named Mosaic Silver, sometimes applied to ornamental purposes. It is principally in the formation of these alloys that bismuth is employed.

CHAP. XIX.

OF ANTIMONY.

The native sulphuret of this metal is the substance to which the name antimony was originally applied; but the name is now appropriated to the metal, and the other in commerce is distinguished by the epithet crude antimony. It is from this sulphuret that the metal is extracted: the usual process is to fuse it with iron-filings, with the addition of a little nitre; the sulphur combines partly with the iron, partly with the potash of the nitre, and the metal is run out.

Antimony is of a light bluish-grey colour, with a lustre not much liable to tarnish; its texture is very distinctly

plated; its hardness is moderate; it is quite brittle, so as to be easily beat to powder. Its specific gravity is 6.7.

At a heat a little above ignition, antimony melts, and in cooling it assumes a crystalline arrangement easily observed on the surface of the mass, and in its structure. At a full white heat it is volatilized.

Heated under exposure to the air it is oxidated; and if the heat be high, the oxide is volatilized, passing at the same time to a higher state of oxidation, and condensing in acicular crystals; the oxidation, if rapid, is attended with a weak flame. By deflagration with nitre, it is also obtained at a high state of oxidation, the oxide remaining combined with a portion of the alkali of the nitre; and it exists in various degrees of oxidation in its saline combinations. Thenard has distinguished not less than six oxides of this metal. Proust has supposed there are only two, one containing 18.5 of oxygen in 100 parts, the other containing 23. It is probable, in conformity to the law which appears to regulate the combination of metals with oxygen, that the degrees of oxidation are numerous, and even indefinite, when not rendered uniform by the operation of external circumstances.

Antimony is acted on by the acids. Sulphuric acid boiled on it is in part decomposed, sulphurous acid being disengaged, the oxidated metal combines with another portion of the acid, forming the sulphate of antimony, which cannot be crystallized, but by evaporation forms a mass which is very deliquescent, and is decomposed by water.

Nitric acid oxidates antimony, and if not too highly con-

centrated, forms a solution which affords by evaporation a deliquescent salt.

Muriatic acid acts on antimony very slowly, but combines easily with its oxides. The nitro-muriatic acid dissolves it still more readily, and when composed of five parts of muriatic, and one of nitric, affords a perfect solution, which, after evaporation of the superfluous water, may be distilled by the application of heat; the muriate comes over of a thick consistence, and melts on the application of a very moderate heat. From these properties, it was termed Butter of Antimony by the older chemists. Various indirect methods of obtaining it were employed. The most common was to mix antimony with corrosive muriate of mercury, and expose it to heat; the antimony attracts the oxygen and muriatic acid from the mercury, and the muriate of antimony distils over. Another process given in the Pharmacopœias, is to mix one part of brown oxide of antimony, and one part of sulphuric acid, with two parts of muriate of soda, and apply heat to the mixture in a retort; the muriatic acid is disengaged, and combines with the oxide, forming the muriate which is sublimed. This salt is extremely corrosive, it liquifies by exposure to the air, from attracting a quantity of water sufficient to dissolve it; but when water is poured upon it, it is decomposed, the water, acting by its quantity, abstracting a portion of the acid, and precipitating sub-muriate of antimony.

The other acids, though unable to dissolve antimony, combine with its oxides. Of these salts, the only one of any importance is a ternary compound of oxide of anti-

mony, tartaric acid, and potash. This has been long employed in medical practice, under the name of Emetic Tartar, as one of the mildest and most manageable of the antimonial preparations. Various processes have been followed for its preparation; that now given in the Pharmacopœia of the Edinburgh College, is to boil three parts of the brown oxide, obtained by deflagrating sulphuret of antimony with nitre, with four parts of super-tartrate of potash, in thirty-two parts of water for half an hour; the solution, when strained, is set aside to crystallize. The excess of tartaric acid in the super-tartrate dissolves a portion of the antimonial oxide, and the crystallized salt is a triple compound of the oxide, the acid, and part of the alkali, the proportions, according to Thenard's analysis of it, being 38 of oxide, 34 of acid, 16 of potash, and 8 of water of crystallization.

The alkalis do not act on antimony, but they combine with some of its oxides. When deflagrated for example with nitre, the oxide remains in combination with the potash of the nitre. If this be submitted to the action of water, it is resolved into two compounds, one having an excess of alkali which is dissolved, the other with an excess of oxide which remains undissolved. The latter has been named Calcined, or Diaphoretic Antimony.

Antimony combines with sulphur by fusion, and forms a compound similar in appearance to the native sulphuret. Sulphuret of antimony has some peculiar chemical relations which require to be pointed out, as in this state antimony has been more frequently submitted to experiment by the chemists than in its pure form, and several pre-

parations are obtained from it, important from their medicinal use.

When native sulphuret of antimony is exposed to heat, sulphureous fumes arise; and if the heat is continued and gradually raised, the metal is converted into a grey oxide, which retains a portion of sulphur in combination. If this be exposed to an intense heat, it melts and forms a transparent glass of a dark brown or reddish colour, the vitrified oxide of antimony, as it is named; it generally contains a little silex from its action on the crucible, in which it is melted.

The metal in the crude antimony is likewise oxidated by deflagrating it with nitrate of potash. If equal parts of the sulphuret and nitre are deflagrated together, the greater part of the sulphur is converted into sulphurous acid, which is partly dissipated, and partly combines with the potash of the nitre, and the antimony is imperfectly oxidated, the oxide, which is of a brown colour, having combined with it a small quantity of sulphur which had escaped deflagration, and a minute portion of hydrogen, probably derived from the water the nitre contained. When a larger quantity of nitre is employed, the oxidation is more perfect, and the white oxide is formed, which has been already noticed.

When sulphuret of antimony is fused with an alkali, with potash for example, and thrown into water, or when an alkaline solution is boiled upon it, part of it is found to be dissolved. If the liquor is strained while hot, a red powder is deposited, which was named by the chemists Kermes Mineral. If an acid is added to the solution

while warm, and previous to this deposition, it combines with the alkali, and a precipitate of a reddish yellow colour is formed, which used to be named Golden Sulphur of Antimony, which is now named Precipitated Sulphuret of Antimony. These two preparations are similar in their composition, being compounds of oxide of antimony, with sulphur and sulphuretted hydrogen, the antimony during the process, having been oxidated probably from the decomposition of the water by the alkaline sulphuret, and the sulphuretted hydrogen being derived from the same source. The yellow precipitate differs from the red, principally in containing a larger proportion of sulphur.

The last preparation of this kind is one that has been celebrated as an empirical medicine, James's Powder, the phosphate of antimony and lime, as it is now named, for the process for the preparation of which we are indebted to Dr Pearson. It consists in exposing first to a moderate heat in an open vessel, and then to a stronger heat in a covered crucible for two hours, equal parts of the sulphuret of antimony, and shavings of bones. The sulphur is dissipated, the metal is oxidated, the animal matter of the bones is burned out, and the phosphate of lime, which is the solid matter of the bones, remains intimately mixed, or perhaps combined with the antimonial oxide. According to Dr Pearson's analysis of it, it consists of 43 parts of phosphate of lime, and 57 of oxide of antimony, about 28 parts of this oxide being vitrified.

Antimony unites with phosphorus; the compound has metallic lustre, and is of a white colour; its fracture is lamellated. It melts, and burns with a green flame when thrown upon ignited fuel.

Antimony combines with nearly all the metals; its alloys are in general brittle, and few of them have been applied to any use. It unites with difficulty with mercury. Fused with lead, it affords a white brittle alloy, of which printing-types are cast; the compound consists of 80 parts of lead, and from 15 to 25 of antimony, with the addition frequently of a small proportion of zinc; this alloy is tolerably hard, without being brittle, and it takes a delicate impression from a mould, owing probably to the expansion which antimony suffers in consolidating from fusion. It is principally in the formation of this alloy, and in the practice of medicine, under different forms of preparation, that antimony is employed. Its oxides sometimes enter into the composition of coloured glasses, and into the formation of certain paints.

CHAP. XX.

OF TELLURIUM.

This is a metal of modern discovery. It occurs in nature alloyed with gold, principally in certain ores of that metal found in Transylvania; when obtained free from alloy, it is of a tin-white colour with metallic lustre, has a foliated fracture, is extremely brittle, and is one of the lightest of the metals, its specific gravity being only 6.1.

It melts easily and at a temperature a little inferior

to that of ignition; and it is also easily volatilized; when heated before the flame of the blow-pipe it inflames, and an oxide is formed in vapours, having a pungent odour, which condense into a white powder. This, heated in a glass retort, melts, and forms when cold a substance of a yellowish colour, and striated texture.

Tellurium is oxidated and dissolved without difficulty by the acids. Sulphuric acid, when concentrated, acquires from it a purple colour; by dilution with water this colour is lost, as it is also from heat; and in either case the small quantity of metallic matter dissolved is precipitated. Nitric acid forms with it a colourless solution, which is not rendered turbid by water, and which, when concentrated, affords needle-shaped crystals. Muriatic acid, to which a little nitric acid has been added, affords a transparent solution, from which a white precipitate is thrown down, on the addition of water, and which, by repeated affusions of water, is dissolved. The alkalis throw down from all these solutions, precipitates of a white colour, which an excess of alkali re-dissolves. They are not precipitated by prussiate of potash: tincture of galls forms a yellow flocculent precipitate. Several metals, as zinc, iron, tin, and antimony, precipitate from them the tellurium in its metallic state, and phosphorus has the same effect.

This metal combines with sulphur by fusion, forming a lead-coloured striated substance. The alkaline sulphurets throw down dark-coloured precipitates from its solutions.

The alloys of tellurium, with the other metals, have scarcely been examined. It does not easily amalgamate with quicksilver, even when their action is aided by heat.

CHAP. XXI.

OF CHROME.

This metal exists in the state of an acid combined with oxide of lead in a mineral the produce of Siberia; and it has been discovered in some other metallic fossils, particularly combined with iron. It is also the colouring principle of the emerald and ruby. Vauquelin, its discoverer, gave it the name of chrome from its most characteristic property, that of assuming different brilliant colours in the combinations into which it enters.

It is extracted from the mineral which affords it, the red lead ore, by adding muriatic acid, which combines with the oxide of lead, the muriate of lead is precipitated, and the chromic acid remains in solution. It is obtained by evaporation in a dry mass, which being exposed to an intense heat in mixture with charcoal, is reduced to the metallic state. The metal is of a white colour, inclining to grey; it is very brittle, and in its fracture displays a radiated structure.

Chrome is very difficult of fusion. At a high temperature it is oxidated by the atmospheric air, its surface being covered with a green oxide. By a higher degree of oxygenation, which is effected most easily by distilling nitric

acid from it repeatedly, it is brought to the state of an acid. It is then combined with about 0.40 of oxygen.

Chrome is little affected by the acids. Even nitric acid requires to be distilled from it a number of times to oxidate it fully. Nor are saline combinations of it easily formed, even when the metal has been previously oxidized.

Chromic acid has more energy of chemical action. It is very soluble in water, forming a solution of an orange-red colour, which affords by evaporation slender prismatic crystals of a ruby-red colour. The portion of oxygen producing its acidification is not retained by a strong affinity, hence it is easily reduced to the state of the green oxide. Exposure to the solar rays has this effect, as has also the action of the greater number of the metals, or ether or alkohol when either of them is boiled with it for a few minutes. Muriatic acid has a similar effect, oxy-muriatic acid gas being disengaged, and the solution assuming a beautiful green colour from the production of oxide of chrome. Even heat produces this change, the green oxide being formed when the acid is heated before the flame of the blow-pipe on charcoal, or when it is fused with borax or phosphoric acid.

This acid combines with the alkalis, earths, and metallic oxides, forming salts, many of which have very brilliant colours. The alkaline chromates are soluble and crystallizable; the colour of their solutions is orange-yellow, and by evaporation they afford crystals of the same colour. The chromate of potash crystallizes in rhomboidal prisms, that of ammonia in plates. The earthy chromates are in general sparingly soluble, and have also an orange colour.

The metallic chromates have various, and generally vivid colours; that of lead is an orange yellow, of mercury a vermilion red, of silver a carmine red, of zinc and bismuth yellow. Some of these would form very beautiful pigments, could the chromic acid be easily procured in sufficient abundance.

CHAP. XXII.

OF MOLYBDENA.

This metal exists in the state of an oxide or acid combined with sulphur, in a mineral similar to plumbago in appearance, to which the name of Molybdena had been given. Scheele discovered the nature of this substance, and gave the processes by which the metal is extracted. The most simple of these, and which at the same time affords the purest product, is to distil from one part of it reduced to powder five parts of diluted nitric acid to dryness, repeating this distillation three or four times with new portions of the acid. The sulphur is converted into sulphuric acid, the molybdena into molybdic oxide or acid; the former is removed by washing with water, the latter, being sparingly soluble, remains undissolved. By mere calcination, too, the sulphur of the native sulphuret may be dissipated, and the oxide or acid of molybdena obtained.

The reduction of this to the metallic state, or rather the fusion of the metal, is extremely difficult. Though reduced by exposure to intense heat in mixture with charcoal and oil, it is scarcely agglutinated, but forms merely a mass which breaks under the finger. Hielm, however, obtained it in a kind of slag, and Bucholz, after repeated experiments with the most intense heat that could be raised by the fire of a forge, succeeded in fusing it so as to obtain it in globules, and even in a mass of two drachms weight. The metal he found to be of a silvery white colour; it had no ductility or malleability, but was so hard as not to be easily broken; its specific gravity was 8.6.

Though this metal is so infusible, it is easily oxidated. Its surface becomes dull from the flame of the blow-pipe. By the continued application of a red heat, it becomes of a brownish-yellow colour, which soon changes to violet. By calcination with a higher heat, or by deflagration with nitre, it is converted into a white oxide, and at its highest degree of oxygenation acquires acid powers. Mr Hatchet concluded that it is susceptible of four degrees of oxygenation; the first forms a black oxide, the second one of a blue colour, the third one that is green, and the fourth produces the molybdic acid. The transitions through this series are best shewn in de-oxidating the acid, or its compounds, these changes being easily effected from the weak affinity with which the oxygen appears to be retained.

These varied and successive degrees of oxygenation are displayed in the actions of the acids on this metal. Nitric acid acts on it rapidly, converts it first into the blue oxide, and ultimately into the molybdic acid. Sulphuric acid

boiled on it, acquires a bluish-green colour, which, by continuing the boiling, almost entirely disappears, apparently from more perfect oxygenation. Muriatic acid does not act on the metal, but oxy-muriatic acid changes it into the blue oxide, and the same oxide is produced by the action of the other acids on the brown oxide. From an excess probably of this oxide, the saline solutions are usually of a blue colour; they can scarcely be obtained crystallized without decomposition.

This blue oxide is, according to Bucholz, soluble in water, reddens litmus paper, and decomposes the alkaline carbonates with effervescence, forming with the alkali a blue solution.

The substance named Molybdic Acid, formed by the preceding processes, is in the state of a yellowish-white powder, having a specific gravity of 3.4. Its taste is sharp and metallic; it is soluble in water, but requires a large quantity for its solution, nearly 1000 parts at 212°; its solution is of a pale yellow colour, has little taste, but reddens infusion of litmus. It is melted by heat, forming a vitreous matter, and if heated strongly, is volatilized. By the action of inflammable and metallic substances, it is reduced to the blue oxide; even the solar light produces this partial de-oxidation, paper immersed in its solution acquiring a rich blue colour from exposure to the rays of the sun, and the action of some of the acids appears to produce a similar change. According to Bucholz, it consists of 77 of the metal with 33 of oxygen.

Molybdic acid combines with the alkalis, and in entering even into these combinations, it appears to suffer a par-

tial decomposition, and to return in part to the state of oxide; the neutral combination with potash does not crystallize; that with soda forms four-sided tables; that with ammonia gives by evaporation a striated yellowish mass.

In its action on the metals, it always suffers decomposition. It may be combined with their oxides by double affinity, and from several metallic salts several compounds of rich colours are thus precipitated by the addition of an alkaline molybdate. The molybdates, added even to the vegetable colouring substances, appear to improve the richness and permanence of their colours.

Molybdena combines with sulphur, forming a substance of a flaky texture, similar to the native sulphuret. With phosphorus it appears to unite, forming a compound not very different in appearance from the metal itself.

Molybdena combines with a number of the metals when exposed with them to an intense heat; but none of its alloys have been applied to any use, nor do they present results sufficiently interesting to require distinct notice.

CHAP. XXIII.

OF TUNGSTEN.

The name of Tungsten had been given to a mineral, which Scheele discovered consists of what he regarded as a peculiar metallic acid combined with lime. The same me-

tallic matter was afterwards discovered in another more common mineral, wolfram, in which it is combined with manganese and iron. In both these minerals it has since been ascertained, that the tungsten is in the state of an oxide, and that it does not even exist in that of an acid. From the first it is extracted merely by digesting the ore in nitric acid, a yellow powder remaining, which is the oxide of tungsten: to obtain it quite pure, however, it is digested with ammonia, which dissolves it, and it is afterwards precipitated by neutralizing the alkali by nitric acid. From wolfram it is procured by digestion in muriatic acid, which dissolves the iron and manganese; the oxide of tungsten remains; it is combined with ammonia by digestion, and is precipitated by nitric acid; either the precipitate, or the entire matter obtained by evaporation, being calcined with a red heat, by which the adhering nitric acid and ammonia are expelled.

The oxide of tungsten may be reduced to the metallic state, by exposing it moistened with oil in a crucible lined with charcoal to an intense heat. The agglutination of the metal by fusion is, however, extremely difficult. In the state in which it was obtained by Mess. D'Elhuyart, the chemists who discovered its existence in wolfram, it is described as being of a greyish-white colour, with considerable lustre, hard, and brittle; its specific gravity they state at 17.6, which is confirmed by the experiments of Aikin and Allen, while by other chemists it has been stated so low as 8, or even 6.8, probably from imperfect fusion.

Tungsten, though so difficult of fusion, appears to be

very susceptible of oxidation, its surface tarnishing when heated under exposure to the air, and a quantity of oxide being formed.

The white powder obtained by the action of nitric acid on tungsten, with subsequent digestion with ammonia and precipitation by nitric acid, Scheele supposed to be a metallic acid. It is soluble in water, requiring not more than 20 parts at 212° for its solution; its taste is acrid, and it reddens the infusion of litmus; it combines too with the alkalis, forming crystallizable neutral salts. From the experiments, however, of Mess. D'Elhuyart, this substance appears to be a ternary compound of oxide of tungsten, nitric acid, and ammonia, which has been confirmed by the experiments of Vauquelin and Hecht. By boiling an acid on it, and afterwards exposing it to a red heat, it is obtained in the state of a yellow powder, which is a pure oxide, and neither possessed of acidity, nor capable of acquiring it. This oxide is insoluble in water, tasteless, and does not change the vegetable colours. By exposure to a strong heat it is partially de-oxidated, and assumes a green colour; and when fused with borax, it forms a globule of a blue tinge, and zinc, iron, or tin, immersed in solutions of its triple salts, with the addition of a little muriatic acid, produces a rich blue colour. It contains about 0.20 of oxygen.

Tungsten is scarcely sensibly acted on by the acids, even nitro-muriatic acid does not dissolve it; nor is its oxide much more soluble. The oxide combines with more facility with the alkalis, especially when a portion of acid is present, and soluble ternary compounds are thus formed.

The combination of tungsten with other metals has been attempted, by exposing to heat mixtures of the different metals with oxide of tungsten and charcoal powder; but these combinations are imperfect, and present no interesting results.

Oxide of tungsten gives permanence to the vegetable colours, and has hence been proposed to be employed in the formation of lakes.

CHAP. XXIV.

OF TITANIUM.

The oxide of this metal was discovered by Mr Gregor in a ferruginous sand, named Menachanite from being found in the vale of Menachan in Cornwall. Klaproth afterwards discovered the same oxide in the fossil known by the name of red schorl, and it has since been discovered in several other minerals.

The reduction of this oxide is extremely difficult. Vauquelin and Hecht obtained only an imperfectly agglutinated mass, with metallic globules interspersed. Lampadius obtained it more perfectly fused, and found it to be of a copper-red colour with much brilliancy, but liable to tarnish. It appears to be volatile at intense heats. The metal, when heated with the admission of the air, assumes tints of purple and blue from oxidation. In the native

oxide, the degree of oxidation appears to be higher, and even it can be oxidated more highly by fusing it with potash, a white precipitate forming when it is dissolved in water, which, according to Vauquelin, contains 0.11 of oxygen.

The acids act very feebly on titanium, and even on the native red oxide. But this oxide, fused with carbonate of potash, being brought to a higher degree of oxidation, and combined with carbonic acid, is more easily dissolved, the carbonic acid being disengaged with effervescence. With sulphuric acid it forms a solution, which on evaporation becomes gelatinous. That in nitric acid affords, by spontaneous evaporation, rhomboidal crystals. The solution in muriatic acid becomes gelatinous when heated, transparent crystals forming in it when cold. Phosphoric and arsénic acids attract the oxide from the other acids, and produce insoluble compounds which are precipitated.

The alkalis decompose the salts of titanium, throwing down white precipitates which are probably sub-salts. The metals immersed in their solutions produce partial de-oxidation, which gives rise to changes of colour.

Titanium does not combine with sulphur; its solutions are not decomposed by sulphuretted hydrogen, but hydrosulphuret of potash throws down a precipitate of a brownish red colour. With phosphorus it forms a compound of a white colour, brittle and not very fusible.

Its combinations with the other metals remain unknown, that with iron excepted, which is of a grey colour, with metallic particles of a golden colour intermixed.

Oxide of titanium has been used to give a brown colour in porcelain-painting, being applied by the usual flux.

CHAP. XXV.

OF URANIUM.

This metal was discovered by Klaproth to form the principal part of the mineral, which had been known by the name of Pechblende, and he afterwards discovered it to exist in the state of oxide, in what had been named green mica, and in another mineral substance which has received the name of uranitic ochre. The reduction of the oxide to the metallic form, he found to be extremely difficult, but by exposing it, formed into a paste with oil or wax, to an intense heat in a charcoal crucible, he obtained a metallic mass. The metal was of a dark grey colour with metallic lustre, and hard with considerable cohesion. Its specific gravity was 8.1.

This metal is extremely infusible, nor does it appear to be very susceptible of oxidation, no change being produced on its surface when it is exposed to the flame of the blow-pipe.

Its oxide is obtained, however, by the action of the nitric or nitro-muriatic acid on its ores, and precipitating the solution by an alkali. It is of a yellow colour, and in-

soluble in water; when heated to ignition, it becomes of a brownish-grey colour.

The acids in general dissolve this oxide. The solution in diluted sulphuric acid affords by evaporation prismatic crystals of a lemon-yellow colour. That formed by nitric acid affords crystals in the form of six-sided tables transparent, and of a light green colour; that by muriatic acid gives crystals in rhomboidal tables, yellowish-green. The compound with phosphoric acid is sparingly soluble, and does not crystallize.

The alkalis throw down from the salts of uranium, precipitates of a lemon-yellow colour. The precipitates by the alkaline carbonates are white. Prussiate of potash forms a brownish-red precipitate, sulphuret of ammonia one brownish yellow, tincture of galls one of a dark brown. The metals have no effect in decomposing them; a proof of the strong attraction which this metal has to oxygen.

The oxide exposed to heat with sulphur appears to form with it an imperfect combination, which is subverted by a greater elevation of temperature.

Its combinations with the other metals are unknown. Its oxide combines by fusion with vitrifiable substances, and gives to them a brown or green colour.

CHAP. XXVI.

OF TANTALUM.

The name of Tantalum has been given to a metal extracted from certain minerals found in Sweden, in which it is associated with ittria, manganese, and iron.—The following are its properties.

Its oxide obtained by the processes by which it is extracted, is in the form of a white heavy powder. When exposed to a strong heat with charcoal, it is reduced to a globule having metallic lustre, of a greyish-black colour. The mineral acids reduce this again to the state of white oxide, but in whatever quantity they are added, do not dissolve it, even when boiled on it, or dissolve it only in minute quantity. It is singular, however, that it is dissolved by the vegetable acids, as the oxalic, tartaric, or citric. It is dissolved by the fixed alkalis, and even by the alkaline carbonates, and in larger quantity by potash than by soda. These solutions are decomposed, and the oxide precipitated by an acid. If only as much acid is added as neutralizes the excess of alkali, infusion of galls causes an orange precipitate, but no precipitation is occasioned by prussiate of potash, or by hydro-sulphuret of potash. Infusion of galls poured on the white oxide recently precipi-

tated, and still moist, likewise forms the orange-coloured compound.

A metallic mineral from America had been examined a few years ago by Mr Hatchet, and a substance obtained from it, which he regarded as a distinct metal, and named Columbium. It has lately been found by Dr Wollaston that this is tantalum, the oxide separated from the mineral having all the properties above described.

CHAP. XXVII.

OF CERIUM.

This metal has been extracted from a Swedish mineral which had been regarded as a variety of wolfram, and in which it is associated with oxide of iron, silex, and lime. The oxide of cerium is obtained by dissolving the mineral in nitro-muriatic acid, and after saturating the solution with an alkali, precipitating by adding tartrate of potash: the precipitate well washed, calcined, and digested in vinegar, is oxide of cerium. It is reduced to the metallic state by exposure to an intense heat in mixture with lamp-black, oil, and borax, but in this state it has been obtained only in such a minute quantity, that the properties of the metal have not been described.

The oxide appears to exist in different degrees of oxidation. When precipitated from its solutions in acids by an alkali, it is white; it becomes yellow when dried in the air, and red when exposed to heat. It melts with borax, assuming with it before the flame of the blow-pipe, a blood-red colour, which disappears on cooling.

Cerium Vauquelin found to be insoluble in any unmixed acid, and to be soluble only in minute quantity in nitro-muriatic acid. Its oxide dissolves in sulphuric acid, forming a solution colourless, or of a light-red tinge, of a sweet taste, and which by evaporation affords white crystals; if the oxide is in a high state of oxidation, the solution is of an orange colour, and affords prismatic crystals of the same colour. Nitric acid dissolves the white oxide; the solution has a sweet taste with some sharpness; it does not easily crystallize. The red oxide is dissolved with more difficulty unless heat be applied; the solution is of a yellowish-green colour; when there is an excess of acid, it affords crystals by evaporation, if neutral, it merely becomes thick. Muriatic acid dissolves the red oxide slowly; the solution, evaporated to the consistence of honey, undergoes an irregular crystallization, and affords a deliquescent mass, soluble in water and in alkohol. Phosphoric and carbonic acids form with it insoluble salts.

The salts of cerium are decomposed by the alkalis; precipitates are thrown down, but if an excess of acid be present, triple salts are formed. From the saturated solutions, prussiate of potash throws down a white precipitate; infusion of galls one which is also white; hydro-sulphuret of ammonia, one which is green or brown accord-

ing to the proportions; and hydro-sulphuret of potash, one which, when iron is not present, is white, and appears to be the pure oxide. Phosphorus throws down a white precipitate; there is no metallic precipitation from the action of iron or zinc.

The alkalis do not act on cerium; ammonia merely renders the oxide yellow without dissolving it; the alkaline carbonates dissolve a small quantity of it, forming ternary salts.

BOOK VII.

OF MINERAL COMPOUNDS.

THE method of classification which I have followed being founded on analogies in chemical constitution and properties, I have in conformity to it placed together, under the above appellation, and as forming a distinct class, substances which in these respects are closely connected. They are those compounds chiefly of earths and metals which occur in nature, forming the principal products of the mineral kingdom.

The characters of these, as objects of chemical science, are rather peculiar. From the nature of their composition, and still more from the state of aggregation, they exert scarcely any important chemical agencies, and display few striking chemical properties; in no case do they enter into chemical combination, and their history is thus in a great measure limited to the description of their physical qualities, and the account of their constitution, so far as this has been discovered by analysis.

From these peculiarities it has happened, that these substances have frequently been regarded as objects of mere description, and hence as belonging to a different department of knowledge from chemistry. It is this which constitutes mineralogy, the object of which strictly is to describe with accuracy the external appearance of minerals, and by these to discriminate them from each other. But still they also fall within the province of chemistry; they are, in common with all natural bodies, objects of its investigations, with the view of discovering their composition; and it is only on this composition that their proper specific distinctions can be established.

It has been attempted, indeed, to establish the species of minerals on other grounds; and in particular it has been assumed, that an agreement in external qualities is sufficient to unite under one species those minerals in which it is observed; and in the system of Werner, this principle frequently regulates the classification, in opposition even to the results of chemical analysis. So far as the properties of bodies are connected with their chemical constitution, an agreement in the former may no doubt be considered as denoting a similarity in the latter; but differences of properties frequently arise from other causes, and in minerals particularly, from the state of aggregation. Hence by attending to such differences alone, substances essentially the same will be regarded as specifically different, and without the light which chemistry reflects, mineralogy would from this cause soon include many inaccurate distinctions.

There is another character connected with the internal

structure of minerals, which has been assumed as a basis of their specific distinctions. Hauy, the celebrated French mineralogist, discovered, that in all crystallized minerals, there exists in the crystal a nucleus of a certain geometric form, capable of being extracted from it by mechanical division in those directions which correspond with the natural joinings of the laminæ that compose the entire crystal. This nucleus, or primitive form, as it has been named, he farther found to be the same in the various crystals of one substance, however diversified their figure might be, as, for example, in the different varieties of carbonate of lime; he hence inferred, that it indicated identity of species, and afforded a just ground for the specific distinctions of minerals. Its insufficiency, taken by itself, however, is sufficiently evident from the fact, that the same primitive form is found in substances acknowledged to be totally different; and there is therefore still the necessity of chemical analysis, or of some other principle, to determine its application. The singular fact has farther been established, that in minerals of precisely the same nature, at least as far as the most rigid analysis can determine, the primitive forms of their crystals are in some cases different. And, lastly, the character, were it admitted, is not applicable to those minerals which do not occur in a crystallized state.

The only proper basis of specific distinction in mineral bodies, is chemical composition. It is this which is the source of all their essential properties, and which properly establishes the identity of two substances; and distinctions from other sources are altogether arbitrary and artificial.

In organised bodies, indeed, there is a different ground of specific distinction,—the peculiar organization and form of each individual as a living being, and the power of transmitting these, or of producing a similar being. But in the mineral kingdom this is altogether wanting, and nothing remains equally determinate but the chemical composition.

It is to be acknowledged, however, that the specific composition of these substances is not always easily determined, so as to admit of a method strictly chemical being followed. They usually consist of several principles combined, and diversities of properties are established from differences of proportions frequently minute, and still more from mere differences in the state of aggregation. Ingredients, too, are often contained in them which are not essential to the composition. Our modes of analysis are imperfect, the proportions cannot always be estimated with accuracy, and the modes of combination are in many cases almost unknown. Hence it is often difficult to establish an identity of composition among minerals which have a resemblance in external qualities, or to unite the varieties of a species by the results of their chemical analysis.

From these circumstances it has been found necessary, in fixing the mineral species, to adopt a less rigorous method. A certain combination may be understood to constitute a species, and this can in many cases be unequivocally determined, as in all those cases in which an earth and an acid are united together. There are others in which the composition is more complicated, and in which it

is more difficult to determine what constitutes the specific composition, as where the analysis discovers four or five ingredients, united perhaps in different varieties of the fossil in different proportions. In such cases it is necessary to have recourse to other sources of distinction: these are drawn from the external properties of the substances, or from the mechanical structure, as developed in their crystalline forms; and thus many of the species at present received in mineralogical systems, are established as much on these distinctions as on the chemical composition.

It is only to be understood, that these methods are provisional and subordinate. A peculiar composition no doubt constitutes every natural species, and will be discovered in all, as the methods of chemical analysis are improved.

The classification of minerals is thus to be regarded as essentially chemical. Each earth, for example, or each metal, forms a genus, under which are arranged as species the particular fossils in which it predominates; the native saline compounds, as well as the mineral inflammables, are arranged on a similar principle. And under all these genera the species are established, as far as the imperfect state of the science admits, on identity of composition.

It is obvious, that in thus considering the description of minerals as subservient to their chemical relations, those minute details of external qualities and appearances which properly belong to a strictly mineralogical work are in a great measure excluded. It is sufficient to enumerate the more important and characteristic properties, those which unite the varieties of the species, and serve to distinguish it from others. It is in conformity to this principle, that

I have given the brief mineralogical descriptions in the following chapters. It is equally evident, that in conformity to these views, a place can be given to those minerals only which have been fully examined, and are well defined.

The properties of minerals being often diversified by slight shades of differences, and such differences being at the same time frequently of importance in affording characters of distinction, it has become necessary to employ mineralogical language with much precision; and hence all the terms employed to denote the external appearances of minerals have been exactly defined. Such a view of this language as is consistent with the limits of this treatise, would scarcely be of any utility; and the subject being scarcely elementary, I refer for an abstract of it to my larger System, or to the treatise by Professor Jameson on the External Characters of Minerals.

CHAP. I.

OF SALINE MINERALS.

Under this order have been frequently placed all those mineral substances which have the general characters of salts,—are sapid, soluble in water, and crystallizable. Several of these, however, have a metallic or earthy base, and according to the principles of chemical arrangement, may be placed under the genus of earthy or metallic fossils,

with which they are connected. There will thus remain included under the order, only those few compounds formed from the combinations of acids with alkaline base. These may be arranged according to their base.

Sect. I.—*Of Native Salts with Base of Ammonia.*

Muriate of ammonia is the only species which can be referred to this genus. It is sometimes found as a product of volcanoes, or predo-volcanoes, being probably formed by the action of heat on substances containing its elements, and sublimed, in the form of an efflorescence, loose and flaky; sometimes also massive, tuberose, or even indistinctly crystallized; and is easily recognised by its chemical properties.

Sect. II.—*Of Native Salts with Base of Potash.*

Nitre or nitrate of potash, is the only species belonging to this genus. It occurs as an efflorescence on the surface of the ground in warm and dry climates, on soils strongly impregnated with vegetable and animal substances, and is evidently formed, as has been already remarked, from the elements evolved in the decomposition of these substances. It sometimes too forms an efflorescence on limestone rocks; it is easily distinguished by its cool taste, and by the deflagration it excites in burning fuel.

Sect. III.—*Of Native Salts with Base of Soda.*

Four salts are comprised under this genus,—sulphate of soda, carbonate of soda, muriate of soda, and borax.

Sulphate of soda is a frequent ingredient in mineral springs; it is sometimes deposited at the sides of salt lakes, or as an efflorescence on the soil in their neighbourhood, and is easily discovered by its chemical characters.

Carbonate of soda is found native in the form of an efflorescence on the surface of the ground in different countries, particularly in India: in some of the interior districts in Africa, it occurs in crystalline layers or deposites. And in Egypt and Hungary, it is found dissolved in the water of certain lakes, from which, in the dry season, it is likewise deposited. In all these cases it is found associated with sulphate and muriate of soda; and from the description given by the French chemists of the lakes in Egypt and the nature of the surrounding rocks and soil, it appears to be derived from the infiltration of water, holding muriate and sulphate of soda dissolved, through a bed of carbonate of lime, the muriatic and sulphuric acids being probably abstracted by the lime, and the carbonate of soda removed by efflorescence, so that the re-action of the muriate of lime on it is obviated.

Muriate of soda, the Rock-salt of mineralogists, is the most abundant saline product of the mineral kingdom, being found in immense deposites, besides what exists in mineral springs, and in the water of the ocean. It is in masses, having a crystalline structure, transparent, or semi-

transparent, of a white-grey or reddish colour, with vitreous lustre, and having a taste purely saline. Its fracture is foliated, sometimes fibrous, and its fragments are cubical. It is usually pure, or contains only a minute quantity of iron. Its beds are connected with rocks of secondary formation.

Borax or sub-borate of soda, it has already been stated, is found in Thibet, being deposited from the water of a lake in which it is dissolved, in crystalline masses, sometimes of regular forms, of a greenish colour, and semi-transparent, with vitreous lustre, having a foliated fracture. There appears to be a constant reproduction of it, as, although it has been long dug, there is no appearance of it being exhausted; but of its origin nothing is known.

CHAP. II.

OF EARTHY MINERALS.

Under this order are placed those fossils in which the primary earths are the predominating ingredients, though with these are frequently combined saline and metallic substances. It is subdivided into genera, according to the particular earth which enters principally into the composition; and under each genus the species containing this earth are arranged. Generally speaking, the earthy fossils are tasteless, insoluble in water, uninflammable, and of moderate specific gravity.

Sect. I.—*Of Barytic Minerals.*

Under this genus there are only two species, the Sulphate and the Carbonate. They are distinguished from other earthy fossils, by their greater specific gravity.

Sulphate of Barytes.—The Heavy Spar of mineralogists forms several sub-species. The common variety, the Lamellar, or Foliated, occurs massive, and often crystallized: the forms of its crystals are numerous, but are all reduced to the oblique four-sided prism, and the rectangular four-sided table, either perfect, or modified by truncation or bevelment of the edges or angles. The colour is white, frequently with shades of grey, yellow, brown, or red; the lustre shining, intermediate between pearly and vitreous: it is transparent, semi-transparent, and, when massive, often only translucent: its fracture is foliated, straight or curved. It is moderately hard; is brittle and heavy, its specific gravity being from 4.3 to 4.5. It melts before the blowpipe into a white enamel. It consists of sulphuric acid and barytes, with, in several varieties of it, small proportions of sulphate of strontites, silex, argil, and iron.

The other varieties are so unimportant, as scarcely to require distinct notice. Granular Heavy Spar presents a fracture very small, and fine foliated, and contains about 10 of silex in 100 parts. Compact Heavy Spar has a fracture fine grained uneven, passing into coarse earthy; has less lustre; is opaque, or only translucent on the edges; is massive, sometimes earthy and dull. Columnar Heavy

Spar derives its name from the appearance of its crystallized masses, which are composed of oblique four-sided prisms, aggregated in a columnar form. The Bolognian Heavy Spar occurs in rounded masses, and presents a radiated fracture; the rays, or narrow planes, being parallel or divergent.

Carbonate of Barytes occurs massive, in globular pieces, and rarely crystallized. Its crystals are six-sided prisms, acuminated by six planes and double six-sided pyramids; its colour is white, with a shade of grey; it is translucent or semi-transparent; its lustre is shining. Its fracture, in one direction, is intermediate between radiated and foliated, in another uneven; its fragments are wedge-shaped; it is semi-hard; its specific gravity is 4.3. It is fused by the flame of the blowpipe into a white enamel; dissolves with effervescence in diluted nitric acid. According to Withering, it consists of barytes 78.6, carbonic acid 20.8. Klaproth found it in a small quantity of carbonate of strontites, with minute traces of argil, oxide of copper, and oxide of iron.

Sect. II.—*Of Strontitic Fossils.*

The natural species of this genus are those in which the earth is mineralized by sulphuric and by carbonic acids. The Sulphate occurs massive, and crystallized in six-sided tables, or in rhomboidal four-sided prisms acuminat-

ed by four planes. Its colour is milk-white, frequently with a shade of blue; sometimes it is of a grey colour, or of a reddish tinge. The crystals are semi transparent, or translucent: the massive is nearly opaque: its lustre, when crystallized, is shining; when massive, it is dull. The fracture is foliated, fibrous, or compact fine splintery. The specific gravity is from 3.5 to 3.8. It consists of strontites 58.25, sulphuric acid 41.75, with a little oxide of iron; and in some varieties, 8 or 10 parts of carbonate of lime.

The CARBONATE has been found only at Strontian in Argyleshire. It is usually massive: sometimes from the mass slender crystals shoot, which appear to be six-sided prisms acuminated by six planes. Its colour is light green: frequently it is only of a greenish white, sometimes of a yellowish colour; its lustre is shining and pearly: its fracture is fibrous or radiated; it is semi-hard, brittle; has a specific gravity of 3.6 or 3.7. Before the flame of the blowpipe it becomes white and opaque, but is not fused. It dissolves in diluted nitric acid with effervescence. According to Dr Hope's analysis of it, it consists of strontites 61.21, carbonic acid 30.2, water 8.59.

SECT. III.—*Of Calcareous Fossils.*

THE fossils which belong to this genus consist of lime, in combination with different acids.

Sulphate of Lime forms the Gypsum of mineralogists. Four varieties have been formed,---the Earthy, Compact, Fibrous, and Foliated. The first occurs pulverulent, or slightly indurated; of a yellowish or greyish-white colour; dull and meagre to the touch. Compact Gypsum is the substance named Alabaster, which is used for statuary. It is massive; its fracture is even; its colours are usually shades of grey: it has little lustre, though it acquires it when polished: it is translucent on the edges, and very soft. Fibrous Gypsum occurs massive: its fracture is distinctly fibrous, more or less broad; the fibres being straight or curved, and always parallel: its usual colour is white, frequently with shades of grey, yellow, or red: its lustre is shining and silky: it is translucent, or semi-transparent; is so soft as to be scratched by the nail: its specific gravity is 2.3. The last variety, the Foliated Gypsum, including the Selenite, occurs massive and crystallized; the forms of its crystals being the oblique six-sided prism bevelled, or acuminated by four convex planes at each extremity; and when the prism is wanting, these planes united form a spherical convex lens. Its colours are generally white: its lustre, when crystallized, is shining, generally pearly: when massive, it is more dull: it is, when crystallized, transparent; when amorphous, it varies from this to translucent: its fracture is curved foliated; sometimes diverging radiated: that of what has been named Selenite is large foliated, or straight, sometimes curved: it is easily split: it is soft, so as to be scratched by the nail; feels smooth; has a specific gravity of 2.3.

All the varieties of native sulphate of lime have nearly the same chemical characters. They lose their transparency before the flame of the blowpipe; and when strongly urged by the flame, give a white or yellowish enamel. They are soluble in sulphuric acid, when its action is aided by heat. Selenite, which is the purest variety, consists of lime 32, sulphuric acid 46, water 22: the several varieties frequently also contain carbonate of lime, oxide of iron, argil, and silex.

A native sulphate of lime has been discovered, into the composition of which water does not appear to enter, and which perhaps forms therefore a distinct species. It has been named the Anhydrous Gypsum, and differs from the other in its forms of crystallization, and in being harder. According to Mr Chenevix's analysis of it, it consists of 44.88 of acid, and 55.12 of lime. The Anhydrite, and the Cube Spar of Werner, have both been described as anhydrous sulphate of lime.

Carbonate of Lime occurs in very different states, arising from differences in its aggregation, and from the intermixture of other substances besides its immediate principles. There is hence considerable difficulty in arranging its varieties, and in determining whether some of them ought not to be regarded as distinct species.

Crystallized Carbonate of Lime.—The Calcareous Spar of mineralogists is the species in its purest state. The primary forms of its crystals are the six-sided pyramid, the three-sided pyramid, and the six-sided prism; with numerous modifications from combination, acumination, bevelment, and truncation, giving rise to a variety

of other forms: the crystals are generally transparent, or semi-transparent: they have very distinctly the property of double refraction; the lustre is usually shining and resplendent, vitreous, or sometimes pearly: the colour is white, sometimes also grey, green, red, yellow, and light purple. The fracture is foliated, with a threefold cleavage: the fragments are rhomboidal: it is semi-hard, so as to be easily scratched with a knife: it is also brittle: its specific gravity is 2.7. It decrepitates before the flame of the blow-pipe, but does not melt: it effervesces strongly with the acids, and is entirely soluble in diluted nitric or muriatic acid. According to its analysis by Vauquelin, it consists of 56 of lime, with 43.5 of carbonic acid.

There are some crystallized fossils, which, from the most accurate chemical analysis, can be discovered to consist only of carbonate of lime, yet which differ from calcareous spar in some of the most essential characters. Arragon Spar, or Arragonite, is the fossil with regard to which this was first observed. Haüy found that the cleavage was different, indicating a different crystalline arrangement, and a difference in the forms of their primitive molecules; and it differs also in hardness and specific gravity. It still continues, therefore, to afford the greatest difficulty in the crystallographic system of Haüy, and presents undoubtedly a singular anomaly. The hard carbonate of lime described by Bournon, and which exhibits a similar anomaly, is probably to be placed with the arragonite. Its specific gravity is nearly the same, being 2.912: its hardness is equally superior to that of calcareous spar, and exceeds a little that of the arragonite itself: and

there appears to be some difference in its crystalline structure; no difference can be discovered in the composition between it and common carbonate of lime.

Fibrous Carbonate of Lime.—This variety occurs massive, or in various imitative shapes; the stalactites and stalagmites, which are deposited from water, holding carbonate of lime in solution, belong to it; but it also occurs, not of stalactitic origin, in veins. Stalactitic carbonate of lime is, from the nature of its formation, presented under various external shapes, conical, tuberose, coraliform, and botryoidal. Its colour is white, frequently with shades of grey, yellow, red, and green: its lustre is usually weakly shining; it is translucent, approaching to semi-transparent; its fracture is fibrous, the fibres being straight, and generally divergent; it is rather softer than the calcareous spar: its specific gravity is 2.7. Its chemical characters are the same with those of the other varieties of carbonate of lime. The Pisolithe, or Peastone, so named from the mass being composed of small rounded concretions like peas, appears to be of a similar origin. Roestone is probably connected with this. It is in small globular concretions, dull, opaque, of a brown or yellowish colour, soft, and easily broken.

Granular Carbonate of Lime, or Granular Limestone, occurs massive, forming extensive strata, generally connected with primitive rocks, or those of transition, and hence sometimes receiving the name of Primitive Limestone. Its fracture is small foliated, sometimes splintery; its colours are white and grey; its lustre varies from shining to glimmering, and is intermediate between pearly and vitreous;

it is translucent; is harder than calcareous spar, and less brittle. Its specific gravity is 2.7 or 2.8. It effervesces with acids. Its analysis has been extended to few of its varieties. It appears often to be a carbonate of lime nearly pure, but it sometimes also contains silex, argil, and magnesia, in proportions variable, and not well determined.

The granular limestone furnishes some of the finest marbles, and particularly those which are used for statuary.

Compact Carbonate of Lime, or Compact Limestone, is carbonate of lime much less pure, other substances being generally present in considerable proportion. Its fracture is always compact, generally small scaly, passing into uneven or earthy. Its usual colour is grey, but frequently diversified with shades of other colours: it is dull, and a little translucid on the edges; it is semi-hard; has a specific gravity of 2.6 or 2.7. It occurs always massive, generally regularly stratified, and in connection with other secondary strata, and often contains in great abundance the remains and impressions of organic beings, particularly of marine animals. It is in common use for burning into lime, and when of a fine grain, is sometimes polished as marble.

Chalk is a carbonate of lime nearly pure, deriving its external characters from its state of aggregation. It occurs massive, generally in beds; is little indurated: its fracture is earthy; its colour white, or yellowish, dull, and opaque; is so soft as to soil. It dissolves in acids with effervescence.

Marl is an impure carbonate in a loose state of aggregation. It is sometimes composed of earthy particles, is dull, and feels meagre: sometimes it is more indurated, but is

still so soft as to yield to the nail; it effervesces with acids, and generally falls to powder in water, or under exposure to atmospheric air. Marls contain, besides carbonate of lime, generally clay, magnesia, silex, and oxide of iron, in variable quantities. The medium proportion of carbonate of lime is from 50 to 60 *per cent.*

There remain some fossils, in which carbonate of lime is chemically combined with other principles, and which perhaps properly constitute distinct species.

Pearl Spar, or Brown Spar, is carbonate of lime, with oxides of iron and manganese: it occurs massive, disseminated, and crystallized; its crystals being rhombs, or lenses: its colours are white, often with shades of grey, yellow, or red; but, from exposure to the air, its colour darkens, and becomes brown. Its lustre is shining and pearly; it is semi-transparent or translucent; its fracture is usually curved foliated; its fragments are rhomboidal; its hardness and specific gravity are a little greater than those of calcareous spar: it blackens before the blowpipe; it effervesces with acids, but not strongly. It usually contains above 50 of carbonate of lime, with variable quantities of iron and manganese. When these are in large proportion, it forms the Sparry Iron Ore. The manganese appears to exist in it at the minimum of oxidizement; and it is from it absorbing oxygen, that the deepening of the colour from exposure to the atmosphere happens.

Rhomb Spar, or Bitter Spar, consists of carbonate of lime with carbonate of magnesia, and a little oxide of iron and oxide of manganese. It occurs crystallized in rhombs, which are semi-transparent, or translucent; has a shining

lustre, and is of a white or grey colour. Its fracture is straight foliated; its fragments are rhomboidal; it is rather harder than calcareous spar; its specific gravity is less, being only 2.48. It effervesces little with acids.

Schieffer Spar, or Argentine, occurs massive; has a high pearly lustre; is translucent, and of a white colour, with shades of green or red; its fracture is curved foliated; its fragments are slaty, or wedge-shaped; is soft; its specific gravity is 2.7: it effervesces strongly with acids. Heated, it becomes brown, and may be fused into a brown porcelain. Its composition, according to Mr Aikin's analysis, is carbonate of lime 98.118, silex 0.5, oxide of iron .8, with 1.032 of loss. It appears to pass into what has been named Silvery Chalk, or Schaum Earth, which has the same pearly lustre and colours, but occurs in a state of less induration. Schaalstone appears to be similar; it occurs massive, is of a white colour, with shades of green, red, or yellow, and a lustre shining and pearly.

Fœtid Carbonate of Lime, or Swinestone, according to Vauquelin, is a carbonate of lime impregnated with sulphuretted hydrogen, from which it derives an unpleasant odour, especially perceptible when rubbed. It occurs massive; its colour is brown, with little lustre; its fracture is earthy, or scaly. When heated, it loses its colour and smell, and is converted into lime.

Phosphate of Lime occurs under different forms, which can be connected only by chemical characters.

What has been named Phosphorite is found massive in extensive beds in an earthy or little indurated state. Its colour is yellowish or greyish white, without lustre or trans-

parency, rough to the touch, and having a specific gravity of 2.8. It is highly phosphorescent when heated or rubbed. Pelletier found it to consist of lime 59, phosphoric acid 34, fluoric acid 2.5, silex 2, iron 1.

Apatite is another variety of phosphate of lime. It occurs generally crystallized; the form of its crystals being the equiangular six-sided prism; the colours are white, green, blue, and red, of various shades, generally pale; the external lustre resplendent, with a transparency more or less perfect; the fracture is imperfectly foliated; the hardness such as to be easily scratched by the knife; the specific gravity is 3.2. When thrown on burning fuel, it gives a greenish phosphoric light. It consists of 55 of lime and 45 of phosphoric acid.

There is still a third variety of phosphate of lime, very different in its external characters. From its lustre and transparency, it had been ranked as a gem, being regarded as a variety of the chrysolite. On analysing it, Vauquelin was surprised to find it composed of phosphoric acid and lime; and the proportions are the same as in the apatite. It occurs crystallized, its crystals being equiangular six-sided prisms, acuminated by six planes. Its colour is asparagus green, whence it has received the name of Asparagus or Spargel Stone: its lustre is shining or resplendent, and resinous; it varies from translucent to nearly transparent: its fracture is foliated: it is semi-hard, brittle, and has a specific gravity of 3. It is soluble in nitric acid, and in diluted muriatic acid; but is not, like the other varieties of this species, phosphorescent.

Fluate of Lime, or Fluor Spar, a fossil, distinguish-

ed very generally by the beauty of its colours, is found massive, and frequently also crystallized; the forms of its crystals are the cube, perfect, or modified by truncation of the angles or edges, bevelment of the edges, and acumination of the angles by three or by six planes. Its colours are numerous, principally shades of purple, yellow, green, blue, red, and grey, and often intermixed: the lustre is resplendent or shining, and is vitreous: the transparency varies from perfectly transparent to translucent: the fracture is foliated; it is scratched by the knife, but it scratches calcareous spar: it is brittle: its specific gravity is 3.2. Exposed to the flame of the blowpipe, it decrepitates, and then melts into an enamel: on burning fuel, or on a red hot iron, it gives a beautiful purple light, and is also phosphorescent from friction. Its composition, as established by Scheele's experiments, is lime 57, fluoric acid 16, water 27.

The variety named Compact Fluor is distinguished principally by its fracture; it is always massive, has less lustre than the foliated, and is only translucent.

Sect. IV.—*Of Magnesian Fossils.*

Under this genus are comprehended those fossils in which magnesia is the ingredient present in largest proportion, and also those in which, though in smaller proportion, the characters peculiar to it exist, those in particular of softness and apparent unctuosity.

What has been named Native Magnesia, appears to be a carbonate, consisting of magnesia and carbonic acid, in nearly equal parts. It occurs in tuberose pieces, of a yellowish-grey colour, without lustre or transparency: it is soft, feels meagre, and adheres a little to the tongue. The substance named Meerschaum, consists of magnesia united with silex, a portion of carbonic acid, and a trace of lime. Its colour is yellowish-white, without any lustre; its fracture is earthy; it is soft, feels a little greasy, and adheres to the tongue. It is not melted by the heat of the blowpipe; nor does it effervesce with acids.

Steatite, named also Soap Rock, from its softness, and feeling soapy, occurs massive. Its colour is greyish, greenish, or reddish-white; it has little lustre; is translucent on the edges: its fracture is uneven, or coarse scaly: it is soft, or very soft; feels unctuous—does not adhere to the tongue: its specific gravity is 2.6. It does not melt before the blowpipe, but becomes white and very hard. The proportions of its constituent parts vary. One variety from Cornwall, analysed by Klaproth, gave silex 48, magnesia 20.5, argil 14, oxide of iron 1, water 15.5.

There are some fossils similar to steatite in external properties, and which have been considered as allied to it, which, it is singular, contain no magnesia. Such is the Plastic Stone, or Figure Stone of China; the Bildstein or Axestone of the Germans, and the Oriental Jade. All these are composed principally of silex, with argil or lime.

Potstone is allied to steatite. It occurs massive; is grey, passing into green, or sometimes with a shade of red. It is dull, and is opaque or translucent on the edges.

Its fracture is curved foliated, or imperfectly slaty: it is soft; feels unctuous: its specific gravity is 2.8. It is infusible before the blowpipe, and hardens in the fire.

SERPENTINE derives its name from the variegated disposition of its colours. The principal colour is green, but with this are intermixed, in stripes or specks, other colours, particularly red. It has no lustre, though it acquires it when polished; it is also without transparency. Its fracture is splintery: its hardness such that it is easily scratched by the knife: its specific gravity is 2.6. It feels soft, but with little unctuosity. It always occurs massive, and forms entire rocks. It consists of silex and magnesia, with a portion of iron, and sometimes of argil.

Schillerstone is regarded by Werner as allied to serpentine, in which it is often imbedded. Its colour is green, generally dark, with sometimes a shade of yellow: its lustre is shining and semi-metallic, and varies according to the position with regard to incident light; it is translucid on the edges: its fracture is foliated; it is soft, and a little unctuous; its specific gravity is 2.8. It consists of silex 41, magnesia 29, argil 3, lime 1, oxide of iron 14, and 10 of water.

CHLORITE.—Of this fossil there are several varieties, differing principally in the state of aggregation. Common Chlorite occurs massive and disseminated. Its colour is dark-green; its lustre is weakly shining, and somewhat greasy; and it is opaque. Its fracture is earthy or fine foliated; it feels meagre, or very slightly unctuous. Foliated Chlorite, so named from its fracture, which is curved foliated, occurs massive and disseminated, and also crys-

tallized in six-sided tables; its colour is dark-green, its lustre shining and pearly, inclining to resinous; it is translucent on the edges; is soft, and feels rather unctuous. Chlorite Slate, distinguished by its slaty fracture, forms a mountain-rock; its colour is dark-green; its internal lustre is weakly shining, and resinous: it is opaque, is soft, and feels unctuous. Earthy Chlorite is composed of small scaly particles, or is quite loose, with little lustre, of a dark-green colour; feels rather greasy; and when breathed on, gives an earthy smell. All these consist of magnesia and silex, with oxide of iron, and small proportions of argil and lime.

Talc occurs massive, disseminated, and in small tabular crystals, confusedly grouped. Its colour is greenish, or yellowish white; its lustre is resplendent; it is translucent, or transparent in thin leaves; its fracture is straight and curved foliated; the plates into which it is divisible are flexible, but not elastic; it is unctuous to the touch. It is infusible before the blowpipe, but is melted in the heat excited by oxygen gas. It consists, according to its analysis by Hœpfner, of silex 50, magnesia 44, and argil 6. Indurated Talc occurs massive; its fracture is slaty; it is less soft and greasy than the common talc, and has less lustre. Earthy Talc is in small scales, of a pearly lustre, friable, soiling a little, and feeling rather unctuous.

Asbestos.—To this species belong several varieties. Common Asbestos occurs massive; its colour is green or grey; its lustre is weakly shining; it is translucid on the edges; its fracture is fibrous or radiated, the fibres being straight or curved; it is soft, or semi-hard, and its fibres

are rigid; it feels a little unctuous. It melts, though with difficulty, before the blowpipe. Silex, magnesia, and iron, appear to be the essential ingredients.

Amianth is a variety of the same species, distinguished by its texture, being more delicately fibrous, so that the fibres are easily separated, are fine and perfectly flexible. It has more lustre also, this being pearly or silky; it is faintly translucent; its colour is lighter, and sometimes it is nearly silvery-white. In composition, it appears to differ from asbestos in containing more silex. It is this substance which was employed by the ancients to form an incombustible cloth to collect the ashes of the dead on the funeral pile.

Mountain Cork is another variety, so named from its resemblance to a piece of cork. It is in flat pieces, of a grey colour, without lustre, and opaque; its fracture is fibrous; the fibres being short, and interwoven; is a little flexible; it feels meagre, and is so light as to float on water. When its texture is more close, and it occurs in thinner pieces, it is named Mountain Leather.

Actynolite.—Of this species there are three varieties, —the asbestous, the common, and the glassy actynolite. Asbestous actynolite occurs massive, or more rarely in capillary crystals. Its fracture is fibrous or radiated; its colour is greenish-grey; its lustre is shining, and silky; it is opaque and soft; its specific gravity is from 2.5 to 2.9. It melts before the blowpipe. Common Actynolite occurs massive and crystallized; its crystals being rhomboidal six-sided prisms frequently acicular, and generally imbedded: its colour is green, usually dark; the external

lustre is resplendent and vitreous: its crystals are transparent, or semi-transparent: it is sufficiently hard to scratch glass; and is brittle. It is composed of silex 64, magnesia 20, argil 2.7, lime 9.3, iron 4. GLASSY ACTINOLITE occurs massive, or in aggregated acicular crystals: its colour is green, passing into greenish white: its lustre is shining and vitreous: it is translucent: its fracture is fibrous or radiated: it is brittle, and moderately hard: it melts at a high heat into a glass. Granular Actynolite is of a grass-green colour; is slightly translucent; internally shining; its fracture is foliated.

TREMOLITE, like the preceding species, comprehends three varieties,—the Asbestous, the Common, and the Glassy Tremolite. The first occurs massive, or in acicular crystals; its colour is white; its lustre is weakly shining, and silky; and it is translucent on the edges: its fracture is fibrous; it is very soft, and brittle. The common tremolite occurs massive, or crystallized in oblique four-sided prisms, bevelled or truncated on the lateral edges, and promiscuously aggregated. Its colours are greenish, greyish, reddish, or yellowish white: its lustre is shining and pearly: it is translucent, or semi-transparent: its fracture is radiated: it is hard so as to scratch glass; is brittle, and somewhat meagre to the touch. The Glassy Tremolite occurs massive, or crystallized in slender prisms aggregated: its colours are the same as those of the others; its lustre is vitreous, passing to pearly; it is translucent; its fracture is radiated, or fibrous: it is semi-hard, brittle, and harsh to the touch. All these varieties are often possessed of the property of phosphorescence, so that a mo-

derate heat, or the slightest friction, produces a luminous appearance. A variety of this species, analyzed by Klaproth, gave silex 65, magnesia 10.33, lime 18, oxide of iron 0.16, water and carbonic acid 6.5.

Sect. V.—*Of Argillaceous Fossils.*

The Argillaceous Fossils afford a striking example of the deficiency of the external characters in uniting the different species which belong to one genus; the gems distinguished by their transparency, lustre, and hardness, being comprised under this genus, equally with the dull and plastic clays. They are connected entirely by their chemical relations.

The gems had been placed among the siliceous fossils, as allied with several of them in external characters, and silex had been supposed to be their principal ingredient. Bergman first shewed the error of this opinion, and proved by analysis, that in the emerald, sapphire, topaz, ruby, and hyacinth, argil predominates. The specific characters of these fossils had also been much perplexed by the distinctions of the jewellers, founded merely on those qualities which give them mercantile value, and particularly on colour, the most variable of all the external characters; and it has required much mineralogical discussion to remove the obscurity, and establish the proper species. It now appears that the principal gems which have been distinguished by the epithet of Oriental, the ruby, sapphire,

and topaz, are mere varieties of one species. They have been ranked as such by Werner under the name of Sapphire, and by Haüy under that of Télésie; and more lately Bournon has shewn that they are allied to the fossil named Corundum, and has distinguished the species by the name of Perfect Corundum. This arrangement has been confirmed by chemical analysis, the experiments of Klaproth, Vauquelin, and Chenevix, having proved that all of them consist of argil nearly pure.

Perfect Corundum, the Sapphire of Werner, occurs in fragments, and crystallized; the forms of its crystals being the double three-sided pyramid, the single six-sided pyramid, and the six-sided prism, variously modified by truncations and acuminations. Its colours are blue, green, red, yellow, and yellowish-white, of numerous shades. It is transparent: its lustre is resplendent and vitreous: the fracture is conchoidal, or imperfectly foliated: the hardness inferior to that of the diamond, but superior to that of every other fossil, and not yielding to the file: the specific gravity is from 3.9 to 4.1. The distinctions from colour form the different oriental gems. The red constitutes the oriental ruby; the blue, the sapphire; the yellow, the topaz; the purple, the amethyst; the green, the emerald; the yellowish-green, the chrysolite. It is only to be remarked, that there are gems to which several of these names belong, distinguished by the epithet Occidental, which are altogether different.

These fossils are not fusible by the blowpipe, but are melted by the heat excited by oxygen gas directed on

burning charcoal. They are generally phosphorescent from friction.

The variety of a blue colour, the Oriental sapphire, analysed by Klaproth, was found to be composed of 98.5 of argil, 1 of oxide of iron, and 0.5 of lime: it is argil, therefore, nearly pure. The ruby afforded to Chenevix, 90 of argil, 7 of silex, and 1.2 of iron.

Imperfect Corundum, or, as it is generally named, simply Corundum, is a fossil which has been long used in India, from its great hardness for polishing hard stones. It occurs massive, disseminated, and crystallized; the forms of its crystals being the same as those of the perfect corundum. Its colour is greenish-white; externally it is dull, internally shining and vitreous: the fracture is foliated; the fragments rhomboidal: it is very hard, but rather less so than the perfect corundum: its specific gravity is 3.7 or 3.8. From the aggregation of this fossil, it is scarcely acted on by any chemical agent, and from this Klaproth at one time supposed it to be composed of a new earth; subsequent investigation proved that it consists chiefly of argil, the proportions being from 84 to 90, with 5 of silex, and from 1 to 7 of oxide of iron.

The fossil substance known by the name Emery is of the same family. It occurs only massive, or disseminated: is of a grey colour, dull and opaque. Its fracture is fine grained uneven: it is nearly as hard as corundum, and is used for the same purposes, and particularly for polishing the metals. Analysed by Mr Tennant, it was found to be composed of 86.5 of argil, 3 of silex, and 4 of iron.

To a species, distinguished by the name of Spinelle, are

referred the gems known by the names of Spinell and Balass Rubies. It occurs in grains, and crystallized; the form of its crystals being the octaedron. Its colour is red, a deep crimson-red forming the spinell ruby; a pale rose-red the balass ruby: its lustre is resplendent and vitreous: it varies from translucid to transparent: its fracture is conchoidal, or foliated: it is very hard: its specific gravity is from 3.5 to 3.7. According to Klaproth, it consists of 74.5 of argil, 15.5 of silex, 3.25 of magnesia, 1.5 oxide of iron, and 0.75 lime; Vauquelin found it to contain chrome.

The Occidental Topaz, which is found principally in Saxony, Siberia, and Brazil, deviates still more in composition from the corundum. It occurs massive, or in fragments, more frequently crystallized: the form of its crystals being the oblique tetraedral prism, variously modified. Its principal colour is yellow: its lustre is resplendent and vitreous: it varies from transparent to translucent: its cross fracture is foliated: it is very hard: its specific gravity is 3.5. The Saxon topaz was found by Vauquelin to consist of 68 of argil, 31 of silex; but, by a subsequent analysis, he discovered fluoric acid in it, as well as in the Brazilian topaz.

Chrysoberyl is a species allied to these. It occurs in grains, and crystallized under the forms of the six-sided table, and the double six sided pyramid. Its colour is pale-green, often exhibiting a milk-white opalescence: its internal lustre is resplendent: it is semi-transparent: its fracture is conchoidal: it is so hard as to scratch glass: its specific gravity is 3. 7. Klaproth found it to be composed

of argil 71.5, silex 18, lime 6, oxide of iron 1.5, with 3 of loss.

Cyanite has been placed under the magnesian genus, but it rather belongs to the argillaceous. It occurs massive, disseminated, and crystallized; the crystals being oblique, flat, tetraedral prisms, truncated on the lateral edges. Its principal colour is blue; but it also occurs white and grey: its lustre is shining and pearly: it is translucent, or transparent. Its fracture is radiated, or foliated: it is semi-hard: its specific gravity is 3.5. It consists of argil 55, silex 29.2, lime 2.25, magnesia 2, oxide of iron 6.65.

Lepidolite occurs massive: the mass is of a purple colour, but presents silvery white scales, of a pearly lustre: it is translucid on the edges: its fracture is small grained uneven; it is soft; its specific gravity is 2.8. It melts before the blowpipe, with intumescence, into a white pearly-like matter. Klaproth found it to be composed of silex 54.5, argil 38.25, oxide of manganese and iron 0.75, potash 4.

Mica is an important fossil, from its extensive distribution, as an ingredient in several of the aggregate rocks. It occurs disseminated, in thin plates, and sometimes crystallized; the crystals being six-sided tables, and six-sided prisms; its usual colour is grey; the lustre of its plates is resplendent, and metallic; in thin plates it is transparent; its fracture is distinctly foliated; and it is very easily split into laminæ, which are flexible and elastic; it is soft, and feels smooth, but not unctuous; its specific gravity is from 2.7 to 2.9. According to Vauque-

lin's analysis, it consists of silex 50, argil 35, oxide of iron 7, lime 1.33, magnesia 1.35, with 5.32 of loss.

Hornblende occurs massive, disseminated, and sometimes crystallized; its crystals being prisms, usually aggregated. Its colour is black, with frequently a tinge of green; its internal lustre is shining; when of a black colour, it is opaque; when green, translucent on the edges. Its fracture is foliated, or broad radiated; its hardness such that it is scratched by the knife; but it cannot be broken but with difficulty. Its specific gravity is from 3.6 to 3.8. Before the blowpipe, it melts into a greyish-black glass. Its analyses have presented different results, but silex, argil, and oxide of iron, are the chief constituents. Labradore Hornblende is merely a variety, distinguished principally by its copper-red colour. Basaltic Hornblende occurs imbedded in crystals, usually small, of the form of the six-sided prism; their colour is black; their surface smooth; their internal lustre splendent. Hornblende Slate is distinguished by its slaty fracture; it occurs always massive, and often in large beds.

Basalt forms an extensive mountain-rock, assuming often a columnar form. Its colour is greyish-black; it is nearly without lustre; is opaque, or feebly translucent on the edges; its fracture is usually uneven; it is hard, so as to be scratched by the knife with some difficulty, and it is not easily frangible; its specific gravity is from 2.8 to 3. It melts easily before the blowpipe into an opaque black glass; and has been from this quality employed in the manufacture of the coarser kinds of glass. According to its analysis by Dr Kennedy, it is composed of silex 48,

argil 16, oxide of iron 16, lime 9, soda 4, muriatic acid 1, water and other volatile matter 5.

Clinkstone has received its name from the peculiar sound it gives when struck. It occurs always massive, and forms beds, and sometimes assumes the columnar form; its colour is grey; it is dull, or weakly shining, and translucent on the edges. Its fracture is slaty; it is semi-hard, or hard; is easily broken; has a specific gravity of 2.5. According to Klaproth's analysis of it, it is composed of silex 57.25, argil 23.5, oxide of iron 2.25, manganese 0.25, soda 8.10, and water 8.

Wacke is intimately connected with basalt, and forms an intermediate substance between it and clay. Its colour is greenish-grey, with shades of brown or red; it has scarcely any lustre, and is opaque; its fracture is even; it is soft, and easily broken, and is liable to fall into pieces from exposure to the air. It occurs in large beds or masses, and often contains organic remains or impressions.

Argillaceous Slate, or Clay Slate, the primitive slate of some mineralogists, forms extensive strata in connection with other primitive rocks, and likewise with those of transition. Its colour is grey, with various shades of blue, purple, and green; its lustre is weakly shining, or dull; it is opaque; its fracture is slaty, or foliated; its specific gravity is from 2.6 to 2.8. It has not been analysed with accuracy, but consists of silex, argil, lime, magnesia, and oxide of iron; the proportions varying in different specimens.

Other kinds of slate have been distinguished, with regard to which it may be doubted if they form proper

chemical species; they pass into each other, and the limits of the divisions cannot always be accurately marked. Whet-slate, or Hone-stone, is distinguished from the other slates by its fracture, which is splintery, or scaly. Drawing-Slate is of a greyish-black colour, dull, opaque, and soft, so as to write and soil. Alum Slate is that which is distinguished by affording alum from exposure to the air. Bituminous Shale is of a brownish-black colour, with little lustre; is very soft, and feels a little greasy. Laid on burning fuel, it gives a weak flame and a black smoke; it appears to consist of clay with bitumen. Slate Clay forms the transition of these fossils into common clay; its fracture is slaty, approaching to earthy; it is opaque and dull; is soft; feels meagre, and adheres to the tongue; it softens and breaks down in water.

The term Clay is rather ambiguous, but is applied to those earthy mixtures, more or less indurated, which imbibe water, and may be kneaded with it into a paste somewhat ductile. Argil is the basis of all of them, or the earth which gives this predominating character; and it is mixed with various proportions of silex, magnesia, lime, and oxide of iron, the mixture being often merely mechanical, and giving rise to different varieties not easily accurately marked.

Indurated Clay, or Claystone, is clay in the highest state of induration. Its fracture is earthy, passing into even or slaty; it is soft, but is not easily diffused in water, and does not form with it a ductile paste; it is dull and opaque. The purest clay is that named Porcelain Clay, from the use to which it is applied; it occurs loosely indu-

rated and earthy; its colour is white, with shades of grey, yellow, and red, without lustre or transparency; it feels soft; in water it falls to powder, and when kneaded forms a ductile paste. It is, in general, infusible by any heat that can be raised. It consists essentially of silex and argil; but the proportions of these vary considerably. Mr Wedgwood found the porcelain clay of Cornwall to be composed of 60 of argil, with 20 of silex; in others the silex is in larger proportion.

Potters' Clay occurs massive; its fracture is earthy; it is opaque, dull; generally of a yellowish or greyish-white colour; it soils, feels soft, and somewhat unctuous; adheres to the tongue; is diffusible in water, and forms with it a ductile paste. Pipe-clay is a variety of this. Loam is the same substance, mixed with sand, oxide of iron, and various other foreign and accidental substances. The Boles, which are of a red or yellow colour, are of similar composition, and appear to owe their colours to oxide of iron. They are distinguished by their conchoidal fracture. The Ochres are similar to the boles, containing only more oxide of iron. Lithomarge is distinguished by its greater fineness, being composed of scaly particles, with a surface more or less smooth and shining; it is soft and mild, feels greasy, and adheres to the tongue. Fullers' Earth occurs massive, but little indurated; its fracture is earthy, sometimes uneven or slaty; without lustre or transparency; it is soft and mild, and does not adhere much to the tongue. In water, it falls to powder, without forming a ductile paste. Tripoli is found loose or indurated; its fracture is earthy; it feels harsh and dry; does

not adhere to the tongue, nor soil; it moulders in water, but does not form a ductile paste. It is used for polishing the metals and glass.

Native Alum, a saline product, is to be regarded as belonging to the argillaceous genus, argil being its base, united with potash and sulphuric acid. It occurs generally as an efflorescence, either in the state of a powder, or in slender silky crystals, and possessed of all the properties of the artificial salt.

Cryolite is a fossil which, from its composition, might be regarded as of a saline nature. It consists of argil with soda, combined with a large quantity of fluoric acid. It has, however, no solubility in water, and is quite insipid. It occurs massive, is of a white colour, with not much lustre, and only translucent. Its fracture is imperfectly foliated; its specific gravity is 2.9. It melts before the blowpipe, and then hardens. It dissolves in sulphuric acid, fluoric acid gas being disengaged. Klaproth finds it to consist of fluoric acid and water 40.5, soda 36, and argil 23.5.

Sect. VI.—*Of Glucine Fossils.*

In the fossils which may be placed under this genus, silex is the earth present in largest quantity, but glucine is the one which gives the predominating character, as is well displayed in the interesting fact which led to the discovery of this earth, that in the beryl and the emerald,

the two principal fossils belonging to it, the primitive form of the crystals is the same.

The Occidental Emerald forms the species to which the name of Emerald is properly applied. It occurs crystallized, in short six-sided equiangular prisms, perfect or truncated on the edges lateral or terminal, or on the terminal angles. Its colour is that pure and rich green, which has derived from it the name of Emerald Green; its lustre is resplendent and vitreous; and it varies from translucent to transparent; its fracture is small conchoidal; it is hard, but much less so than the preceding gems; its specific gravity is 2.6 or 2.7. It is melted, though with difficulty, by the blowpipe into a white glass. It consists, according to Vauquelin's analysis, of silex 64.5, argil 16, glucine 13, oxide of chrome 3.25, lime 1.6, water 2.

Beryl is so analogous in properties and composition to the emerald, that it may be doubted if they are not varieties of the same species, chrome only being wanting, to which is probably to be ascribed the absence of the rich green colour of the emerald. Its colour is pale green, which passes into blue or yellow. It occurs in crystals of the same forms as the emerald; their lustre is shining and vitreous; and they are usually transparent; the fracture is imperfectly conchoidal; the hardness superior to that of quartz; the specific gravity is 2.6 or 2.7. The beryl is melted with difficulty before the blowpipe alone. According to Vauquelin's analysis of it, it is composed of silex 68, argil 15, glucine 14, lime 2, and oxide of iron 1.

With these species, the fossil, which has received the name of Euclase, is connected, its composition being si-

milar to that of the beryl; its analysis, according to Vauquelin, affording silex 36, argil 19, glucine 15, iron 3, with 27 of loss. It occurs crystallized. Its colour is green; its lustre resplendent and vitreous; it is transparent; the fracture is foliated; the hardness superior to that of quartz, with much brittleness; the specific gravity 3.0. It loses its transparency before the blowpipe, and melts into a white enamel.

Sect. VII.—*Of Siliceous Fossils.*

The siliceous fossils can scarcely be distinguished by any common characters, but are connected in a great measure from their chemical relations.

Quartz may be placed at the head of the genus, as consisting almost entirely of silex. Analysed by Bergman, it was found to be composed of 93 of silex, 6 of argil, and 1 of oxide of iron. When perfectly transparent, it is named Rock Crystal. It occurs crystallized; the perfect form of its crystals being the six-sided prism acuminated at both extremities by six planes, set on the lateral planes; but sometimes the prism is wanting, or nearly so, and then the form is the double six-sided pyramid, and frequently the single six-sided pyramid only is apparent. It occurs also massive and disseminated. Its most common colour is white; it also occurs brown, and more rarely yellow and red. Its lustre is highly vitreous; it is transparent, or semi-transparent. Its fracture is splintery, or conchoidal; it is hard, so as to give sparks

with steel; its specific gravity is 2.6. It is infusible before the blowpipe, and is imperfectly softened by the heat excited by a stream of oxygen gas. It is a fossil extremely abundant, and of extensive distribution.

When quartz is of a purple colour, it has received the name of AMETHYST. ROSE QUARTZ, or Milk Quartz as it has been named, usually of a rose-red colour, sometimes milk-white, is another variety, as is the fossil named PRASE, distinguished by its leek-green colour.

CHRYSOPRASE is a pure siliceous fossil, containing, according to Klaproth, in 100 parts, 96.16 of silex, with 0.83 of lime, and one of oxide of nickel. Its colour is apple-green; it has little lustre; is translucent or semi-transparent; its fracture is even; its specific gravity 3.2. Before the blowpipe it loses its colour, but does not melt.

OPAL is a siliceous fossil not less pure. In the Noble or Perfect Opal, Klaproth found the composition to be 90 of silex, with 10 of water; in the common opal, 94.5 of silex, 5 of water, and 1 of oxide of iron. The perfect opal is distinguished by the beautiful play of colours which it exhibits, green, red, blue, and yellow of numerous shades, varied according to the position. Its proper colour is milk-white; its lustre is splendent and vitreous; it is translucent; its fracture is conchoidal. The common opal has the same characters, but does not present the beautiful effulgence of colours of the precious opal. The semi-opal has less lustre and transparency, is more dense, hard, and heavy, and contains a large portion of oxide of iron. Some varieties of opal, which appear to have lost the water they contain from exposure to the air, and in conse-

quence have become opaque, recover their transparency when immersed in water. These have been named Hydrophanes. The fossil named Cat's Eye, from its property of reflecting in certain directions a changeable whitish effulgence similar to the eye of a cat, appears to belong to the same family.

Chalcedony is a species which has relations with the preceding fossils, and is of similar composition, containing 84 or 86 of silex, with from 4 to 16 of argil, and a trace of lime and oxide of iron. It occurs massive, frequently in nodules, botryoidal, stalactitic, and in other imitative shapes, sometimes in veins. Its colours are white, with shades of blue, grey, and yellow; and these are often arranged in stripes parallel or concentric; it has not much lustre, but is susceptible of a fine polish, from which lustre is acquired; it is semi-transparent or translucid; its fracture is even; it is hard, so as to strike sparks with steel; its specific gravity is 2.6. Carnelian is a variety distinguished principally by its red colour and conchoidal fracture. Cacholong is chalcedony of a milk-white colour. Onyx is that variety in which stripes of different colours alternate. Chalcedony stained with dark-coloured spots, veins, or arborizations, forms the Mocho stone. To this species may also be referred the greater number of Agates, as chalcedony is generally their basis, there being intermixed with it jasper, quartz, flint, or other siliceous fossils, forming a blended mass.

Flint is a very pure siliceous fossil; the silex in its composition amounting to 97 or 98 in 100 parts, with minute traces of argil, lime, and oxide of iron. It occurs in no-

dules, imbedded in chalk or limestone; its colour is grey, of various shades, passing into yellow, and brown or black; its lustre is weakly shining; in thin pieces it is translucent; its fracture is very perfectly conchoidal; its fragments sharp-edged; its hardness such that it gives copious sparks with steel. It is infusible before the blowpipe, but loses its colour. It is phosphorescent from friction. Flint Slate, or Siliceous Schistus, approaches to flint in colour, lustre, transparency, and hardness, and is distinguished by its fracture, which is slaty.

Hornstone, or Petrosilex, is allied to these. Its colour is grey; it is dull, and only translucent on the edges; its fracture is splintery, or conchoidal; its fragments are sharp-edged. Like the preceding fossils, it is infusible before the blowpipe, and, according to Kirwan's analysis, contains more argil. Under this species is placed the siliceous petrified wood, or Woodstone, this being composed of the matter of hornstone, introduced, by slow infiltration, into the substance of wood, while the vegetable matter, by a slow decomposition, has been removed. It retains the appearance of the ligneous texture, and often its organic form.

Jasper.—In this fossil the proportion of argil to silex becomes larger, and in some varieties increases so much, that there is a transition to indurated clay; it also contains oxide of iron. Its colours are numerous, and generally dark; the most common are red, yellow, and brown; its lustre is weakly shining; and it is opaque, even on the edges. Its fracture is more or less perfectly conchoidal; it is inferior in hardness to flint, but still is not scratched by

the knife; its specific gravity is from 2.3. to 2.7. Riband Jasper, or Striped Jasper, is distinguished by its colours being arranged in stripes generally straight. The Egyptian Pebble, which occurs in nodules, and exhibits various shades of colour, generally brown, in concentric stripes, is also a variety of jasper. Heliotrope, or Bloodstone, though ranked as a distinct species, differs little from jasper. Its colour is green, generally marked with small crimson-red spots.

Pitchstone has received its name from the resemblance in lustre and texture which it frequently has to pitch. Its colours are green, brown, red, and black; its lustre is shining, and resinous; it is translucent on the edges; its fracture is imperfectly conchoidal; it is moderately hard, and very brittle. It is fusible before the blowpipe, by which it is distinguished from any varieties either of opal or jasper. Its analysis by Klaproth gave 73 of silex, 14.5 of argil, 1 of lime, 1 of oxide of iron, 1.75 of soda and 8.5 of water. From pitchstone, there is a transition to what has been called Pearlstone, and from that to Pumice, both of which occur vesicular, have a shining pearly lustre, and are brittle, soft, and light. They are also of similar composition. Obsidian is also related to them. It is of a deep black colour; its lustre is highly splendent and vitreous; its fracture is large conchoidal; its fragments sharp-edged; its specific gravity is 2.3. It melts before the blowpipe into an opaque spongy glass. It is composed of 69 of silex, 22 of argil, and 9 of oxide of iron.

Feldspar is an important fossil, from its extensive distribution, as a component part of several aggregate rocks.

Foliated or Common Feldspar occurs massive, disseminated, and frequently crystallized; its crystals being prisms of four or six sides, variously modified. It colours are numerous, principally red, white, and grey; its lustre is shining, and intermediate between vitreous and pearly, and is varied, according to the position with regard to incident light: it is more or less translucent; its fracture is foliated, and its fragments rhomboidal. It is moderately hard, so as to scratch glass. Its specific gravity is from 2.2 to 2.5. It melts before the blowpipe into a white glass. Its analysis has given very different results, but silex and argil are always its chief constituents, with small proportions of magnesia, lime, potash, and oxide of iron. Some varieties of feldspar decompose from exposure to the air, become earthy, and at the same time lose their fusibility; a change probably produced by the removal of some of their principles, perhaps of potash or lime, by the infiltration of water.

Foliated Feldspar enters into the composition of many of the most important aggregate rocks, and in those of every formation. Granite consists of it, intermixed with quartz and mica, and the feldspar almost always forms the principal part or basis of the granite. Gneiss is the same aggregate, having a slaty texture; and Siennite is characterised by the addition of hornblende to the other ingredients. Greenstone is an aggregate of feldspar and hornblende alone: and the name of Porphyry is appropriated to that rock where grains or crystals of feldspar are imbedded in a certain basis, as in hornstone, pitchstone, or indurated clay.

Adularia is a variety of foliated feldspar, distinguished

from the common variety by a greater degree of lustre, which is pearly, and reflected from the internal plates, so as to give in different positions a silvery appearance, by more transparency, and rather greater hardness. Labradore Feldspar is distinguished by the property of reflecting in certain positions, as the light falls upon it, very beautiful colours, particularly blue, green, and red; a property probably arising from decomposition, and the consequent alteration of its lamellæ. Compact Feldspar has less lustre and transparency; its fracture is splintery, fine grained, or very imperfectly foliated; and its fragments are not rhomboidal; its hardness is also inferior. It is allied to common feldspar, however, by its general relations, and its chemical characters.

Jade, the Nephritic Stone of mineralogists, appears to approach to compact feldspar. The greasy polish which it receives had caused it to be classed among the magnesian fossils; but late analysis has shewn that it contains no magnesia; its composition being silex 53.75, lime 12.75, argil 1.5, oxide of iron 5, oxide of manganese 2, soda 10.75, potash 8.5, water 2.25. It occurs in rounded masses; its colour is leek green, which passes into greenish-white or light yellow; it is dull and nearly opaque; it is hard and difficult to break; is slightly unctuous to the touch. Before the blowpipe it melts into a white semi-transparent glass. Bildstein, the figure stone of the Chinese, appears to belong to the same species; its characters are not very dissimilar, and it is of nearly the same composition, its constituent parts, according to Klaproth's analysis, being silex 62, argil 24, lime 1, oxide of iron 0.5, water

10, with a little potash, as ascertained by Vauquelin. The Axe-stone, which has derived its name from being used by the natives of the South Sea in making hatchets, is probably also a variety of the Bildstein.

ZEOLITE is well distinguished as a species by two chemical characters. It fuses with intumescence before the blowpipe into a white spongy glass, and it dissolves in acids, the solution being gelatinous. The Radiated variety occurs in mass, more frequently crystallized in four-sided prisms or tables. Its colour is white, with shades of grey, yellow, or red; its lustre shining and pearly; it is translucent and semi-transparent. Its fracture is radiated; the rays being generally diverging, and broad or narrow; the narrow radiated passes into fibrous, as on the other hand the broad radiated passes into a variety which is foliated; it is semi-hard, brittle, and light, its specific gravity seldom exceeding 2. The species appears to consist essentially of silex and argil, with a smaller proportion of lime, and a considerable quantity of water. From the analysis of the different varieties, the proportions are from 50 to 58 of silex, from 17 to 29 of argil, from 6 to 9 of lime, and from 10 to 22 of water. When acted on by acids, the lime and argil are dissolved, while the silex, in minute particles, and probably in combination with water, being diffused through the liquid, gives the gelatinous consistence. The intumescence before the blowpipe is probably owing to the expulsion of the water from the fused matter.

CUBIZITE, or ANALCIME, was formerly known by the name of Cubical Zeolite, but it appears to be a distinct

species. The form of its crystals is the cube, perfect or acuminated on each angle by three planes. Its colour is white; its lustre splendent and vitreous; it is transparent, or semi-transparent; its fracture is imperfectly foliated; is harder than zeolite, so that it scratches glass; it is also heavier, and does not form a jelly with acids. NEEDLE-STONE, which had been regarded as a zeolite, has also been formed into a distinct species, probably without any sufficient reason; it differs from the radiated zeolite, in being much harder and more brittle; and in its lustre being greater, and of the vitreous kind.

PREHNITE has some of the characters of zeolite, but is distinguished by being harder and heavier, and by not forming a jelly with acids. It occurs massive, and crystallized in quadrangular prisms, and oblique four-sided or six-sided tables, often aggregated. Its colour is green; its lustre is shining; it is of various degrees of transparency; its fracture is foliated, or radiated; it is hard, so as to scratch glass; its specific gravity is from 2.6 to 2.9. It melts before the blowpipe with intumescence. Klaproth found it to be composed of 43.83 of silex, 30.33 of argil, 18.33 of lime, 5.66 of oxide of iron, and 1.83 of water.

NATROLITE belongs to this family. It occurs massive, and, in its fracture, presents straight or diverging fibres; its colour is light yellow, with little lustre; it is translucent on the edges, and is nearly of the hardness of prehnite. It fuses very readily before the blowpipe, and contains not less than 16 of soda in 100 parts.

LAZULITE.—Lapis Lazuli, or Azure Stone, is of a rich azure-blue colour, approaching sometimes to sky-blue;

with little lustre, and only translucent on the edges. It occurs massive; its fracture is uneven or earthy; it is so hard as to scratch glass; its specific gravity is 2.7. It melts before the blowpipe into a white enamel, and, if previously calcined, is soluble in acids, forming a jelly. Klaproth found it to be composed of 46 of silex, 14.5 of argil, 28 of carbonate of lime, 6.5 of sulphate of lime, 3 of oxide of iron, and 2 of water. It is used in Mosaic work, and its powder affords the valuable paint known by the name of Ultramarine.

Staurolite, or Cross Stone, derives its name from occurring in twin crystals, (rectangular four-sided prisms acuminated by four planes), which intersect each other, so that the double crystal has the appearance of a cross. It occurs also in single crystals of the same form. Its colour is white; its lustre shining and vitreous; it is translucent, or semi-transparent. Its fracture is foliated; it is hard; its specific gravity 2.3. It melts before the blowpipe, and is phosphorescent when thrown on burning fuel. It consists of 40 of silex, 16 of argil, 18 of barytes, and 15 of water.

Garnet occurs both massive and crystallized: the forms of its crystals are the dodecaedron, with rhomboidal planes, either perfect, or truncated on all its edges, giving 36 faces. The variety named the precious garnet is almost always crystallized; the common is often massive. The former is of a red colour, of various shades; the lustre is more or less shining, and is vitreous; it varies in transparency from completely transparent to translucent; its fracture is conchoidal; it is harder than quartz, so as to scratch

it; its specific gravity is from 4 to 4.3; it is therefore one of the heaviest of the earthy fossils. The common garnet has less lustre and transparency, and its colours are deeper; it is also inferior in hardness and specific gravity. Both varieties are melted before the blowpipe. They consist of silex and argil, with a large proportion of oxide of iron.

Leucite, a fossil which occurs imbedded in lava, was, from the appearance of its crystallization, named White Garnet; but it differs altogether in its characters. Its colour is white, with a yellowish or greyish tinge; its internal lustre is shining, and somewhat vitreous; the crystals vary from opaque to transparent; its fracture is foliated; its specific gravity is 2.4. It is not fused before the blowpipe. It consists of 54 of silex, 24 of argil, 21 of potash, and 2 of lime.

Vesuvian is crystallized in rectangular four-sided prisms, more or less deeply truncated on all its edges. Its colour is olive-green, passing into yellow, or brown; its external lustre is splendent and vitreous; it is translucent; its fracture is small-grained uneven; it is harder than quartz; its specific gravity is from 3.3 to 3.5. It melts before the blowpipe into a yellowish glass. It consists of silex 35.5, lime 33, argil 22.25, oxide of iron 7.5, oxide of manganese 6.25.

Olivin occurs in grains or rounded pieces, or sometimes, though rarely, crystallized in rectangular four-sided prisms. Its colour is green, of different shades; its lustre is shining and vitreous; it is semi-transparent; its fracture is small conchoidal; it is inferior in hardness to quartz; its specific gravity is 3.2. It consists of silex from 40 to 50, of magnesia from 37 to 38, lime 20.5, oxide of iron,

12.5. With this fossil the CHRYSOLITE has been united by Haüy: in composition they are nearly the same; and in colour, lustre, hardness, fracture, and forms of crystallization, they are similar. AUGITE has also considerable resemblances to olivin, and is frequently found with it. It differs in the form of its crystals, which is a rectangular six-sided prism bevelled on the extremities; in its colour being a darker green, approaching to black; in being harder and heavier, the specific gravity being from 3.4 to 3.7. It is composed of 52 of silex, 13.2 of lime, 3.33 of argil, 10 of magnesia, 14.66 of oxide of iron, and 2 of oxide of manganese.

THUMERSTONE, or VIOLET SCHORL, occurs generally crystallized in very flat and obscure rhombs. Its colour is clove-brown, which passes into violet, or into grey; its external lustre is splendent, and it varies from transparent to translucent; its fracture is uneven; it is nearly of the hardness of quartz: its specific gravity is 3.2. It melts before the blowpipe, into a semi-transparent greenish glass. It consists of 44 of silex, 18 of argil, 19 of lime, 14 of oxide of iron, 4 of oxide of manganese.

SCHORL is of a black colour, with a lustre which is weakly shining, and is generally opaque, or slightly translucent on the edges. It occurs massive, and frequently crystallized in prisms; its fracture is imperfectly conchoidal, or uneven; its hardness is a little inferior to that of quartz; its specific gravity is 3. It melts with ebullition before the blowpipe into a greyish slag. It is distinguished by becoming electric by heat, presenting at one extremity positive electricity, at the other negative. The

Tourmalin is very nearly allied to schorl, and is chiefly distinguished from it by its colours, which are brown, green, red, and blue, of numerous shades, generally dark, and by its greater lustre. It consists, according to Vauquelin, of 40 of silex, 39 of argil, 3.84 of lime, 12.5 of oxide of iron, and 2 of oxide of manganese.

Pistacite, Epidote, or Thallite, has been ranked as a variety of actynolite; but in composition it approaches to the tourmalin, its analysis by Descostils affording silex 37, argil 27, lime 14, oxide of iron 17, oxide of manganese 1.5. It is usually crystallized in six-sided, or oblique four-sided prisms; is of a pistachio-green colour; the lustre is shining and vitreous; the crystals are more or less transparent; the fracture is foliated or radiated; it is hard and brittle.

Schorlite, having a considerable resemblance to schorl, was regarded as a variety of it; but it appears to be a distinct species. It is usually of a light yellow colour, which passes into deep yellow, green, or greenish-white, and also violet-blue and red. It occurs massive, or crystallized in long hexaedral prisms, more or less translucent, and having a shining lustre; its cross fracture is foliated; it is moderately hard and brittle. It consists, according to Klaproth, of 50 of argil, and 50 of silex; according to Vauquelin, of argil 52.6, silex 36.8, lime 33, and water 1.5.

Besides these fossils, silex is found deposited in a stalactitic form from waters, in which it has been previously in a state of solution. The deposite from the Geyser fountain is the principal example of this kind. It occurs in massive pieces; the surface sometimes botryoidal; its fracture is either compact or fibrous; it has scarcely any

lustre; is of a greyish-white colour; and is only semi-indurated, so as to be easily broken. It consists, according to Klaproth's analysis, of 98 of silex, 1.5 of argil, 0.5 of oxide of iron. Similar deposites are formed from other mineral springs: in some siliceous stalactites, the surface is even covered with crystals of quartz.

Sect. VIII.—*Of Zircon Fossils.*

To the zircon genus of fossils belong two fossils in which this earth is found, the Zircon and Hyacinth. To these Werner has added another, from its external colours, the Cinnamon Stone.

Zircon or Jargon occurs in rounded or angular grains, and crystallized. Its principal colour is grey, but it has often shades of green, blue, yellow, and brown; its internal lustre is resplendent and adamantine; it is transparent; its fracture is small conchoidal; it is extremely hard, so as to be scarcely affected by the file; its specific gravity is 4.6 or 4.7. It does not melt alone before the flame of the blowpipe, but with borax added it forms a transparent glass. It consists of zircon 68, silex 31.5, oxide of iron 0.5. It is cut as a gem, and is sometimes sold for the diamond, as, when cut, it has a similar play of colours.

The Hyacinth occurs in grains, or crystallized; its principal colour is what has been named Hyacinth Red, but often with various other shades; its lustre is resplendent and resinous; it is transparent or semi-transparent;

its fracture is foliated; it is very hard, scratching quartz; its specific gravity is 4.6. It loses its colour before the flame of the blowpipe, is not fused, but melts with borax into a transparent glass. It consists of zircon 70, silex 25, oxide of iron 0.5, with 4.5 of loss.

Cinnamon Stone occurs in fragments of a yellowish-brown colour, internally shining, its lustre being intermediate between resinous and vitreous; it varies from transparent to translucent; is hard, and has an imperfect conchoidal fracture. Its composition, according to its analysis by Lampadius, is silex 42.8, zircon 28.8, argil 8.6, potash 6, lime 3.8, oxide of iron 3, with 7 of loss. Klaproth, however, has been unable to discover zircon in it.

Sect. IX.—*Gadolinite.*

This forms the only known species of the genus of earthy fossils of which Ittria is the base. The Gadolinite occurs massive and disseminated; its colour is deep black; its internal lustre is resplendent; it is opaque, or feebly translucent; its fracture is conchoidal; its hardness is such that it is not scratched by the knife; its specific gravity is 4.2. It intumesces before the blowpipe, but is not fused. With nitric acid it forms a gelatinous solution. It consists of ittria 59.75, silex 21.25, oxide of iron 17.5, argil 0.5, water 0.5.

CHAP. III.

OF METALLIC MINERALS.

UNDER this order are comprised those native combinations in which metals are alloyed with each other, or are united with other substances. The individuals under each genus are connected, even in the strictest mineralogical systems, entirely by their common relation to the metal which forms its base, and not by any analogies in external properties; the arrangement, therefore, is purely chemical. Metallic minerals retain in general the characteristic metallic qualities, lustre, opacity, and great specific gravity, though to this there are many exceptions.

SECT. I.—*Of Native Gold.*

NATIVE gold occurs pure, or alloyed with portions of other metals, more particularly with silver, copper, and tellurium. Its colour is yellow, approaching to that of pure gold, according as it is more free from other metals. Its lustre is metallic and shining; it is soft, highly malleable, and ductile; its fracture is hackly; its specific gravity is always above 12, and rarely equal to 19. It occurs sometimes, though rarely crystallized; the forms of the crystals being the cube, the octaedron, and the dodecae-

dron, with rhomboidal planes: it is also found capillary, filiform, in thin plates or spangles, and sometimes massive; sometimes also in small grains in the sand of rivers and streams, forming what is named Gold Dust. Besides this, which is the common variety, there is one of a brass yellow colour, generally disseminated, or in small plates, in which the gold appears to be alloyed with silver and a little iron; and another of a steel-grey colour, passing to yellow, in which the proportion of alloy is greater.

Some minerals have been regarded as ores of gold, though they are not strictly so, as they contain larger quantities of other metals. The principal of these are the two native alloys of tellurium, the graphic gold ore, or graphic silvanite, and the white silvanite, which pass into each other. These consist of from 20 to 27 of gold, with from 45 to 60 of tellurium, 10 of silver, and sometimes a little lead. The alloy is in minute indeterminate crystals of a greyish-white colour, generally attached to each other laterally, and dispersed on the surface of the matrix, so as to bear some resemblance to printed letters; hence the name, graphic gold ore. Gold is also found in smaller quantity in some other ores, especially in some varieties of sulphuret of iron, or pyrites, which are hence named Auriferous, as well as in some of the other native sulphurets, in all which it is supposed to be merely disseminated without being combined.

Sect. II.—*Of Native Platina.*

Platina, like gold, is found only in the metallic form. It has not been found in the original repository, but in the sand of certain streams, and this forms what is named Native Platina, hitherto discovered only in South America. It is in the form of grains, but pieces have been found of a greater size. Its colour is white, approaching to a light steel-grey; its lustre metallic and shining. It is semi-hard, perfectly malleable, flexible, and has a specific gravity above 15. It is the least fusible of the native metals, not melting except in a heat such as that excited by a powerful burning mirror, and it is soluble only in nitro-muriatic acid.

Sect. III.—*Of Ores of Silver.*

Silver is found native, and also mineralized. Native silver has the general qualities of the metal. Its colour is white, though frequently tarnished; its lustre metallic; it is perfectly malleable and ductile, usually flexible; it is soft; its fracture is hackly. It occurs massive, branched, capillary, in thin plates, and crystallized; the crystals being generally small and aggregated.

By an alloy of antimony with silver, characters are ac-

quired sufficiently distinctive to form a species, which has been named Antimonial Silver. It differs from the preceding in having less external lustre, in its colour being tin-white, its fracture being lamellated, and in being brittle. It consists of from 67 to 84 of silver, with from 24 to 16 of antimony. Another native alloy of silver, forming a species, is that with arsenic, containing also sometimes iron and antimony, named Arsenical Silver. Its colour is tin-white, which is always tarnished, and often approaches to grey. Its external lustre is weakly shining; its fracture is foliated; it is soft and brittle. It occurs massive, disseminated, and crystallized; the forms of its crystals being the six-sided prism or pyramid. Before the blowpipe it exhales vapours of arsenic and antimony. It consists of 35 arsenic, 44.25 iron, 12.75 silver, and 7 of antimony.

Silver mineralized by sulphur, forms the Vitreous Silver Ore, or Silver Glance; Sulphuretted Silver. Its colour is lead-grey, passing to steel-grey; its lustre is shining, or glistening, and metallic; its fracture is uneven; it is soft, so as to be cut by the knife, malleable and flexible; its specific gravity is about 7.200. It occurs massive, disseminated, of various imitative shapes, as filiform, and in minute crystals. It consists of about 84 of silver, with 16 of sulphur.

The name of Red Silver Ore is given to a species, which, from its composition, may be named Sulphuretted Antimonial Silver. Its colour is red, of various shades; its lustre is shining, and metallic or adamantine; when massive, it is opaque; when crystallized, transparent or semi-

transparent; its fracture is uneven, is soft and brittle; has a specific gravity from 5.56 to 5.59. It occurs massive, disseminated, dendritic, and minutely crystallized. Heated on charcoal by the blowpipe, it decrepitates, melts, exhales a white vapour having an unpleasant odour, and gives a globule of silver. It consists, according to Vauquelin's analysis, of silver 56.67, antimony 16.13, sulphur 15.07, and oxygen 12.13, this oxygen, as he supposes, being divided between the metals, forming oxides, with which the sulphur is combined.

Grey Silver Ore, as it has been named, can scarcely be regarded as an ore of silver, since it contains not more than from 9 to 20 parts of silver in 100 parts, while it contains from 40 to 48 of lead, and from 8 to 21 of antimony. It consists besides of from 12 to 22 of sulphur, 1 or 2 of iron, from 1 to 7 of argil, and a minute trace of silex. There are two varieties of it, the light grey, or white silver ore, the colour of which is a light lead grey; its lustre shining and metallic, and which occurs always massive or disseminated; and the dark-grey silver ore, the colour of which is iron grey, passing to black, without lustre; and its fracture is earthy. They pass into each other, and into the other native metallic sulphurets.

Silver mineralized by muriatic acid, forms a well-defined species, Horn Silver Ore, as it has been named. Its colour is pearl-grey, of various shades, passing into white or blue; externally, its lustre is shining; it is translucent, gives a shining streak; is soft, so as to be easily cut, is also malleable; its fracture is fine grained uneven, specific gravity about 4.7. It occurs rarely massive, more fre-

quently crystallized; its crystals being acicular, or cubes which are aggregated. Heated before the blowpipe it melts, exhales a disagreeable odour, and gives a globule of silver. Another characteristic chemical character of it is, that when breathed on, and rubbed by a piece of iron or zinc, the rubbed surface exhibits a thin film of reduced silver. It consists of silver 67.75, muriatic acid 21, sulphuric acid 0.25, oxide of iron 6, argil 1.75, lime 0.25.

These are the proper silver ores. This metal is likewise present in small quantity in other metallic ores; from which, from its commercial value, it is an object to extract it; but these do not properly belong to this genus,

Sect. IV.—*Of Ores of Quicksilver.*

This metal occurs native and mineralized. Native Quicksilver is found in globules, on the surface, or in the crevices of other mercurial ores, or other fossils, retaining the lustre, opacity, mobility, and other properties of the pure metal. Sometimes it has an alloy of silver, so as to give a soft, and even a firm consistence; and when the proportion of silver is large, it forms a proper species, which occurs in a crystallized form, having the general qualities of the metals of which it is composed. It exhales the quicksilver in vapour when exposed to the heat of the blowpipe, and the silver remains.

Quicksilver in the state of oxide combined with mu-

riatic, and a portion of sulphuric acid, forms the species which has been named Mercurial Horn Ore. This generally occurs in small crystals. Its colour is grey, with a pearly lustre. It is faintly translucent: its fracture is foliated; it is soft and brittle, so as to be easily scraped, or cut with a knife. Before the blowpipe it is volatilized.

Quicksilver mineralized by sulphur, forms Cinnabar, its most abundant ore. Its colour is red, of various shades; its lustre various, passing from shining to dull. It occurs massive, disseminated, and crystallized, the crystals being always small. When crystallized, it is translucent or semi-transparent; when massive, opaque. It is brittle and soft. Its specific gravity varies from 6 to 10. Heated by the blowpipe, it is volatilized, with smoke, a blue flame, and an odour of sulphur. It consists, when free from foreign matter, according to Klaproth's analysis, of 84.5 of quicksilver, and 14.75 of sulphur.

Hepatic Quicksilver Ore occurs massive. Its colour is intermediate between dark-red and lead-grey, or iron-black. It has little lustre, and is perfectly opaque. Its fracture is even or slaty. It is soft, brittle, and has a specific gravity of from 7 to 9. Its nature was not well ascertained, until it was examined by Klaproth, who has given as the results of the analysis,—quicksilver 81.8, sulphur 13.7, charcoal 2.3, silex 0.65, argil 0.55, oxide of copper 0.2, water and loss 0.7. It is probably cinnabar, altered by the intermixture of small quantities of foreign substances.

Sect. V.—*Of Ores of Copper.*

Copper occurs native, and likewise mineralized, forming several species of ores, in general well defined.

Native Copper has the general properties of the pure metal. Its colour is red, but frequently tarnished: its lustre metallic; it is flexible, ductile, and malleable; its fracture, like that of other metals, is hackly. Its specific gravity is from 7.6 to 8.5. It occurs massive, in branched pieces, dendritic, in thin plates, and indistinctly crystallized.

Copper mineralized by oxygen, forms Red Copper Ore, of which what is named florid red copper ore is the purest form. It occurs massive, in plates, disseminated, and crystallized. Its colour is cochineal-red, of various shades, approaching to carmine-red; its lustre is semi-metallic, or adamantine; it is opaque when massive; transparent, or semi-transparent, when crystallized; it is semi-hard, brittle; its specific gravity is about 3.9. Its fracture is compact, foliated, or fibrous; whence different varieties are formed. It appears to be pure oxide of copper; consisting, according to Chenevix's analysis of it, of about 88.5 of copper, and 11.5 of oxygen. The brick-red or tile-red copper ore, which occurs earthy or little indurated, appears to be a mixture of oxide of copper and oxide of iron.

Oxide of copper combined with carbonic acid, appears to form two natural species, the Blue Carbonate and the Green Carbonate; the differences between which arise

probably from different states of oxidizement of the metal, or perhaps in part from the combination of water.

The Blue Carbonate is known under the name of Mountain Blue. One variety is earthy, usually forming an incrustation, sometimes massive, the colour of which is smalt blue without any lustre. The other is indurated; its principal colour is azure-blue; when crystallized, its lustre is shining and glassy; when massive, it is rather dull; the latter is opaque, while the crystals are translucent, or semi-transparent; the forms of its crystals are the rectangular and the rhomboidal four-sided prism, acuminated by four planes; they are small and aggregated. This species dissolves in nitrous acid with effervescence. Analysed by Pelletier, its constituent parts were from 66 to 70 of copper, from 8 to 10 of oxygen, from 18 to 20 of carbonic acid, and 2 of water.

The Green Carbonate of copper comprises two varieties, what have been named Mountain Green, and Malachite. The first is massive, but more generally occurs as an incrustation; its colour is verdegris-green; it is generally dull; its fracture is earthy or small conchoidal; and it is soft and brittle; it effervesces, though slightly, with acids, and appears to consist of oxide or carbonate of copper, with argil and lime. The other variety, Malachite, occurs massive, disseminated, incrusting, and crystallized in capillary and acicular prismatic crystals; its colour is green; its lustre is silky or pearly; its fracture striated, the striæ being usually divergent. One variety has a compact fracture. This species effervesces with acids. The fibrous malachite analysed by Klaproth was found to con-

sist of 58 of copper, 18 of oxygen, 12.5 of carbonic acid, and 11.5 of water. It contains therefore more oxygen and more water than the blue carbonate.

Copper mineralized by phosphoric acid forms a rare ore, formerly confounded with malachite, but analysed by Klaproth, and found to consist of oxide of copper 68.13, phosphoric acid 30.95. It occurs massive, disseminated, in cubic crystals very small and grouped, of a green colour, often black on the surface, with a vitreous lustre, and opaque: its fracture is fibrous.

Copper occurs also mineralized by muriatic acid: This fossil was first observed in angular grains; it has since been obtained massive, and crystallized in six and in four sided prisms, transparent, with considerable lustre; when massive, it is opaque. It dissolves in nitric and muriatic acids without effervescence, and distilled with sulphuric acid, exhales muriatic acid. Analysed by Klaproth and Proust, it has given nearly the same results, from 70 to 76 of oxide of copper, about 10 of muriatic acid, and from 12 to 16 of water.

Sulphate of copper occurs in solution in the water of some copper-mines; and sometimes deposited stalactitic or crystallized; its crystals being either capillary, or cubes truncated on the edges or angles, of a blue colour, shining and translucent.

Copper occurs mineralized by arsénic acid, forming combinations which differ with regard to proportions, and the presence of water; giving rise to several varieties, which have even been regarded as distinct species, and the composition of which has been established by Chenevix. There

is one which occurs crystallized, in the form of an obtuse octaedron. Its usual colour is sky-blue; though sometimes it is of an apple or grass green; it is translucent, shining; it is brittle; has a specific gravity of 2.881. It consists of 49 of oxide of copper, 14 of arsénic acid, and not less than 35 of water. A second is crystallized in hexaedral tables, bevelled on the terminal planes; its colour is a deep emerald-green, with much lustre and transparency; it is less hard, and likewise less heavy; its specific gravity being only 2.548. It consists of 58 of oxide of copper, 21 of arsénic acid, and 21 of water. A third is crystallized in the form of an acute octaedron, the crystals sometimes being lengthened and capillary; frequently capillary and indeterminate; in some specimens appearing as delicate fibres parallel or divergent; and sometimes in layers, flat or mammillated, and of a fibrous texture. The colour in these different states is dark olive-green, often passing into brown or yellow, or greenish-white; it is generally transparent, or semi-transparent; the lustre is externally shining; it is harder than the preceding varieties, and is much heavier; the specific gravity being 4.280. It consists of from 50 to 60 of oxide of copper, from 30 to 40 of arsénic acid, with, in some varieties, water amounting to 18 or 20 parts. The last variety occurs crystallized in triedral prisms, generally extremely small; they are of a beautiful bluish-green colour, but from decomposition often black; when unaltered, they are transparent. Its specific gravity is 4.280. It consists of 54 oxide of copper, 30 arsénic acid, and 16 water.

Copper, in combination with sulphur, with variable proportions of several other metals, forms a series of ores,

which pass into each other, and which it is difficult to arrange as distinct species, as it is not easy to determine whether some of them are aggregates or compounds of different metallic sulphurets, or whether two or more of the metals associated together are in immediate combination with each other, and with the sulphur. What is named Vitreous Copper Ore appears to be the sulphuret of copper in its purest form; it consists of 78.50 of copper, 18.50 of sulphur, 2.25 of iron, and 0.75 of silex. It occurs massive, disseminated, and crystallized, the forms of its crystals being numerous and often imperfect. Its colour is grey; its lustre metallic; its fracture is conchoidal or even, or foliated; its specific gravity is from 4 to 5.3. In the Purple, or Variegated Copper Ore, the proportion of iron is larger, and either it or the copper appears to be slightly oxidated. Klaproth's analysis gave of copper 69.5, of iron 17.5, of sulphur 19, and of oxygen 4 or 5. The colour of a fresh fracture is reddish-brown, but it quickly tarnishes; various tints of purple, blue, red, reddish-yellow, and green, being assumed and intermixed on the same surface. It occurs usually massive, sometimes disseminated; its lustre is shining and metallic, but is diminished with the tarnishing; it is opaque; is soft and brittle; its specific gravity from 4.3 to 4.9. Copper Pyrites is a compound of sulphur, copper, and iron; or, in another point of view, a combination of sulphuret of copper, and sulphuret of iron, and these are in various proportions. Its colour is brass-yellow, being deeper as the copper is more abundant in its composition; it is generally tarnished, and often iridescent. It occurs mas-

sive, disseminated, in botryoidal and stalactitic forms, and crystallized. Its lustre is shining and metallic; its fracture uneven; it is brittle, and has a specific gravity from 4.1 to 4.3. The last of these sulphurets is the Grey Copper Ore. It contains, combined with the sulphur and copper, various metals, lead, antimony, silver, and iron, in very variable proportions; and what proves it to be a proper sulphuret of copper, and that these are merely mixed with it, is that, when present, they do not materially modify its properties, and that it occurs composed of copper, iron, and sulphur alone; one specimen analysed by Chenevix having given 52 of copper, 31 of iron, and 14 of sulphur. It occurs massive, disseminated, and crystallized; the principal form of its crystals being the tetraedron or three-sided pyramid, variously modified. Its colour is steel-grey, which is liable to tarnish: its lustre is shining and metallic; its fracture uneven; it is brittle, and has a specific gravity from 4.4 to 4.8.

What is named White Copper Ore has not been accurately analysed, but it appears to contain arsenic, from the odour it exhales when heated by the blowpipe, in combination with copper, and probably iron, and sulphur. Its colour is white, with a shade of grey or yellow; its lustre is metallic; it is brittle, and has a fine-grained uneven fracture; it occurs either massive or disseminated, and is a very rare ore.

Sect. VI.—*Of Ores of Iron.*

Iron is of all metals the one of most extensive distribution. It occurs generally in the state of oxide, pure or combined with other substances, forming an extensive family of ores.

Besides these, the singular fact has been established, that it is a meteoric or atmospheric production, the stony masses which it has been established by the most ample evidence have fallen from the clouds at different periods, and in different countries, being composed principally of iron. As natural compounds of this metal, they may be considered in this place.

These meteoric stones are heterogeneous in their structure. They have externally a thin black crust. When broken, they are of an ash-grey colour, and granulated texture, and appear to be composed of four substances, which can be distinguished by a lens. One of these is in small globular or elliptical grains of a grey colour, having a conchoidal fracture, a lustre resembling that of enamel, and so hard as to scratch glass; this has a resemblance in characters and composition to the Chrysolite. Another consists of iron pyrites of a reddish-yellow colour, and granulated texture. The third consists of particles of iron in a metallic state, capable of being extended under the hammer, and giving to the entire stone the property of being attracted by the magnet. These three substances are united by a fourth, which is nearly of an earthy consistence. Mr How-

ard, some years ago, investigated the composition of these. Both the metallic pyrites and the iron contain nickel. The vitrified substance consists of silex, magnesia, oxide of iron, and a little nickel. The composition of the earthy matter is nearly the same, and it differs principally in aggregation. The external crust consisted of iron and nickel partially oxidized. In all the specimens the same elements were found, and in proportions not very different; and this agreement in fossils, found in countries so remote, is a proof of their common origin.

There is every reason to believe, that the large insulated masses of iron which have been observed in America and Siberia have had the same origin. Proust, in analysing a fragment of that from America, found it to contain nickel; and Mr Howard, on repeating the analysis, likewise ascertained this, 100 grains giving 7½ of nickel. That from Siberia he equally found to contain nickel. And both these masses have a vitrified matter, resembling chrysolite, intermixed in their substance, analogous to that present in the meteoric stones.

From a number of the accounts authenticated with regard to the fall of these masses, it appears that they have been highly heated, and probably in a state of fusion. The stone, when touched after its fall, has been felt quite hot, and the external crust has appeared newly vitrified. The fall has also been frequently accompanied with the appearance of a fiery meteor, as of a luminous ball, and sometimes with discharges of lightning, and with a loud noise, or repeated explosions.

With regard to the origin of these masses, it is extreme-

ly difficult to advance any hypothesis at all satisfactory. They have been supposed to be projected from volcanoes, a supposition refuted by the consideration of their entire dissimilarity to any known volcanic production, and of their fall in countries so remote from any volcanoes. La Place advanced the bold conjecture, that they have been projected from the moon, and endeavoured to shew by calculation, that a force might be exerted at the surface of that planet adequate to this effect,—a calculation involving, however, the gratuitous and improbable assumption, that the moon has no atmosphere, and liable to other objections. The more moderate hypothesis is obvious, that they may be the products of combinations in the upper regions of the atmosphere. But all such conjectures must of course rest on very hypothetical grounds.

The most abundant and most numerous ores of iron are those in which it is mineralized by oxygen, of which there is a series differing in the degree of oxidation of the metal, and in the intermixture of other substances. These may be arranged, principally from their chemical relations.

One species well defined is that named Magnetic Iron Ore, from its high magnetic power. It occurs massive and crystallized; the forms of its crystals being the cube, octaedron, and rectangular tetraedral prism. Its colour is black or deep-grey; its lustre is shining and metallic; and it is opaque: its fracture is uneven, or imperfectly foliated; it is brittle, and hard; its specific gravity is from 4.2 to 4.9: it is insoluble in nitric acid, but dissolves in muriatic acid, with the assistance of heat. It yields from 80 to 90 in 100 of iron, and may be regarded as a pure oxide. Sometimes

it occurs in the form of small particles or grains, forming what is named Magnetic Iron Sand.

The next species is equally determinate,—that named Specular Iron Ore, or Iron Glance. In it the magnetic power is so far impaired by a higher degree of oxidizement, that it is attracted by the magnet only when in fine powder. It occurs massive, and frequently crystallized; the forms of its crystals being very numerous, and variously modified; its colour is steel-grey, but is often tarnished and iridescent; the lustre is highly shining and metallic; its fracture is uneven, sometimes foliated; it is so hard as to scratch glass, and is brittle; its specific gravity is from 4.6 to 5.2. It is insoluble in nitric acid, but dissolves in the muriatic acid, with the assistance of heat. It consists of from 60 to 80 of iron, and from 20 to 30 of oxygen. The Micaceous Iron Ore has been regarded as a variety of this species. It is massive, disseminated, or crystallized, in small and thin six-sided plates; is shining, and feels somewhat greasy, but without staining the fingers; and is not so hard as the specular iron ore; its fracture is foliated.

The next family of ores it is more difficult to arrange as species. The iron is in a higher state of oxidation, and the oxide is mixed with quantities of several other substances, principally argil, silex, and lime, but in such variable proportions, and passing so much into each other, that their specific distinctions can be only imperfectly determined. The principal of these ores are the Red Ironstone, Brown Ironstone, Black Ironstone, and Clay Ironstone.

Of Red Ironstone, there are two principal varieties, the

compact red ironstone, the fracture of which is even; and the hæmatite, the fracture of which is fibrous, the fibres being straight, parallel, or diverging. The former occurs generally massive, or in detached masses, nodular, or stalactitic, the latter almost always in globular or kidney-shaped masses, stalactitic or botryoidal. The colour of both is intermediate between brownish-red and steel-grey; but in the streak, and in powder, always blood-red. Their specific gravity is from 3.5 to 5. Brown ironstone is distinguished from the red, principally by the colour being brown in the mass, and in the streak yellow, or yellowish-brown. Of it, too, there are two principal varieties, distinguished by the fracture,—the compact brown ironstone, the fracture of which is even; and the brown hæmatite, the fracture of which is fibrous, the fibres being in general diverging. The compact occurs massive, sometimes in masses of various imitative forms. The fibrous occurs generally in masses, stalactitic, kidney-shaped, or botryoidal. The colour of both is brown, of various shades and intensities; sometimes tarnished, so as to be iridescent, with a degree of lustre that is semi-metallic; the specific gravity is about 3.4 or 3.5. The analysis of these has not been executed with any accuracy, but they appear to contain, with oxide of iron, argil, lime, and, as has been supposed, oxide of manganese. They yield from 40 to 60 of iron, in general of excellent quality, from 100 of ore. With these are connected the less important varieties of Scaly Iron Ore, and of Iron Ochre;—the former generally incrusting the other ores of the species, or lining their cavities, and, being composed of scaly particles,

which have a shining lustre, soil, and feel unctuous; the latter being earthy and little indurated, of a red or yellowish-brown colour, dull, and staining the finger.

Black Ironstone, like the red and brown, comprises two principal varieties,—the compact, and the fibrous or black hæmatite. Its colour is bluish-black, or dark steel-grey, with a semi-metallic lustre. It occurs massive, and in tuberose, kidney-shaped, and botryoidal pieces. Its composition is not known, but it is supposed to contain a large proportion of oxide of manganese.

Argillaceous Iron Ore, or Clay Ironstone, comprises a series of ores, in which oxide of iron is mixed with a large proportion of argil or clay, the limits of which are not easily marked, as they pass into each other. The common argillaceous ironstone occurs massive, generally in beds or strata. Its colour is grey, of different tints, which passes into various shades of a yellowish or reddish-brown, especially from exposure to the air; it has no lustre, and is perfectly opaque; its fracture is earthy; sometimes even; sometimes inclining to slaty; it is soft, feels meagre, adheres a little to the tongue; its specific gravity is about 3.3 or 3.4. It consists of oxide of iron, clay, with portions of lime and silex; and affords from 30 to 40 of iron in 100, of good quality. Nodular Ironstone, reniform iron ore, or eagle stone, belongs to this species; it occurs in rounded masses, sometimes spherical, generally somewhat oblate, or approaching to the kidney form; composed of concentric lamellar concretions, and sometimes inclosing a nodule slightly adhering or quite loose. Pisiform Iron Ore is a similar variety, in small rounded

grains, whence its name; of a yellowish-brown colour, having an earthy fracture, with little coherence. It has been analysed by Vauquelin, and gave 30 of iron, 18 of oxygen, 31 of argil, 15 of silex, and 6 of water.

Sparry Iron Ore is a species well determined from its chemical relations. It consists of oxide of iron, oxide of manganese, and carbonate of lime. The proportions vary, and the carbonate of lime augments in some varieties so much, that they are placed among the calcareous fossils, forming the Pearl Spar; and it is only when the proportion of metallic matter is abundant, that it is regarded as an iron ore. It occurs massive, disseminated, and crystallized; the forms of its crystals being the rhomb, perfected or truncated, the lens, the octaedron, and the dodecaedron. Its colour is white, grey, yellow, or brown; but what is a peculiar property of it, the colour darkens from exposure to the air: it thus becomes brown, and at length black,—a change owing to the manganese existing in it in a low state of oxidizement, and absorbing oxygen from the atmosphere; its lustre is pearly; it is translucent on the edges: its fracture is foliated: its fragments are rhomboidal; it is harder than calcareous spar, so as to scratch it; its specific gravity is from 3.6 to 3.8; it is soluble with effervescence in acids. It blackens before the blowpipe, and loses weight. Analysed by Bergman, it afforded in different specimens, from 22 to 38 of oxide of iron, from 24 to 28 of oxide of manganese, from 19 to 24 of lime, from 10 to 17 of carbonic acid, and from 9 to 6 of water. Descostils has found magnesia in it. It is considered as affording the iron best adapted to the manufacture of steel.

Oxide of iron deposited from water, holding it in solution, and stagnant in swampy situations, forms Bog or Swamp Iron Ore, which is in different degrees of induration, in masses which are corroded, cellular, and sometimes tuberose, of a yellow or brown colour, dull, and earthy. With oxide of iron, those ores have been supposed to contain argil, silex, and phosphoric acid. Vauquelin, with these ingredients, discovered in them lime, magnesia, manganese, and chrome. Blue Iron Earth is probably of similar origin, as it is associated with bog iron ore, and, according to Haüy, consists of oxide of iron, with argil, and a little phosphoric acid; though Vauquelin found in it only oxide of iron, argil, and silex. It is at first of a white colour, but becomes blue from exposure; is loose and friable, without any lustre. Green Iron Earth has likewise been supposed to consist of iron and phosphoric acid. It is earthy, more or less coherent, of a green colour, without lustre. An ore of this family, in which the presence of phosphoric acid is less ambiguous, has been analysed by Vauquelin, and was found to consist of 27 of phosphoric acid, 31 of oxide of iron, and 42 of manganese. And iron mineralized by phosphoric acid alone, has also been discovered to be a natural production, forming a mineral of a deep blue colour, in small plates adhering slightly, the surface of which is brilliant; they are translucent, but some, apparently from the loss of water they contain, are opaque. The specific gravity is 2.6.

Iron mineralized by arsénic acid, forms an ore, formerly regarded as an arseniate of copper. It occurs massive, but generally crystallized in small cubes, smooth, and highly shining, the lustre being adamantine; the colour is a

dark green, sometimes with a brown or yellowish tinge. The crystals are translucent. The fracture is imperfect foliated; the specific gravity 3000. Analysed by Chenevix, this species was found to consist of 31 arsénic acid, 45.5 oxide of iron, 9 oxide of copper, 4 silex, and 16.5 of water. The copper he regards as accidental, not essential to the composition. Another was discovered, however, in which it was more constant, and in larger proportion, the proportions being 33.5 arsénic acid, 27.5 oxide of iron, 22.5 oxide of copper, 3 of silex, and 12 of water. This species occurs in minute crystals, of a faint sky-blue colour; perfectly transparent, and of very high lustre, and generally grouped irregularly, sometimes united so as to assume a mammillary form.

Sulphate of Iron sometimes occurs in tuberose or stalactitic masses; sometimes in capillary crystals, in imperfect rhombs, or in octaedrons; of a green colour, easily recognised by its solubility in water, its astringent taste, and the usual chemical tests of the salts of iron.

Iron, in combination with sulphur, forms a well-defined species, that known under the name of Pyrites. It occurs massive, disseminated, and frequently crystallized; the forms of its crystals are various, but the most common is the cube regular or modified by truncation of the angles or edges, or acumination of three planes on the angles. Its colour is brass yellow, and the lustre is always fully metallic; it is opaque. The fracture is uneven. It is brittle; its hardness is such as to strike fire with steel; its specific gravity is from 4.6 to 4.8. By friction it exhales a sulphureous smell. This odour is strong when it is heated

before the blowpipe; it gives also a blue flame. Various analyses of it have been given; according to those executed by Hatchet, it consists of 52 of sulphur, with 48 of iron.

Besides this Common Pyrites, there are some others, varieties of the species, differing principally in structure or form. The Striated or Radiated Pyrites presents a striated fracture, the striæ being generally diverging. Capillary Pyrites occurs in delicate capillary crystals, grouped, parallel, diverging, or interwoven, slightly flexible, having a metallic lustre, and a colour passing from yellow to steel-grey. Hepatic Pyrites is so named from the liver-brown colour which it assumes from exposure to the air. It occurs massive, of various imitative forms, and crystallized in six-sided prisms, or six-sided pyramids; has less lustre than the others, and is more subject to decomposition.

Magnetic Pyrites, distinguished, as the name implies, by its magnetic quality, has been considered as forming a distinct species. Its colour is deeper, being intermediate between brass-yellow and copper-red, and approaching to brown, often tarnished; its lustre is inferior, but is still metallic. It occurs only massive or disseminated. Its fracture is compact; it is hard and brittle; its specific gravity is 4.5. From Mr Hatchet's analysis of it, it differs from the other iron pyrites, in containing a larger proportion of metal, the proportions of its constituent parts being 36.5 of sulphur, and 63.5 of iron.

There has been much difference of opinion among chemists, with regard to the state of the metal in iron pyrites, whether it is oxidized or not. Vauquelin affirmed, in con-

formity to an opinion that had been before maintained, that the iron in pyrites is oxidized nearly to the point at which it is easily soluble in acids. Proust, on the contrary, asserts, that in pyrites the iron is entirely in the metallic state: when subjected to distillation, sulphur only was afforded; and the residual matter, he inferred from its resemblance to the artificial sulphuret, did not contain oxygen. The opinion, that the iron in pyrites is in its metallic state, is confirmed by the result of Mr Hatchet's analyses.

Sect. VII.—*Of Ores of Lead.*

Lead occurs principally mineralized by different acids, and by sulphur.

Carbonate of Lead, the White Lead Ore of mineralogists, is presented under different forms,—earthy, indurated, and crystallized. In the last state, it appears under the forms of the hexaedral prism, the tetraedral prism, the double hexaedral pyramid, the four and the six sided table; and, in acicular crystals, aggregated, and intersecting each other. The surface of the crystals is highly shining, the lustre being adamantine; the colour generally white, sometimes grey, yellowish, or brown; they are transparent, or translucent; are brittle and soft, so as to be easily scratched by the knife. The specific gravity is from 6 to 7. When massive, it has less lustre and transparency. Urged by the flame of the blowpipe, it decre-

pitates, becomes yellow or red, and melts into a metallic globule. It effervesces with acids, and in diluted nitric acid is completely dissolved. Its composition varies with regard to the proportions of its constituent parts; and it often contains variable quantities of oxide of iron, argil, silex, and lime. A specimen of it, pure, was found by Klaproth to be composed of 77 of lead, 5 of oxygen, 16 of carbonic acid, and 2 of water.

Earthy Lead Ore, which occurs friable or indurated, of a grey colour, of various shades and intermixtures, without lustre or transparency, appears to be a mixture of carbonate of lead with various earthy matters. When associated with an ochrey earth, so as to assume a red colour, it has been named Native Minium. Black Lead Ore appears to be carbonate of lead, altered probably by the action of sulphur, or by intermixture with it, especially as it is found generally incrusting the native sulphuret, and is itself incrusted by the carbonate. A lead ore, which occurs crystallized in cubes similar in appearance to carbonate of lead, but being softer, and having less specific gravity, was found by Chenevix to contain both carbonic and muriatic acid.

Lead occurs mineralized by sulphuric acid. This ore is always crystallized; the form of the crystals being the octaedron, modified by truncation or bevelment. Its colour is white, with shades of grey; the crystals are transparent, or semi-transparent; their lustre shining and adamantine; the fracture compact; the specific gravity 6.300. It does not effervesce with acids, and is not soluble in nitric acid. According to Klaproth's analysis, it consists of

oxide of lead 71, sulphuric acid 24.8, water 2, oxide of iron 1.

Native Phosphate of Lead is a common ore. Its usual colour is green, of various shades; but it passes through yellowish-green into pure yellow. It occurs in general in an incrustation, often mammillary or botryoidal, composed of minute crystals, more or less aggregated, the form of which is the hexaedral prism, truncated or acuminated, and the hexaedral pyramid. They have a waxy lustre, and are translucent; the fracture is uneven; it is brittle and soft. The specific gravity is from 6.2 to 6.9. It does not decrepitate before the blowpipe, but becomes white, and melts easily into a globule of a grey colour, without the lead being reduced. It does not effervesce with nitric acid, but is dissolved by it. It was found by Klaproth to consist of oxide of lead, in various specimens, from 78 to 80, phosphoric acid 18 or 19, muriatic acid 1.5 or 1.7, and a minute trace of oxide of iron. A variety of this species, named Brown Lead Ore, occurs massive, and crystallized in hexaedral prisms, having a waxy lustre, and opaque: it has been found by Klaproth to consist of oxide of lead 78.58, phosphoric acid 19.73, muriatic acid 1.65.

Fourcroy has given the analysis of a lead ore, which occurs in mammillary masses of a yellowish-green colour, containing both phosphoric and arsénic acid, with a little oxide of iron. Lead, too, occurs mineralized by arsénic acid alone. Its colour is green, which passes to yellow; it occurs in acicular or capillary crystals, and also massive. Another variety of native arseniate of lead, with an intermixture of iron, occurs in uniform masses of a rough sur-

face and yellow colour, opaque and dull. These are all distinguished by the strong arsenical odour they give when heated on charcoal by the blowpipe.

Yellow Lead Ore is a species, in which the lead is mineralized by a metallic acid,—the Molybdic Acid. It occurs massive, more commonly in small crystals, the forms of which are rectangular tables of four or of eight sides bevelled, the cube, octaedron, and double eight-sided pyramid. Its colour is wax-yellow, and its lustre waxy; it is translucent, is soft, and easily broken. It decrepitates before the blowpipe, and melts into a globule of a grey colour, in which are disseminated particles of metallic lead; is insoluble in nitric acid. It consists of oxide of lead 58.40, molybdic acid 38, oxide of iron 2.08, and silex 0.28.

Chromate of lead may be noticed under the ores of chrome.

Lead, mineralized by sulphur, forms the most abundant ore of the metal, that named Galena. It occurs massive, disseminated, incrusting, in corroded or reticulated masses, in grains, and crystallized. The forms of its crystals are the cube, the octaedron, the tetraedral prism, the hexaedral prism, and the three-sided table, all perfect or modified by truncation, acumination, or bevelment. Its colour is bluish or lead-grey, sometimes inclining to black, and sometimes iridescent on the surface. Its lustre is splendent and completely metallic; it is perfectly opaque; its fracture is distinctly foliated, in one variety compact; its fragments of a cubical form: it is soft, so as to be easily scratched; it is also easily frangible; its spe-

cific gravity is from 7 to 7.7. It decrepitates before the flame of the blowpipe, melts, exhales a sulphureous odour, and affords a globule of lead. The proportions of lead and sulphur vary considerably; that of the lead is from 50 to 83, of the sulphur from 10 to 25. It always contains too a small quantity of silver; and frequently iron, silex, and lime.

Sect. VIII.—*Of Ores of Tin.*

Tin occurs in nature principally in the state of oxide, and in smaller quantity in that of sulphuret.

Native oxide of tin, or Tinstone, occurs massive, disseminated, and frequently crystallized. The forms of its crystals are numerous, in general complicated and imperfectly marked. Its usual colour is brown, of various shades. Its lustre is shining, and, externally in the crystals, is highly splendent; when of a dark colour, it is opaque; when of a lighter shade, translucent, or semi-transparent; its fracture is uneven; it is hard and brittle; its specific gravity is from 6.3 to 6.9. It decrepitates before the blowpipe, and, when heated on charcoal, is reduced. The proportions of its parts vary little. A specimen analysed by Klaproth, gave 77.5 of tin, 0.25 of iron, 21.5 of oxygen, and 0.75 of silex.

Wood Tin Ore, being an oxide of tin, may probably be regarded as a sub-species; though, as Klaproth discovered in it likewise iron and arsenic, it may perhaps form

a species. It is found only in small rolled pieces or fragments, and has a distinctly fibrous fracture, whence its name has been derived. Its colour is brown; its lustre glistening; it is opaque, hard, brittle, and has a specific gravity of 6.456. It is not reduced before the blowpipe.

Tin mineralized by sulphur, with copper and a little iron, forms Tin Pyrites. It occurs massive or disseminated; its colour is steel-grey, passing into yellowish-grey; its lustre is metallic and shining, or glistening; it is opaque; its fracture is uneven; it is semi-hard, brittle, and has a specific gravity of 4.350. It is composed of 25 of sulphur, 34 of tin, 36 of copper, and two of iron.

Sect. IX.—*Of Ores of Zinc.*

Zinc is mineralized by oxygen, carbonic acid, sulphuric acid, and sulphur.

Its most abundant ore, Calamine, occurs earthy, or without much induration, sometimes more highly indurated, of a compact or striated texture, forming different varieties. It is massive, often cellular or corroded, or botryoidal, sometimes in minute crystals, forming a drusy incrustation. Its colour is white, but with various shades of yellow; it is dull, translucent; the crystals are nearly semi-transparent; the earthy is opaque. Its specific gravity is from 3.5 to 4. It has the property of becoming electric by heat; when heated before the blowpipe, it becomes white, but is not reduced. Some varieties effer-

vesce with acids; others do not; they dissolve in the nitric acid, forming a solution of a gelatinous consistence. The composition varies much. Some varieties appear to be composed only of oxide of zinc and silex, with or without water. Thus Klaproth found a specimen to consist of 66 of oxide of zinc and 33 of silex; and Pelletier another, of oxide of zinc 36, silex 52, and water 12. More generally, however, carbonic acid is present, and then the silex is wanting. Mr Smithson analysed several of these varieties, and found the proportions to be about 65 of oxide of zinc, and 35 of carbonic acid; in some, water was present. Perhaps calamine properly forms two species, the one carbonate of zinc, the other oxide of zinc with silex. It is the latter which forms a gelatinous solution with acids, and becomes electric by heat.

Sulphate of zinc sometimes occurs with the sulphuret, tuberose or stalactitic, of a greyish colour, and translucent; and distinguished by its solubility in water, and its styptic taste.

Blende, or native sulphuret of zinc, presents several diversities in appearance. From difference of colour, three subspecies have been formed, the yellow, the brown, and the black; of which the brown is the most common. Its colour is brown, with shades of yellow and red, and often tarnished; its lustre is splendent inclining to resinous; it is more or less translucent; its fracture is foliated, sometimes fibrous; it is semi-hard, brittle, and has a specific gravity of from 3.7 to 4. It occurs massive and disseminated, and often crystallized; the forms of its crystals being both numerous and complicated. Yellow blende has a yellow colour of

various shades, passing into green or into red; its lustre is rather greater, and is adamantine; and when the colour is light, it is semi-transparent. Black blende has a black colour with a shade of brown or red; its lustre is metallic; its fracture foliated; it is opaque or translucent on the edges. Blende, in addition to zinc and sulphur, contains generally iron, and often silex, argil, water, and sometimes lead, arsenic, silver, or copper. The yellow variety, according to Bergman, contains fluoric acid. The proportion of zinc is from 45 to 65, and of sulphur from 17 to 30. The metal has been supposed to exist in the ore as an oxide, but it appears rather to be in the metallic form.

Sect. X.—*Of Ores of Nickel.*

Nickel occurs alloyed with arsenic, and a little sulphur; and in the state of oxide. The first species, the Kupfernickel of mineralogists, is the most abundant. It occurs massive and disseminated; its colour is copper-red, of various shades; its lustre is weakly shining and metallic; it is perfectly opaque; its fracture is uneven; it is hard and not easily broken; its specific gravity is from 6.6 to 7.5. Before the flame of the blowpipe, it gives arsenical vapours, and melts with difficulty. It dissolves in acids, giving a green solution. Bergman found it to be composed of nickel, iron, cobalt, arsenic, and sulphur. Vauquelin regards it as an alloy of nickel and arsenic, the others being accidental.

Oxide of nickel occurs generally as an incrustation, sometimes disseminated, of a friable texture and earthy appearance; of an apple-green colour, without lustre. Its solution in acids is of a green colour. It occurs generally with kupfer-nickel, or with certain cobalt ores.

Sect. XI.—*Of the Ores of Cobalt.*

The ores of cobalt are distinguished by giving to borax, when fused with it by the blowpipe, a blue colour, and forming, when dissolved in nitric acid, a solution which becomes green from heat.

White Cobalt Ore is an alloy of cobalt and arsenic, with a little sulphur, and in some specimens a little iron, the two latter being probably accidental. Its colour is tin-white, liable to tarnish, and thus to assume a grey or reddish tinge; its lustre is weakly shining and metallic. It occurs massive and disseminated, of various imitative shapes, and crystallized in cubes, and in octaedrons; the fracture is uneven; it is hard and brittle. Before the blowpipe it melts easily, and gives out an arsenical smoke and odour; it forms a metallic globule, and gives to borax a blue colour. To this species probably belongs the Shining Cobalt Ore, or Cobalt Glance: the colour, lustre, fracture, forms of crystallization, and the chemical characters, being the same, and the differences trivial and accidental.

Grey Cobalt Ore appears to be an alloy of cobalt with arsenic and iron; sometimes with small portions of nickel

and bismuth. Its colour is light grey, but liable to tarnish; its lustre weakly shining and metallic. It occurs massive or disseminated; its fracture is even; it is semihard, passing into hard, brittle; and has a specific gravity of from 5.5 to 7.7. Exposed to the flame of the blowpipe, it gives an arsenical odour and smoke; to borax it gives a blue colour.

Native Oxide of Cobalt occurs in a loose form, or of various degrees of induration, but always dull, and earthy in its fracture, soft, and easily broken. It is also of different colours, from the intermixture of oxide of iron, and perhaps other metallic oxides; whence varieties, which have been regarded as the Black, Brown, and Yellow Cobalt Ochres. These all give a blue colour to glass or to borax when fused with it, and sometimes exhale an arsenical odour.

The Peach Bloom Cobalt Ore derives its name from its colour, which is a beautiful red, similar to that of the peach blossom, passing however into other shades of red, and from decomposition into other colours. It occurs massive, disseminated, and in minute crystals. One variety has an earthy fracture, without lustre, and occurs generally as an incrustation: before the blowpipe both varieties lose their colour, become grey, and give a weak arsenical odour; borax receives a rich blue colour. This species has not been accurately analysed, but it is considered as an arseniate of cobalt.

Sect. XII.—*Of Ores of Manganese.*

The principal ore of manganese is the black oxide. There is another, the Red Ore, the nature of which does not appear to be well determined.

The Native Oxide occurs massive, or in crystals of the form of rhomboidal tetraedral prisms, or in one variety of rhombs. Its usual colour is steel-grey, inclining to brown or black, and varying in its lustre: when crystallized, the surface of the crystals is generally shining; when amorphous, and especially when the fracture is earthy, it is more dull. Its texture is radiated, foliated, compact, or earthy. The specific gravity varies from 3.5 to 4.7. All the varieties have the same chemical characters. They are not melted by the blowpipe, but assume a brown colour. To borax they communicate by fusion a violet-blue colour. With sulphuric acid they yield oxygen gas, on the application of a moderate heat, and muriatic acid they convert into oxymuriatic acid. The radiated variety appears to be a pure oxide, composed, according to Vauquelin's analysis, in one specimen, of 92.75 of oxide of manganese, and 7 of water; in another, of 99.25 of oxide, with 0.25 of water. But there are also frequently present oxide of iron, carbonate of lime, silex, and barytes. The earthy variety contains the largest proportion of oxide of iron; and what has been named Black Wad, which occurs as an earthy incrustation, consists of 43 of oxide of manganese, and 43 of oxide of iron.

Oxide of manganese, probably in a less high state of oxidizement, combined with carbonic acid, has been considered as the basis of what is named Red Manganese Ore; though some have considered the carbonic acid as not essential, and have supposed this ore to be a compound of oxide of manganese with silex. Its colour is rose-red, more or less pale, passing, from exposure to the air and light, to light yellow, or even to white. It has little lustre; occurs massive and disseminated; its specific gravity is 3.233. Before the flame of the blowpipe it does not melt, but acquires a dark-grey colour: to borax it gives, by fusion, a violet tinge.

Sect. XIII.—*Of Ores of Arsenic.*

Arsenic is found native, pure, or alloyed with other metals, and combined with a little sulphur; and also mineralized by sulphur, by oxygen, and in the state of acid with lime.

Native arsenic is of a white colour, with a slight shade of grey, with metallic lustre; but it tarnishes very quickly on exposure to the air, changing its colour, and losing its lustre. It occurs massive and disseminated; its fracture is uneven; it is semi-hard, very brittle, and has a specific gravity of 5.6 or 5.7. It generally contains a portion of iron, with sometimes a little silver or gold.

Arsenic alloyed with a larger quantity of iron, and with a little sulphur, constitutes the species named Arsenical

Pyrites or Mispickel. Its colour is silver-white, but it quickly tarnishes, and becomes yellow and iridescent; the lustre of its fresh fracture is shining and metallic. It occurs massive, disseminated, and often crystallized; the forms of its crystals being the tetraedral prism, and the octaedron very acute. Its fracture is uneven; it is hard and brittle; has a specific gravity of from 5.7 to 6.5. It contains very little sulphur, and, according to Bergman, from a half to two-thirds of its weight of iron.

Argentiferous Arsenical Pyrites differs not much from the preceding species: its colour is silver-white, with a yellow tarnish, its lustre metallic: with arsenic and iron it contains a portion of silver, which varies from 1 to 10 hundredth parts.

Arsenic, mineralized by sulphur, forms two ores, named Orpiment and Realgar. Realgar is of a red colour, inclining to scarlet, sometimes to orange. It occurs massive, disseminated, and crystallized in oblique tetraedral or hexaedral prisms, generally small, and translucent, or semi-transparent, with a shining lustre. It exhales before the blowpipe a white arsenical smoke, with an arsenical and sulphurous odour, and gives a blue flame. It consists of arsenic and sulphur, in the proportions of 80 of the former, and 20 of the latter. Orpiment is of a yellow colour, with a highly shining lustre, is translucent, or semi-transparent when in thin leaves. It occurs massive, and in very minute crystals. Its fracture is distinctly foliated; it is soft, capable of being cut, and somewhat flexible: it exhibits the same appearances before the blowpipe as the red sulphuret. It has been supposed to differ from the red, in con-

taining a much larger proportion of sulphur. Others have supposed, that in both the arsenic may be oxidized, and that in the yellow the degree of oxidizement is greater than in the red. Thenard has lately inferred, that neither of them contains oxygen; they are both sulphurets, the realgar containing the largest proportion of arsenic.

Native oxide of arsenic occurs in the form of an incrustation on other ores, friable or little indurated, sometimes botryoidal, and even in minute crystals. Its colour is white, with shades of yellow or grey, dull and opaque; when crystallized, translucent; its taste is acrid, and it is soluble in water.

Lastly, arsenic has been discovered in the state of acid united with lime, forming the ore named Pharmacolite. This occurs as an incrustation, botryoidal, or in capillary crystals, of a white colour, with sometimes a shade of red, translucent on the edges, and with a silky lustre; its fracture is striated or fibrous; it is soft, so as to soil, and light, the specific gravity being 2.5 or 2.6. It dissolves in nitric acid without effervescence, and gives the arsenical odour by the blowpipe. It contains 23 of lime, 46.5 arsénic acid, 0.5 oxide of cobalt, 6 argil and silex, 22.5 water.

Sect. XIV.—*Of Ores of Bismuth.*

Bismuth occurs native, mineralized by oxygen, and by sulphur.

Native bismuth has nearly the properties of the pure

metal. Its colour is white, verging to red, and often tarnished, with metallic lustre; its fracture is foliated. It occurs massive, disseminated, sometimes crystallized, its crystals being four-sided tables, and cubes, generally small and indistinct. It melts even in the flame of a candle. It dissolves in nitric acid, and its solution is decomposed by the affusion of water.

Oxide of bismuth occurs as an incrustation of a yellowish-grey colour, earthy, or when indurated, having an uneven or foliated fracture; dull when earthy, shining when foliated, opaque and soft.

Sulphuretted bismuth occurs massive, disseminated, and in capillary crystals, of a light green colour, and shining lustre. It melts in the flame of a candle, and when heated, exhales sulphurous fumes.

Sect. XV.—*Of Ores of Antimony.*

This metal is found native, combined with oxygen and muriatic acid, and mineralized by sulphur.

Native antimony is of very rare occurrence. It has the usual characters of the metal, and contains a very minute portion of silver and iron.

Antimonial Ochre, as it has been named, occurs as an earthy-like incrustation, of a straw-yellow colour, on the surface of the sulphuret, and has been supposed to be an oxide. Another ore, which appears to be an oxide of more uniform composition, is that named White Antimonial Ore,

occurring in acicular crystals, grouped and divergent, so as to form a stellular appearance, and likewise in tables and in cubes, of a snow-white colour, silky lustre, translucent and soft. Lampadius had assigned muriatic acid as a constituent principle of it, but both Vauquelin and Klaproth have found it to be an oxide without any traces of this acid, its composition, as stated by the former chemist, being 84 of antimony, 3 of oxides of antimony and iron, and 8 of silex.

The sulphuret is the principal antimonial ore. It occurs massive, disseminated, or crystallized, its crystals being acicular or prismatic, and often aggregated. Its colour is lead-grey, frequently tarnished or iridescent; its lustre is shining and metallic. Its fracture is commonly striated or radiated; in one variety it is foliated, and in another small-grained uneven. It melts easily before the blowpipe, and exhales fumes of sulphur and oxide of antimony. It consists of 74 of antimony, and 26 of sulphur. Plumose Grey Antimonial Ore is a variety of this, or perhaps a distinct species, containing, with sulphuret of antimony, portions of arsenic and iron, and sometimes a little silver. It occurs generally in capillary crystals.

Red Antimonial Ore is probably a sulphuretted oxide of antimony, its composition, as determined by Klaproth, being 67.5 of antimony, 10.8 of oxygen, and 19.7 of sulphur. It occurs in capillary crystals of a deep red colour, opaque, and shining. It melts before the blowpipe, and exhales in vapour.

Sect. XVI.—*Of Ores of Tellurium.*

This metal occurs chiefly alloyed with other metals.

In its purest state it forms an alloy formerly named Aurum Paradoxicum, the proportion of tellurium being 90 in 100 parts, with a portion of iron and gold varying from 1 to 9 parts. It is massive, disseminated, or in small crystals of a white colour, and shining metallic lustre, having a foliated fracture, and a specific gravity from 5.7 to 6.1. It melts before the blowpipe, gives a white smoke, and is oxidized.

In the graphic gold ore, the portion of gold is larger, and silver is associated with it, the proportions, as determined by Klaproth, being 69 of tellurium, 30 of gold, and 10 of silver. It is usually crystallized in minute prisms, superficially aggregated on quartz in a form giving the appearance of letters, whence the name Graphic is applied to it. Its colour is steel-grey, its lustre metallic, but liable to tarnish, its fracture uneven, its specific gravity 5.7. It burns before the blowpipe with a green flame, and is volatilized.

In the white or yellow sylvanite, there is present a portion of lead, with tellurium, gold, and silver. Its colour is silver-white, inclining to yellow; its lustre metallic; its fracture foliated; its specific gravity 10.6. It occurs disseminated, or in minute crystals.

In the black tellurium ore, a number of metals are

combined with a little sulphur, the composition, as stated by Klaproth, being tellurium 82, lead 54, gold 9, copper 1.3, silver 0.5, and sulphur 3. It occurs massive, and crystallized in six-sided tables; its colour is blackish-grey; its lustre metallic; its fracture foliated; its specific gravity 8.9. It melts before the blowpipe, and is partly volatilized.

Sect. XVII.—*Of Ores of Chrome.*

Chrome is found in the mineral kingdom in the state of acid combined with oxide of lead, and in that of oxide or acid united with oxide of iron, forming two species.

Chromate of Lead, the red lead ore of mineralogists, is usually crystallized in rhomboidal four-sided prisms. Its colour is aurora red, is lustre shining and adamantine; it is translucent; its specific gravity is 6. It consists of 64 of oxide of lead, and 36 of chromic acid.

The second species occurs massive, is of a dark-brown colour, dull, and opaque; hard, difficult to break, and has an uneven fracture; its specific gravity is 4. It consists of oxide of chrome 55.5, oxide of iron 33, argil 6, silex 2, and 3.5 of loss. It appears to be more extensively diffused than the other.

Sect. XVIII.—*Of Ores of Molybdena.*

There is only one ore of this metal,—the sulphuret. It occurs massive, disseminated, and sometimes crystallized in hexaedral prisms or tables. Its colour is lead-grey, its lustre is shining and metallic, its fracture is foliated; and it is easily split; it is soft, so as to soil; it feels unctuous. Its specific gravity is from 4 to 4.7. It consists, according to Klaproth and Bucholz, of 60 of molybdena, and 40 of sulphur.

Sect. XIX.—*Of Ores of Tungsten.*

The mineral named Tungsten consists of the oxide of the metal to which this name is now appropriated, with lime, the proportions, according to D'Elhuyart, being 68 of the former with 30 of the latter. It occurs massive, disseminated, and in octaedral crystals. Its colour is yellowish or greyish white; its lustre shining and vitreous; it is translucent or semi-transparent, is soft, has a foliated fracture, and a specific gravity from 5 to 6. Digested in nitric or muriatic acid, it affords a yellow powder, which is the oxide of tungsten.

The other species of this genus is the mineral named Wolfram. It occurs massive and crystallized in broad hexaedral prisms, or four-sided tables. Its colour is black,

its lustre weakly shining; it is opaque; its fracture is distinctly foliated; its specific gravity is from 6.8 to 7.1. It consists of oxide of tungsten, with oxides of iron and manganese, the proportions of which differ much in different specimens.

Sect. XX.—*Of Ores of Titanium.*

Under this genus are placed several species, differing much in their external characters.

Rutile, Titanite, or Red Shorl, is nearly a pure oxide of titanium. It occurs crystallized in prisms, frequently capillary, and penetrating quartz; its colour is red or reddish brown; its lustre shining; it is slightly translucent; it is hard and brittle, and has a foliated fracture; its specific gravity is 4.1. Rutilite, which occurs in rhomboidal four-sided prisms of a reddish-brown colour, appears to be a variety of this, containing, with oxide of titanium, silex and lime.

Oisanite, octahedrite, or blue shorl, is regarded by Vauquelin as a pure oxide of titanium, differing from rutile in being free from iron. It is crystallized in acute octohedrons; its colour is blue, passing sometimes into brown; its lustre is shining and adamantine; it is translucent or semi-transparent; its fracture is foliated; its specific gravity 3.8.

Menachanite occurs in small irregular grains or sand, of a greyish-black colour, opaque, with semi-metallic lustre, having a specific gravity of 4.4, and weakly attracted by

the magnet. It consists of oxide of iron 51, oxide of titanium 45.25, oxide of manganese 0.25, and silex 3.5. Nigrine is perhaps a variety of this; it is also in angular grains of a brownish-black colour, with little lustre, and opaque; its specific gravity is 4.5; it is not attracted by the magnet; it consists of 84 of oxide of titanium, 14 of oxide of iron, and 2 of oxide of manganese. Iserine occurs likewise in angular grains, of a black colour and weak lustre, and opaque, having a specific gravity of 4.5. It consists of oxide of titanium 59.1, oxide of iron 30.1, and oxide of uranium 10.2.

Sect. XXI.—*Of Ores of Uranium.*

The mineral named Pechblende is the ore in which this metal was first discovered. It is generally massive, of a black colour, with an internal lustre, shining, and resinous; opaque, brittle, and soft; having a specific gravity of 7.5. It consists of 86.5 of oxide of uranium, with 6 of sulphuret of lead, 5 of silex, and 2.5 of oxide of iron.

Green Mica, or Micaceous Uranitic Ore, is oxide of uranium nearly pure, or mixed only with a little copper. It occurs in thin leaves, or crystallized in minute four-sided tables; its colour is green; its lustre shining, with little transparency; its fracture is foliated; and it is soft and easily broken.

Uranitic ochre occurs usually as an incrustation or efflorescence, of a straw-yellow colour, without lustre, opaque,

soft, and friable. It is oxide of uranium nearly pure, containing sometimes a little oxide of iron.

Sect. XXII.—*Of Ores of Tantalum.*

The alloy of this metal with iron and manganese, forms the mineral named Tantalite. It occurs in imperfect octaedral crystals of a black colour, with an internal metallic lustre; hard so as to give sparks with steel, and having a specific gravity of 7.9. Ittrotantalite is composed of tantalum, with iron and a portion of the earth ittria; it is in small imbedded masses of a black colour, with metallic lustre; having a granulated fracture, and a specific gravity of 5.1. Columbium being the same as tantalum, the mineral in which Mr Hatchet discovered that metal must be regarded as belonging to this genus. Dr Wollaston has remarked, that in external appearance it is perfectly similar to tantalite; and its composition is the same.

Sect. XXIII.—*Of Ores of Cerium.*

There is only one ore belonging to this genus, Cerite, or, as it was first named, False Tungsten. It occurs massive or disseminated; of a flesh-red colour, semi-transparent; and having, in the fresh fracture, considerable

lustre; it is so hard as to strike fire with steel; and has a specific gravity of from 4.7 to 4.9. It consists of oxide of cerium 50, oxide of iron 22, silex 23, and 5.5 of carbonate of lime.

CHAP. IV.

OF INFLAMMABLE MINERALS.

UNDER this order are placed those minerals not metallic, which have the property of inflammability. They admit of being arranged under three genera, resting on chemical distinctions. Sulphur constitutes one genus. Under a second may be placed those composed of carbon principally,—the Diamond, Plumbago, and Coal. To a third I have referred the Bitumens. These consist chiefly of carbon and hydrogen, forming a series in which these principles are combined in different proportions, the hydrogen being usually predominant. Under this genus may probably be placed amber and honey-stone.

SECT. I.—*Of Native Sulphur.*

SULPHUR occurs in the mineral kingdom principally as a volcanic product, though it is also found not of volca-

nic origin. It is usually pure, of its characteristic yellow colour, semi-transparent, or sometimes transparent, with shining lustre; it occurs massive, disseminated, or crystallized, the form of its crystals being the octohedron or dodecaedron under various modifications. It also occurs corroded, vesicular, in masses, and as a light sublimate. Its other physical and its chemical properties are those of pure sulphur.

Sect. II.—*Of Carbonaceous Minerals.*

Of these the Diamond is the purest. From its external characters, it has been placed among the earthy fossils; but as it is inflammable, and its nature perfectly ascertained, it must, in conformity to its chemical relations, be placed under the present genus, though differing widely from the other substances with which it is associated.

The Diamond is not met with in its original situation, but in the beds of streams, or in a loose ferruginous sand beneath the soil, either in perfect crystals, or in fragments often encrusted with a hard coating. The usual forms are the octohedron and dodecaedron variously modified, and generally imperfect. It is colourless, or tinged of various colours; it is generally transparent, and has the property of single refraction; its fracture is lamellated, and it can be split by striking it in the direction of the plates. Its hardness is such that it is not impressed by steel. Its specific gravity is from 3500 to 3600.

Plumbago, or Graphite, is a carburet of iron, the proportion of the metal, in different specimens, being very various. Graphite occurs massive, or disseminated; its colour is black, or dark steel-grey; its lustre weakly shining and metallic; it is opaque; its fracture is compact, foliated, or slaty; it is soft, soils the fingers, and feels unctuous; its specific gravity is from 2.1 to 2.6. It burns with great difficulty, and consumes slowly, leaving oxide of iron as a residuum, frequently mixed with argil and silex.

Coal consists essentially of carbonaceous matter, and in one variety, the blind coal, this is nearly pure; but in the greater number of the varieties of coal, there is associated with this a soft bituminous matter, which communicates to them some peculiar properties. Those which contain much bitumen are highly inflammable, take fire readily, and burn with a bright flame; those in which the proportion of bitumen is less, and in which the carbon predominates, burn less vividly; they require a higher heat to kindle them, and burn without flame, or only with a red glow.

Numerous varieties of coal exist, deriving their distinctions partly from their state of aggregation, but principally from the proportions of their bitumen and carbon. The series may be briefly described, as they are connected, on the one hand, with vegetable matter, and on the other, with carbon not of vegetable origin.

Blind Coal, the Anthracite of mineralogists, the Glance Coal of Werner, consists almost entirely of carbon, with a little earthy matter and iron, and forms the connection of coal with plumbago. It burns with difficulty,

without flame, without exhaling any bituminous odour, and without softening or caking; its colour is usually black; its lustre shining, and nearly metallic; its fracture slaty; its hardness such as to yield easily to the knife; it is brittle, and has a specific gravity of about 1.5. It occurs often in primitive rocks, or in those of transition in imbedded masses, in beds and veins; and there appears no reason to infer that it is of vegetable origin.

Black Coal, as it is named by Werner, is the common coal, of which there are several varieties. That which is of a slaty fracture is the variety most abundant in this country; its principal fracture is slaty, the cross fracture small grained uneven; its colour is black, frequently with a shade of grey; its lustre resinous; it is soft, and has a specific gravity of about 1.25. It softens, cakes, and burns brightly, and leaves, when entirely burnt, a small residuum of ashes. It contains a considerable proportion of bitumen, varying, however, so much as from 24 to 40, with from 53 to 70 of carbon, and 2 or 3 of earthy matter. Foliated coal approaches to the slaty, being distinguished by its fracture and its greater lustre; it is softer, and appears to contain more bitumen. Columnar coal is so named from occurring in columnar distinct concretions, and is more rare. Cannel coal is distinguished by its smooth conchoidal fracture; it has a resinous lustre and black colour, and burns at first with a clear light, which, however, soon ceases. It contains about 75 of carbon, with 22 of bitumen, and 3 of foreign matter. Pitch coal has also a smooth conchoidal fracture; from the closeness

of its texture it takes a polish, and forms what is named Jet.

Brown Coal occurs massive, having an imperfect conchoidal fracture, sometimes fibrous and woody, soft and light; it burns with a blue flame, and gives a smell like bituminous wood; it occurs with some of the following varieties, in alluvial land: it contains little bitumen. Connected with this is what is named Earthy Bituminous Wood, or Earthy Coal, which is found of a loose consistence, nearly earthy, dull, of a blackish-brown colour, light and soft. The last of the series, or that most evidently of vegetable origin, is Bituminous Wood. The ligneous texture is very distinctly marked, and even the external shape of the branches and stems of trees, and the annual rings of the wood, are distinctly preserved, so as to resemble wood imperfectly charred. Its colour is brown, of different shades; it is opaque, with little lustre; has little density or hardness, and is so light as nearly to float on water. It burns with a clear flame, and with a bituminous odour, and leaves a small quantity of white ashes, similar to those from wood.

Coal, excluding the anthracite or blind coal, is evidently of vegetable origin. We trace in it the gradation from bituminated wood; we often discover in its varieties the ligneous structure, and even the remains of plants; and its chemical composition agrees with that of vegetable matter. It is difficult, however, to determine in what manner it has been formed, or by what operations the vegetable matter from which it is originated, has been so far modified as to have assumed the properties under which

it exists. The discussion of this subject is intimately connected with geological speculation; for the opinion which is adopted must be in conformity to the general theory which is held with regard to the structure of the globe. It is accordingly maintained in one geological system, that it derives its origin from vegetable matter which had been exposed under compression to subterranean heat; while in another it is supposed to have been formed from vegetable matter suffering slow decomposition under water, or at least in a state of humidity, by which its oxygen and hydrogen had been in a great measure withdrawn, and its carbonaceous base left predominant. The merits of either theory must rest on those of the more general systems with which they are connected.

The bituminous part of coal is separated from the carbonaceous part by the application of heat. We perceive this separation in its combustion in a common fire; the coal, when first kindled, swelling and softening, exhaling a kind of bitumen, and burning with smoke and light; while, after a certain period, these appearances cease, and it burns only with a red light. The separation is effected more completely by the application of heat in close vessels; the bitumen is melted out, and there are disengaged a large quantity of ammonia, partly in the state of carbonate with a quantity of empyreumatic oil, and a gas, a variety of oxy-carburetted hydrogen, approaching in its nature to olefiant gas, which burns with a bright flame; the carbonaceous matter is in a great measure left, forming Coak.

This decomposition of coal by heat has been carried on on a large scale, with a view to collect the products; the

bituminous matter, or mineral tar, being applied to the uses for which vegetable tar and pitch are employed, and the coaked coal being used in the smelting of metallic ores, and for other purposes. More lately the distillation of coal has been applied to the procuring an elastic fluid, to afford by its combustion artificial light, and has some advantages, particularly of affording a steady, uniform, and easily-regulated light, and of being economical, especially when the process is conducted on a large scale.

Sect. III.—*Of Inflammable Minerals, in which Hydrogen predominates.*

To this genus belong principally the liquid bitumens.

Of these Naphtha is the purest. It is very light, of a pale yellow-green colour, transparent, thin and liquid, odoriferous, volatile, and inflammable, and in burning is entirely consumed, emitting a smoke more or less dense. Petroleum, or Mineral Tar, is semi-liquid, often of a thicker consistence, tenacious, semi-transparent, of a reddish-brown colour, and fætid odour. Mineral Pitch, or Maltha, is solid, but soft, has a degree of tenacity, and a strong bituminous smell. Its colour is black, its lustre highly resinous. It is sometimes elastic, forming what has been named the Elastic Bitumen. Asphaltum is the last of the series, and forms the connection with pitch coal. It is of a black colour, and resinous lustre, without transparency; its fracture is conchoidal; it is light, and has a

bituminous smell when rubbed or heated. It melts easily, takes fire, and burns without leaving any ashes. Through all these substances there is a perfect gradation; naphtha, by inspissation, becoming petroleum, and this, by the same operation, passing into asphaltum; and even the different specimens of these are frequently found in the same situation. They also agree in their chemical characters, are inflammable, insoluble in water and in alkohol, but combine with fixed and essential oils, and are partially soluble in ether. They are not dissolved by the alkalis, and are decomposed by the more powerful acids.

Amber is usually placed among the bitumens, though it differs considerably in its properties. It is of a yellow colour, pale or deep, with a shining lustre, and a transparency more or less perfect; its fracture is conchoidal; it is brittle, and has a specific gravity of about 1.08. It is inodorous except when heated; when rubbed, it becomes strongly electrical. It occurs in fragments, or sometimes in large masses; it is found in layers of bituminated wood, often also buried in sand on the sea-shore. No satisfactory theory has been given of its origin. It often contains very perfect organic remains,—a proof of its having been once perfectly fluid.

When amber is exposed to heat in close vessels, it softens and swells; and with a portion of empyreumatic oil, a quantity of an acidulous liquor passes over; this is succeeded by a concrete acid, which condenses in flakes or needles, which is obtained from no other substance, and is different from all the other acids. When heated in contact with the air, it inflames, burns with much smoke, and with a strong bituminous smell, and leaves little residue.

Water exerts no action on amber. Alkohol acts o nit weakly, acquiring only some degree of colour and tenacity. The alkalis dissolve it, forming a kind of soap. The acids decompose it, changing it into a species of resin, and ultimately into tannin. It is not dissolved either by the expressed or essential oils; but it becomes soluble by being roasted gently. Solutions of this kind are used as varnishes.

The empyreumatic oil obtained from the decomposition of amber by heat is thick, and of a dark colour; by distilling it repeatedly with water, it becomes thinner and of a lighter colour. It still retains a fœtid smell; is volatile and inflammable; insoluble in water, and imperfectly soluble in alkohol. It also combines imperfectly with the alkalis.

The acid obtained by the same decomposition, the Succinic Acid, is possessed of properties which sufficiently distinguish it. When freed from the small portion of oily matter which adheres to it at its first sublimation, it is white, and crystallizes in four-sided rhomboidal plates; its taste is sour, and it reddens infusion of litmus; it is soluble in 24 parts of water at 60, and is also soluble in alkohol. It is volatile and inflammable. Like the other vegetable acids, it has a compound base of carbon and hydrogen.

Succinic acid combines with the alkalis, earths, and metallic oxides, but these combinations present no important results. The succinate of iron is insoluble; hence succinic acid has been employed as a test of this metal, and as a re-agent by which substances may be freed from it, succinate of potash being added to any solution contain-

ing iron, and the succinate of iron being precipitated. It is also used to discriminate between magnesia and argil, the succinate of magnesia being soluble, while that of argil is insoluble, and is therefore precipitated.

MELLITE, or Honey-stone, has been placed among the bituments, with which, though it differs from them considerably, it has some relations. In its external appearance it has some resemblance to amber: it is of a honey-yellow colour, is more or less transparent; its lustre is intermediate between vitreous and resinous; its surface smooth; its fracture conchoidal; it is brittle, and softer than amber; has a specific gravity of 1.6. It occurs generally crystallized; its crystals being octaedrons, dodecaedrons, or four-sided prisms acuminated by four planes. It becomes weakly electrical from friction. When heated in contact with the air, it becomes white, and burns without becoming sensibly charred, leaving a white matter, which produces a slight effervescence with acids.

This substance is found in the layers of bituminated wood. Its nature was unknown until it was analysed by Klaproth, who found it to consist of a peculiar acid, which has hence received the name of Mellitic Acid, united with argil.

The acid may be extracted merely by the action of water, and by evaporation can be obtained in a mass, which, when subjected to the action of alkohol, to separate a portion of earthy matter, may be crystallized. Its crystals are prisms, have a yellowish tinge, and a slight acid taste, accompanied with bitterness. It is sparingly soluble in water. Exposed to heat it swells up, emits a dense smoke,

is charred, and leaves a light coal, and, from the products of its decomposition, is evidently analogous in constitution to the vegetable acids.

Mellitic acid combines with the different salifiable bases, but these combinations have been only imperfectly examined, and present no important results. They are somewhat similar to those of oxalic acid, and to this acid, too, the mellitic acid has a considerable resemblance.

In concluding the history of mineral substances, it might be supposed necessary to take a view of the theories which have been advanced with regard to their formation. The subject, however, involves details not strictly chemical, and cannot be considered as purely elementary. The opinions which are maintained with regard to it are so discordant, and our knowledge of the facts so imperfect, that a brief statement, such as is consistent with the limits of this work, would scarcely be satisfactory. I may therefore refer to the view which I have given of it in my System of Chemistry, or to the more ample discussion of the controversy, in the Comparative View of the Huttonian and Neptunian Systems of Geology.

CHAP. V.

OF MINERAL WATERS.

Mineral waters, containing very various ingredients, cannot properly be placed under any of the established classes of chemical agents; but they may be considered after the metallic and earthy fossils, as it is from these that they derive in general their peculiar properties. Though all waters, that which descends in rain excepted, may be styled Mineral, as they contain more or less of saline and earthy matter, yet the term is restricted to those in which the quantity is such as gives the water taste or smell, renders it capable of producing peculiar effects on the animal system, or communicates to it distinguishing chemical properties.

The substances found in mineral waters are extremely numerous. The most common are, carbonic acid; sulphuretted hydrogen; carbonates, sulphates, and muriates of soda, lime, and magnesia; and carbonate and sulphate of iron. These are variously intermixed, and the water is classed as acidulous, sulphureous, saline, or chalybeate, according to the ingredients which predominate in it. Substances of more rare occurrence are, sulphurous acid, nitrogen gas, sulphate of argil, muriate of manganese, and siliceous earth.

The first step in the analysis of a mineral water is to as-

certain the gaseous substances it contains, as these frequently contribute to hold the solid substances dissolved.

Carbonic acid, when uncombined, or in excess, may be discovered by the pungent acidulous taste of the water, and its sparkling appearance when poured into a glass. They become vapid from exposure to the air, or to a moderate heat, from the escape of the gas. The chemical tests to discover it are infusion of litmus and lime-water; the first receiving from the mineral water containing it an evanescent redness, the second producing a milkiness or precipitation which disappears when an excess of the mineral water is added, the carbonic acid rendering soluble the carbonate of lime, to which the turbid appearance is owing. The transparency is equally restored by dropping into the liquid a little muriatic or nitric acid. By the evanescent redness given to litmus, carbonic acid is distinguished from any other free acid that might be present, and by the transparency being restored by these re-agents, the fallacy is guarded against that might arise from the precipitation of the lime by any sulphate in the water. The quantity of free carbonic acid gas may be ascertained by exposing the water to heat in a retort, collecting the gas disengaged from it in a jar over mercury, and introducing to it a solution of potash, by which the carbonic acid gas is absorbed.

Sulphurous acid gas is very seldom to be looked for; when present, it is discovered by its smell, by giving a permanent red colour to a solution of litmus, and by rendering colourless an infusion of roses. Its quantity is estimated by expelling it, exposing the gas to a solution of

potash, and obtaining the sulphite of potash; or by adding to it sulphuretted hydrogen gas as long as any diminution of volume is produced, these two gases, by their mutual action, being converted into water and sulphuric acid, and being therefore entirely condensed.

Nitrogen gas is discovered by remaining unabsorbed when the elastic fluid expelled from a mineral water by heat has been exposed to the action of a solution of potash.

Sulphuretted hydrogen, existing in a water, is discovered by its smell, by the deposition of sulphur from it on exposure to the air, or on the addition of nitrous acid, by blackening silver or mercury immersed in it, and affording a dark-coloured precipitate with acetate of lead. The quantity of it has been estimated by expelling it from the water by the application of heat, but the whole of it cannot thus be expelled; it cannot easily be collected to be measured with accuracy, as it is absorbed by water, and acts on quicksilver. It may be decomposed by the addition of fuming nitrous acid; or, according to Kirwan's method, a quantity of the water is inclosed in a jar with atmospheric air, which is inverted in water: nitrous gas is passed through the water, so as to combine with the oxygen of the atmospheric air: nitrous acid is formed, and this, being absorbed by the water, decomposes the sulphuretted hydrogen; the quantity that has been present may be discovered from the quantity of sulphur precipitated, and collected on a filtre, 30 grains of sulphur being held equivalent to 100 cubic inches of sulphuretted hydrogen gas. When sulphuretted hydrogen and carbonic acid gases exist together in the mineral water, the elastic fluid ob-

tained from the water by heat, is exposed in a tube to nitrous acid, by which the sulphuretted hydrogen is immediately absorbed and decomposed.

After the gaseous substances existing in mineral waters have been ascertained, the solid contents are to be examined.

The mineral acids, when combined with any base, or in excess, are discovered by the water giving a permanent red colour to vegetable infusions; but in this state they are very rarely present.

The neutral and earthy salts are the chief ingredients of mineral waters. We have to ascertain the acids they contain, and the bases with which these are united; and for this purpose it is in general necessary to reduce the volume of the water by evaporation, to render more sensible the operation of the re-agents by which they are detected, taking care only, when the evaporation is executed with this view, not to carry it so far as to give rise to the separation of any of the solid ingredients.

Sulphuric acid, in combination with the alkalis or earths, is detected by muriate of barytes, acetate of lead, and nitrate of mercury, all of these producing an immediate precipitation. The first is at once the most delicate and most accurate, and the others therefore may be regarded as superfluous. Its delicacy is such, that it discovers the most minute quantity of sulphuric acid. The only fallacy to which it is liable, is one easily guarded against, that of affording a precipitate from the presence of alkaline or earthy carbonate; this is obviated by adding, previously to the water, a small quantity of pure nitric or

muriatic acid, or by the turbid appearance, after it has been produced, disappearing, if it has arisen from this, on the addition of a few drops of either of the acids.

Muriatic acid is detected by the nitrate of silver; the muriate of silver which is formed being, from its very sparing solubility, instantly precipitated, and giving rise to a bluish turbid appearance. The delicacy of this as a re-agent is great, the most minute quantity of muriatic acid in any state of combination being detected. It is liable to fallacy, however, from a precipitate being likewise produced by it from the presence either of any carbonate or any sulphate. The operation of the former is obviated by the previous addition of a few drops of pure nitric acid, which decomposes the carbonate, and expels the carbonic acid; to avoid the latter, it is necessary to decompose any sulphate, if present, by the addition of nitrate of barytes.

Carbonic acid, in a state of combination with the alkalis or earths, may be discovered by the effervescence produced by the addition of sulphuric acid, and by muriate of barytes forming a precipitate soluble with effervescence in nitric or muriatic acid, the effervescence being in particular apparent when concentration has been produced by evaporation. The alkaline carbonates are distinguished by their power of changing the vegetable colours; the earthy and metallic carbonates, by being precipitated when the water is partly evaporated.

These are the acids usually met with in mineral waters. They are commonly combined with the fixed alkalis, lime, magnesia, or argil, or with oxide of iron.

Lime is *immediately* precipitated from all its combinations by oxalic acid. Some of the mineral acids, however, either decompose this acid, or hold dissolved the precipitate it forms with the lime, and hence, if disengaged by the decomposition itself, may have this effect. This fallacy is in a great measure guarded against by using, not the pure acid, but oxalate of potash; the potash neutralizing the acid disengaged from the lime; oxalic acid produces a precipitate likewise with magnesia, but this takes place very slowly, even when the magnesian salt is in large quantity, while with lime it is immediate. Sulphuric acid is also a test to discover lime; but it is one of much less delicacy.

Ammonia and lime-water are the tests of magnesia, the former precipitating it partially, the latter entirely. In order that the lime may be an accurate test, it is necessary to remove any carbonic acid which may exist in the water, by previously adding nitric acid; and any sulphuric acid, by muriate of barytes. Another source of fallacy more important, arises from argil being precipitated by these tests, as well as magnesia. The nature of the precipitate may be discovered by dissolving it in nitric or muriatic acid, and again precipitating the solution by carbonate of potash. If this dried precipitate be subjected to the action of diluted sulphuric or muriatic acid, it will be immediately dissolved if the earth be magnesia, while, if it be argil, it will dissolve slowly. Another test which discriminates between these earths is boiling the precipitate in a solution of potash; if it be argil, it is dissolved, while magnesia remains undissolved. Succinate of ammonia, too,

precipitates argil, but not magnesia. By these tests argil is likewise discovered.

The alkalis, when in a state of combination, cannot be discovered by any striking tests, but their presence is inferred when acids are discovered in a mineral water, which are not free, and which at the same time, from the application of tests, do not appear to be combined with earthy or metallic bases. Soda is the alkali generally present. The peculiar salts which it and potash form with the different acids, serve to distinguish them. With oxalic acid, soda forms a salt sparingly soluble; while potash forms, with the same acid, a salt easily dissolved. With tartaric acid, on the contrary, soda forms a soluble salt; while with potash, an acidulous tartrate is formed, of comparatively sparing solubility. Muriate of platina affords a test still more delicate, giving a precipitate with the salts of potash, but not with those of soda.

Siliceous earth is contained in some waters, not combined, however, with any acid. A portion of alkali, likewise, generally exists in such water; but this is either in the state of carbonate, or in such small quantity that it can scarcely be considered as the solvent of the silex. This earth may be discovered by evaporating the water, and adding to the solid residuum nitric or muriatic acid; the silex will remain undissolved; and its nature may be still more clearly proved by fusing it by the blowpipe, with either of the fixed alkalis.

Of the metals existing in mineral waters, iron is the principal; any other, indeed, is of very rare occurrence, and only in particular situations. It is combined some-

times with sulphuric acid, but much more generally is held dissolved by carbonic acid.

Chalybeate waters, as those impregnated with iron are named, deposite an ochrey sediment on exposure to the air. The iron is discovered by very delicate tests, principally the infusion of galls, and the prussiate of potash, the former striking a purple colour, the other giving rise to a blue precipitate. The latter is liable to fallacy, principally from the iron which exists in its composition, and which is liable to be evolved by an acid, so as to give rise to the blue precipitate. The former is not liable to this or any other important fallacy, and is much more delicate, a deep colour being struck when the iron is present in very small proportion. The colour is liable to be varied by the action of various salts; alkaline and earthy carbonates rendering it violet, neutral alkaline salts deepening the purple tint, and sulphate of lime rendering the precipitate at first whitish, and afterwards black. Carbonate of lime has a singular effect. If the iron be in small quantity, and at a high state of oxidation, the colour does not even appear; while, if it is at a low state of oxidation, the purple tint is even heightened. By applying this test before and after ebullition of the mineral water, we discover whether the oxide of iron has been held dissolved by carbonic acid or sulphuric acid, as if the former has been the solvent, being expelled during the boiling, the oxide is in a great measure precipitated, so that the liquor, after filtration, when cold, either does not suffer the change of colour, or the tint is much less deep. The quantity of oxide may be in some measure determined by its precipitation from expo-

sure to the air and ebullition; or, according to a more recent mode, it may be precipitated by succinate of soda, and the precipitate, calcined at a red heat with a little carbonaceous matter, gives the quantity of oxide of iron.

Besides the methods of discovering the saline compounds in mineral waters by the application of re-agents which indicate their principles, they may, by certain methods, be obtained in their entire state, and their quantities determined.

Evaporation is employed with this view, different substances being successively obtained as the evaporation is carried to a greater or less extent. Thus the carbonates of lime and magnesia are usually first precipitated, afterwards sulphate of lime falls down; if after these precipitations the liquor be drawn off and allowed to cool, the alkaline neutral salts and the sulphate of magnesia crystallize, while muriate of magnesia and muriate of lime, if present, will remain dissolved, forming an uncrystallizable residue.

Alkohol facilitates the analysis by a similar operation. When added to the water brought to a certain state of concentration, it throws down first sulphate of lime, afterwards carbonate of lime and carbonate of magnesia; and if added in larger quantity, or after a renewed evaporation, it either precipitates or causes to crystallize sulphate of magnesia and sulphate of soda, while any muriates remain dissolved. Advantage too is taken of its solvent power, the solid substances being obtained by evaporation to dryness, and their separation being facilitated by the addition of alkohol in successive portions.

By these methods, the quantities of the solid substances contained in a mineral water are determined. These are also frequently inferred by estimation from the precipitates afforded by the usual re-agents. Thus the quantity of sulphuric acid may be ascertained from the weight of the precipitate formed by adding muriate of barytes, the proportion of sulphuric acid which a given weight of this brought to a certain state of desiccation contains, being known. The quantity of muriatic acid may be inferred from the weight of the precipitate formed by adding nitrate of silver; that of carbonic acid, from the weight of the precipitate formed by water of barytes or lime; that of lime from the weight of the oxalate of lime precipitated by oxalate of potash; and, in a similar manner, the weights of other substances that can be precipitated by re-agents in new states of combination may be determined. The method is indeed liable to some fallacy, from the uncertainties which attend the determination of the proportions of compound salts. But it may be combined with the others, and it is only from these combined methods that an accurate analysis can be obtained.

BOOK VIII.

OF VEGETABLE COMPOUNDS.

THE compounds which are the products of the chemical processes carried on in the vegetable, and also in the animal system, have peculiar chemical characters, by which they are distinguished from the compounds which exist native in the mineral kingdom, or which are capable of being artificially formed. Their composition is in general more uniform with regard to the principles of which they are composed, but more complicated with regard to the number of elements existing in simultaneous combination, and much more diversified in the proportions and modes in which these are united. Carbon, hydrogen, and oxygen, are their chief constituent principles, to which are sometimes added, in smaller proportions, nitrogen, sulphur, phosphorus, lime, and iron; and it is from differences in the proportions, and in the modes of combination, that the immense diversities of properties by which these substances are distinguished are derived These principles, too, are not united in binary compounds, but exist in more complicated states of union; their affinities are therefore more

nearly balanced, and of course are more easily subverted. Hence the susceptibility of decomposition, by which the vegetable and animal compounds are distinguished; they are liable to spontaneous change from the mere re-action of their elements, especially when this is favoured by a state of solution, or the presence of humidity; they are, even at common temperatures, acted on by the oxygen of the atmosphere; and at elevated temperatures, their existing composition is entirely subverted. In all the decompositions, too, to which they are liable, their principles are not disengaged in an insulated state; for, having strong mutual affinities, they enter into combination, and form new products. From this circumstance, and from the similarity in composition with regard to the principles of these compounds, the products of their analysis are nearly the same, differing principally, at least, in the proportions in which they are disengaged. It is therefore difficult, from the results of the analysis, to determine the composition with perfect accuracy; and we are in all cases unable to confirm it by synthesis, for we have not the power, by any adjustment, of balancing the affinities of the ultimate principles, or of placing them under circumstances similar to those in which they have been combined; and hence these compounds can never, by direct combination, be artificially formed.

The vegetable compounds are rather more simple in their composition than those formed in the animal system. They consist chiefly of carbon, hydrogen, and oxygen, and more rarely contain nitrogen, sulphur, or phosphorus; hence their composition is rather more permanent, as it

depends on a less nice adjustment of affinities; they are at least less susceptible of spontaneous decomposition; and from this diversity in the nature of their elements, the products of their analysis are not precisely the same.

Vegetable compounds are all formed by actions subservient to the general process of vegetation, and are derived from new combinations established by that process among the elements of the substances absorbed by the growing plant. Hence the relation of vegetation to chemistry, and the advantage of considering it so far as it is chemical, before proceeding to the history of the compounds themselves.

CHAP. I.

OF VEGETATION, AND THE FORMATION OF VEGETABLE COMPOUNDS.

VEGETABLES are, like animals, endowed with life. At one period, indeed, it was attempted to account for the functions they perform from their peculiar mechanism, and the action of mechanical powers. The rise of the sap, and the propulsion of their fluids, were ascribed to capillary attraction, and the motions of different parts to the elasticity of fibres. But such causes are utterly inadequate. The absorption of external matter, the movement of the fluids direct and retrograde, the secretions whence new products are formed, the motions of the leaves as they are

excited by light and other external agents, the developement and growth of new parts, and the formation and evolution of the embryo plant,—are phenomena inexplicable on any principle of mechanism, and so strictly analogous to corresponding phenomena in the animal system, that they must be referred to a similar cause.

Vitality in vegetables observes even the same laws as that by which it is regulated in the animal frame. The motions and functions dependent on it require to be excited by the due application of external agents; if these are withdrawn, the functions languish or cease; if they act too forcibly, the vital power is impaired; if they have been previously abstracted, more vigorous action is exerted when their application is renewed; or if too suddenly and forcibly applied, the excitement may produce an exhaustion of power. The effects of soil, of moisture, of heat, light, and electricity, on plants,—their sleep, germination, efflorescence, fructification, and decay, afford many illustrations of the operation of this principle in conformity to these laws.

As vegetables and animals are thus endowed with similar powers, there is a similarity in their general structure and organization, and in the functions they perform. In vegetables these are indeed more simple than in the more perfect animals, but still the analogy is easily traced.

There moves through the vessels of plants a common juice or sap, supposed to be analogous to the blood of animals, and from changes in the composition of which the products of the plant are formed. The sap or common vessels, as they are named, rise longitudinally from the

root to the upper extremities, passing beneath the cellular tissure of the stem and branches, or through the wood, and conveying apparently the fluid which is absorbed by the roots from the soil. Similar vessels run from the bark in an horizontal or oblique direction, conveying what may be absorbed from the atmosphere at the surface of the leaves, or of the branches or stem.

There are vessels distinct from these, named the Proper Vessels, in which the common sap has been supposed to suffer peculiar elaboration. They are situated principally in the cellular tissure and internal bark; they appear to descend towards the root, and to convey a fluid in that direction, as, when cut, the liquor which exudes comes from the upper margin of the incision.

As the common vessels can be traced from the root to the leaves, and the proper vessels descend in the opposite direction, it appears to follow, that any connection between them is established in the leaf. Darwin supposed that the large vessel, or bundle of vessels, which runs from the leaf-stalk through the centre of the leaf to its apex, is formed by the union of smaller sap-vessels; that the purpose it serves is to distribute the sap over the surface of the leaves in minute ramifications, in which it may be exposed to the action of air and light; and that the sap thus changed is brought back by other vessels which pass along the under surface of the leaf, unite at the commencement of the stalk, and probably form the proper vessels; in its progress through which, in different parts of the plant, the juice undergoes farther changes. And he stated some experiments on the absorption of coloured fluids, and

their progress through the leaf, which accorded with this view. It has been more recently established by the experiments of Knight.

Another set of vessels have been observed in vegetables, the functions of which are not well ascertained,—those of a spiral form. They are found around the pith, in the slender branches, the leaf-stalk, and the petals of the flower. As they are always empty, they have been supposed to convey air; others have supposed them to be absorbents, which contract forcibly when cut, and hence discharge their contents. Knight regards them as subservient to the sap-vessels, as they are generally connected with them, and supposes, that by some mechanism they facilitate the propulsion of the sap.

The functions performed by vegetables, subservient to the formation of their chemical products, are, Absorption, Perspiration, Respiration, and Secretion.

Absorption is performed by vessels arising from the roots, and probably also from the bark and leaves. From the soil a large quantity of water appears to be taken up by these vessels, holding dissolved, it is probable, the soluble parts of the vegetable and animal matter which the soil contains, and a portion of its saline and earthy matter. This absorbed fluid appears to be the source of the sap; in its ascent it is changed in its qualities, acquiring greater specific gravity, and holding a larger portion of matter dissolved; changes which may arise in part from the action of the vessels through which it is propelled, and partly from the intermixture of the proper juices of the plant, and also, according to the conclusions drawn by Darwin

and Knight, from the extraction of solid matter from the wood. According to the extent of these changes, and probably also according to the materials furnished from the soil, the sap varies in its qualities. Vauquelin found, that it always holds dissolved a considerable quantity of saline matter, principally acetate of potash and lime, and sometimes carbonate of lime, with smaller portions of sulphate, muriate, and nitrate of potash; it contains, too, vegetable matter, principally extract, and tannin, and sometimes sugar, the two latter being probably derived from intermixture of the proper juices. Knight always found the sap to be largely impregnated with air.

Perspiration is observed in plants, and when vegetation is vigorous, or under exposure to heat or light, takes place even to a very considerable extent. The perspired fluid appears to be chiefly water, with a slight impregnation of vegetable matter.

Respiration, or the function by which changes are produced in the composition of the surrounding air, is performed by vegetables by the medium of their leaves, is necessary to sustain their life, and is probably strictly connected with the chemical changes which constitute vegetation. Considerable difficulty, however, has been experienced in determining the precise nature of the reciprocal action exerted between a growing plant, and the surrounding atmosphere.

Priestley observed at an early period, that plants absorb carbonic acid from atmospheric air, when it is mixed with it, even in considerable quantity, and communicate to it oxygen; and this suggested the speculation already noticed,

that vegetables and animals stand opposed to each other in the changes they produce in the atmosphere, and by this opposition preserve it at its due purity, and of uniform composition. This view, pleasing from its apparent adaptation to the œconomy of nature, was received without being submitted to very strict examination; though facts, not altogether in conformity to it, appeared to be established on other authorities. Even the experiments of Priestley afforded discordant results, and proved, that in some cases the changes produced in the air by vegetables are precisely the reverse of those whence his conclusions were drawn; and in those made by Scheele, the deterioration of the air and the production of carbonic acid gas were uniformly observed.

A fact ascertained by Ingenhouz appeared to point out the principle from which this discordance might be explained. He observed that the evolution of oxygen gas from the leaves of vegetables takes place principally when they are under exposure to solar light; whence he inferred, as the result of an extensive series of experiments, made by exposing the leaves of plants, their green shoots or branches, or even the entire vegetable, under water to the solar rays, that "oxygen is elaborated in the vessels or other organs of vegetables, by a vital action, excited and sustained by the light of the sun;" and he added a number of facts in proof of the conclusion that the organic structure of the vegetable is necessary to this; that it is the result of a function performed by it, and is therefore connected with the œconomy of the plant. The production of oxygen he found at the same

time to be considerably dependant on the nature of the water under which the vegetable was immersed; and it has been more lately shewn, by the experiments of Sennebier, Woodhouse, and Saussure, that it is much connected with the presence of carbonic acid, so that in water entirely free from this, the evolution of oxygen is very inconsiderable, while in water impregnated with it, it is abundant. It may be inferred, therefore, that it is principally from the decomposition of the carbonic acid, by the powers of the plant, aided by the agency of the light, that the oxygen is evolved. Some have supposed even that the decomposition is produced by the action of the light alone, and that the vegetable matter affords merely a surface on which this acts on the water or the carbonic acid in a favourable manner—a supposition, however, which appears to be refuted by various facts stated by Ingenhouz, which prove the necessity of organic structure, and organic action, to the evolution of oxygen; particularly that other substances, which might equally afford a surface, as silk, have not the same effect; that the quantity evolved is greater, as the leaves are in a state of maturity and vigour; and that the evolution ceases when their life or organization is destroyed.

Still it is more satisfactory to determine the changes which the entire vegetable produces in the surrounding air, in its natural situation; and on this subject many experiments have been made. Priestley in general found, that air vitiated by respiration or combustion, has its purity restored by a growing plant, and that, by introducing the flexible shoots of plants into jars containing air, the

air is ameliorated. Ingenhouz observed that plants confined in air, containing a portion of carbonic acid gas, decompose this gas, and produce oxygen when under direct exposure to solar light, but that if this is excluded, the reverse changes take place, oxygen is consumed, and carbonic acid formed. With this the experiments of Sennebier nearly correspond, the proportion of oxygen being increased in air, in which the branches of plants were placed over water and exposed to the sun, and this to a greater extent when the branches were removed during the night. Woodhouse at a later period drew the conclusion from his experiments, that plants confined in atmospheric air produce in general any change in it very slowly; carbonic acid was frequently formed, and oxygen consumed, but not, as he supposed, from any function of the vegetable, but rather from the chemical action of the oxygen on the carbonaceous matter of the plant; and the change more directly produced by the vital action of the vegetable, excited by solar light, is the decomposition of carbonic acid, and consequent evolution of oxygen; though, as the quantity of this acid diffused in the atmosphere is inconsiderable, vegetation, he supposes, can have little effect in preserving its purity.

The investigation of this subject has been prosecuted still more minutely by T. Saussure. The view suggested by his experiments, and which led to their more extensive prosecution, is, that carbonic acid is decomposed by growing vegetables, as the result of the process of vegetation; the carbon is fixed in the vegetable matter, contributing to the growth of the plant, and the formation of

its products, part of the oxygen is also retained, and the remainder is evolved. Hence, when growing plants are placed in atmospheric air, to which carbonic acid has been added, and exposed to solar light, the carbonic acid, if not in too large quantity, disappears, oxygen is evolved, vegetation is vigorous, and the proportion of carbon in the plant is increased. It is this, according to Saussure, which is the source of the carbon in vegetables, for when they are made to vegetate in pure water, and in atmospheric air, deprived of carbonic acid, there is, he maintains, a mere enlargement of their bulk without any addition of weight. At the same time, the action of light is necessary to these changes. If it is excluded, the presence of carbonic acid gas, instead of being useful, is injurious, and no sensible quantity of it is decomposed; and a growing plant placed in common atmospheric air, under the exclusion of light, consumes oxygen, and forms carbonic acid. If the light be admitted, the reverse changes are established, and thus, under the alternate admission and exclusion of light, little sensible change is produced in the constitution of the air.

Mr Ellis has, in the last place, given another view of the changes produced by vegetables in atmospheric air, and of the connection of these with vegetation, nearly the reverse of that advanced by Saussure, though admitting a number of the same facts. His experiments prove, that growing plants uniformly, and in all periods of vegetation, consume the oxygen of the air, and form carbonic acid in quantity equivalent to the portion of oxygen thus consumed; this takes place even under clear day-light, and is only suspended, and the reverse changes established by

the direct action of the solar rays. Carbonic acid is not necessary, he conceives, to their growth, for they die when it is abundantly supplied, if oxygen is not present; while they live and flourish as long as oxygen is supplied, though carbonic acid be completely abstracted.

It appears to be sufficiently established by the general results of the different experiments that have been made on this interesting subject, that growing vegetables produce very different changes on the air which surrounds them, according as they are exposed or not to the solar rays. Under this exposure they decompose carbonic acid when it is present, either in its elastic form or condensed by water, and exhale oxygen; when excluded from this, even though diffused light be present, they produce precisely the reverse changes, consume oxygen, and form carbonic acid.

The question, therefore, obviously is, which of these series of changes is the result of the natural function of the plant, connected with its growth and the formation of its products. And on this point Mr Ellis has very forcibly remarked, that as so many plants grow and form all their products without being directly exposed to the rays of the sun; and as at certain seasons, and in many climates, the degree of this exposure is inconsiderable compared with their seclusion from it, we are led to the conclusion that it cannot be essential to their growth, but that the changes which they more constantly produce, must be those on which vegetation depends.

This opinion may be just; yet the subject is not altogether free from obscurity; for, independent of the circum-

stance, that there is still some discordance with regard to some of the facts connected with it, it must be admitted as singular, that plants can without injury so change the state of the functions they perform, as at different times to produce changes precisely the reverse of each other, though extremely important in themselves; and farther, that they should exist in greatest vigour, and form their peculiar products in greatest perfection, generally in those climates, and universally in that season, in which they have, from situation with regard to solar light, been exerting to the greatest extent that very function with regard to the air, supposed to be least natural to them, or the reverse of that to which their economy is adapted, and which they usually perform. We have the farther difficulty, if we adopt this view, of accounting for the origin, (particularly in the case of plants growing when supplied only with water and atmospheric air), not only of the carbon which makes part of their substance, but of the much larger quantity which must be spent in this formation and evolution of carbonic acid. And, lastly, the experiments of Saussure appear to prove, that the decomposition of carbonic acid by plants, instead of being an unnecessary process, dependent on the accidental chemical agency of solar light, is essential to their growth; for he found, that if the small portion of carbonic acid which atmospheric air naturally contains were removed, by washing with lime-water, the vegetable to which such air was applied merely expanded, without any real addition of vegetable matter, while, when supplied with water and with atmospheric air in its natural state, the proportion of vegetable matter in-

creased with its growth, proving that it had fixed the carbon of this carbonic acid.

It may be remarked, in concluding this subject, that the changes effected by plants in a state of full growth and vigour on the surrounding air, appear to be less than have been usually imagined; water is more essential to them, and they are unquestionably much less dependent than animals on the surrounding air. They require also a less supply of nutritious matter, as their growth is more slow, and they lose less by any excretion. There appears, too, to be a much greater diversity in plants than in animals with regard to their relation to the air, some affecting it very slowly, others producing changes in it more speedily, and some being injured by one gas in which others live sufficiently well.

Vegetables are capable of acting on the other aerial fluids besides atmospheric air or carbonic acid; but the facts on this subject are somewhat discordant, and are less interesting, as having little connection with vegetation.

Changes analogous to those produced by the leaves on the surrounding air, are produced by the action of other parts, particularly the stems and young green shoots. The leaves, however, are the proper respiratory organs of plants, and their importance is sufficiently shewn by the fact, that when they are destroyed during the period of rapid vegetation, the plant decays, and even dies. The under surface of the leaf appears to perform the functions of transpiration and absorption of watery vapour, while it is at the upper surface that the chemical changes produced by the action of light principally take place.

Secretion, or a process analogous to it, is performed by vegetables; in other words, from the common juice or sap very different products are formed, by the action of the vessels giving rise to new combinations of the principles it affords. These changes have been supposed, but without any sufficient proof, to be produced principally in the utricles or bundles of vessels situated in the stem and other parts. The secreted products form the vegetable proximate principles, and they are adapted to different purposes in the economy of the plant.

Having traced the functions of vegetables, it remains to connect with them the general process of vegetation, and the consequent formation of the vegetable compounds.

The seed of a vegetable consists of two principal parts, —the germs, or part endowed with life, and the cotyledons or seed-lobes connected with it, and which, in the commencement of its growth, afford it nutrition and support. In the germ two parts are discoverable,—the radicle, which descends from the seed forming the root, and the plumula forming the stem; and it is connected with the cotyledons by slender vessels, which ramify through their substance, and unite at their connection with the germ. When the seed is planted in the ground, or placed in other situations favourable to its vegetation, it absorbs moisture, and swells; the radicle shoots out, and the substance of the seed-lobes soon suffers a change in its qualities, the fecula of which it principally consists being converted into sugar. This constitutes the vegetable function of germination, the first stage in the process of vegetation.

The presence of oxygen is indispensable to germination.

If seeds moistened are placed *in vacuo*, or if they are confined in nitrogen or hydrogen gas, or carbonic acid, they do not germinate; when immersed in water from which the atmospheric air is excluded, they swell, and the radicle is formed, but vegetation makes no farther progress; the life of the germ is soon lost, and the chemical decomposition of the matter of the seed takes place. But if atmospheric air or oxygen be admitted, germination soon commences, and if the seed be placed in a favourable situation, proceeds to vegetation. Humidity is essential to the process, probably by favouring the developement and action of the minute vessels of the embryo plant, as well as the chemical changes, which convert the substance of the seed into matter adapted to its nutrition. A certain temperature, always superior to the freezing-point of water, is also necessary, and probably operates both by favouring these changes, and exciting the vital powers of the germ. Light rather retards the process, and, indeed, under full exposure to light, seeds do not germinate, or if they do, the plant on its evolution is extremely weak. When placed in the soil, therefore, seeds are under the most favourable situation for germination. The direct action of light is excluded, from the looseness of the soil the air is admitted, the due degree of humidity is supplied, and the temperature is preserved uniform.

During germination, the oxygen of the air is consumed, and carbonic acid is formed; the volume of the air is not sensibly altered; and as in the change of oxygen by combination with carbon into carbonic acid, there is no change of volume, this proves, that no part of the oxygen consumed in germination is absorbed by the seed, but that it merely

combines with a portion of its carbon. Some chemists have supposed, however, that a portion of water is decomposed during the process, the oxygen and hydrogen of which combines with the elements of the fecula of the seed-lobes.

By the chemical changes which occur in germination, the fecula of the seed is converted into sugar. This appears designed to serve as nourishment to the young plant; being soluble in water, it is absorbed in a state of solution by the vessels of the radicle, which begin to expand; and a supply of nutritious matter is thus afforded independent of any external source, until the powers of the plant are developed. The necessity of this is shewn by the fact, that if the seed-lobes are removed from the germ, the latter, when planted in the earth, either does not vegetate, or does so very imperfectly, and soon dies.

When germination has been established, the powers of the plant are excited, and its parts expand. The radicle first shoots out, penetrates the soil, and increases in length; the plumula rises from the ground to form the stem, and the different organs are successively unfolded, according to the structure of the plant. Nutritious matter is now supplied to it from without, and from changes in the substances it receives, all its products are formed.

Air and water are the principal vehicles of the food of plants. The soil, except with regard to some vegetables, affords little directly nutritious, and scarcely any of the earthy matter, it has been sufficiently demonstrated, is absorbed. The earth in which a plant is made to grow, it has been shewn by experiment, suffers little diminution of

weight, though the plant placed in it has increased greatly in bulk. Many vegetables grow when supplied with pure water alone. Parasitic plants, and those which grow on stones or rocks, can derive no nourishment from the earth; and the analysis of vegetable matter has shown, that their solid substance, and all their products, are formed of principles very different from those of which the soil is composed.

Water enters largely into the composition of vegetable matter; but it has also been concluded that it suffers decomposition in the process of vegetation, and that its hydrogen, with at least a part of its oxygen, contribute to the formation of the vegetable products. The conclusion has been drawn partly from the consideration, that in plants supported on air and water alone, there is no other source whence the hydrogen so abundant in their composition can be derived, and partly from the fact that vegetables growing in water exhale oxygen, at least when exposed to the action of solar light, the source of which, it is inferred, can only be the water which the light enables the plant to decompose.

From the atmospheric air, plants, it has been supposed, may receive carbonic acid, and this decomposed may be the source of the carbon, which, with hydrogen and oxygen, is the basis of their composition. In support of this, experiments have been stated by T. Saussure and others, proving that in an atmosphere composed partly of carbonic acid, growing plants cause a quantity of it to disappear, and that when supplied even with the small portion of carbonic acid contained in common atmospheric air, they grow, and increase their quantity of carbon, which

they do not do if the carbonic acid of the air has been previously abstracted. This, however, must be regarded as doubtful, if the fact be established, that the immediate result of vegetation is to consume the oxygen of the air, and to convert it into carbonic acid. The influence of the nitrogen of the atmosphere in vegetation appears to be negative; that of the oxygen must remain doubtful, until it is clearly established whether the consumption of oxygen and formation of carbonic acid, or the decomposition of carbonic acid and evolution of oxygen, are the changes connected with the growth of plants.

It must be admitted, on the general view of the subject, that in the present state of our knowledge, there are considerable difficulties in accounting for the nutrition and growth of those plants which are supplied with air and water alone,—an admission, however, which will be more easily received, since the recent discoveries in chemistry abundantly demonstrate that we know little of the ultimate principles of bodies, and confirm the suspicion, that those which in our speculations have been regarded as simple, are probably very remote from an elementary state.

It is farther to be stated, however, that it has been questioned whether plants do grow and flourish, when supplied with air and water alone. There is, it has been contended, a mere developement of parts without any actual increase of vegetable matter, unless where other sources have existed whence nutrition could be conveyed. Thus, Hassenfratz has affirmed, that in plants which expand when merely supplied with water, as hyacinths, kid-

ney-beans, or cresses, the vegetation is in this situation always imperfect, and the plants, when dried, afford no more carbon than what is contained in the seed or bulb. Saussure remarks, that these and similar plants, if supplied merely with distilled water, though they advance so far in growth, do not come to maturity. And Knight has remarked, that bulbous and tuberose roots contain within them the matter which serves for the developement of their parts, and their growth, to a certain extent. In the celebrated experiment of Van Helmont, in which a small willow was placed in a vessel containing dried earth, and supplied with water for several years, until it had grown to such a size as to have increased in weight from 5 to 169 pounds, though the earth had lost only two ounces of weight, and in other experiments of a similar kind, it has been contended, that sources of fallacy exist, particularly in the foreign matter conveyed by the water with which the plant was supplied.

It may be true, that in many plants vegetation, in the first stages of their growth, may be little more than an expansion of their substance by the operation of humidity, and the vital powers of the plant; and it is also not to be doubted, that there are many, the growth of which is imperfect unless they receive nutritious matter from the soil. But still these facts are insufficient to invalidate the conclusion, that vegetation may be supported by air and water alone, and that many plants supplied with these will flourish, and form their peculiar products.

This conclusion is in fact established, if we attend merely to the circumstances connected with the growth of a

large vegetable, as of any of our common trees. Its roots stretch to no great extent or depth in the soil, and that soil does not require to be renewed, or to receive any supply of manure. Nay, frequently the situation is such, that nothing is afforded but a support by which the plant is exposed to the air, and occasionally supplied with water. Yet the growth of the tree advances, its solid matter increases, and in many of them much vegetable matter is annually lost in the fruit and foliage. It is obvious, that the portion of soil with which the plant can be supposed to communicate could not have contained the matter from which this is derived, and there is no external supply but from water and atmospheric air.

There are, however, many vegetables which require other nutritious substances for their support and growth. This is proved by the most familiar facts in agriculture. Many vegetables flourish only in certain soils; those which require a rich soil vegetate only feebly when made to grow in a poorer, and many exhaust that in which they grow, so that it requires to be renewed by manure.

The two series of facts on this subject apparently opposed to each other,—one proving that vegetables grow when supplied with air and water alone, the other equally proving that vegetation under such circumstances is imperfect, and that a supply of matter more directly nutritious is required,—perhaps admit of being reconciled. In plants which expand rapidly, and soon proceed to maturity, the aid of nutritious matter may be required to bring them to perfection; the developement of their parts may so far exceed the slow supply of principles which they

can assimilate from water and atmospheric air, that they decay before their vegetation under such circumstances can be completed. But in plants which grow more slowly, air and water may afford a sufficient supply. It is accordingly those vegetables which grow with most rapidity, and which afford the largest produce of seed or fruit compared with the plant at the commencement of its growth, that require a rich soil. Such are those plants which are cultivated for the nourishment of animals.

Of the substances which contribute to the growth of vegetables besides air and water, the most important is vegetable or animal matter in a state of decomposition. This constitutes the richness or fertility of a soil; and its operation probably arises partly from its affording matter already assimilated to the nature of the vegetable, which is directly absorbed, dissolved or suspended in water, and partly from the elastic products evolved during its slow decomposition, which contain the principles required for vegetable nutrition in comparatively a condensed state, and which may also enter the vegetable by absorption, either in the elastic form, or imbibed by the water of the soil.

Besides this species of manure, which is perhaps alone directly nutritious, there are others scarcely less useful, which appear to operate either by accelerating the decomposition of vegetable and animal matter, or by exciting the plant to more vigorous action. Such is lime, the utility of which is sufficiently established, both in increasing the products of vegetation, and improving their quality. The theory of its operation cannot be said to be fully understood; it may in part act by its intermixture with the

other earths composing the soil, giving those qualities most favourable to vegetation which depend on its cohesion; it may also stimulate the absorbent vessels of the root; it may, either in its entire state, or in that of its elements, enter into the composition of the vegetable products; but its principal operation probably is that of accelerating, by its chemical action, the decomposition of matter which would otherwise remain inert: hence its utility is greatest in soils abounding with vegetable and animal matter; and when this is exhausted, less advantage is derived from it, until this species of manure is supplied. It acts most powerfully in its pure state, though similar advantages are derived from it to a certain extent, when it is combined with carbonic or sulphuric acid.

The nature of the soil, with regard to its earthy and metallic ingredients, has likewise an important influence on vegetation. These may have a diversity of effect in exciting the actions of the vessels of the roots; if absorbed even in sparing quantity, they may have a similar effect on other organs of the plant; and it is obvious that they must differ in the mechanical support they afford, in the facility with which they allow the roots to extend, and in the force with which they absorb water, and retain it. As these qualities must be various in their relation to different plants, some requiring a more firm support, or a more ample supply of humidity than others, it is not possible to determine exactly what constitutes a well-constructed soil. Experiments made by Tillet on the comparative powers of various earthy mixtures in sustaining the vegetation of those plants which are cultivated for nourishment, such as

wheat, have shewn that there is a considerable latitude in this respect,—the plants flourishing in mixtures of very different kinds. Giobert has also given the analysis of soils actually barren and fertile, whence it appears that a large proportion of siliceous earth is useful. But all such observations are necessarily limited, as the qualities of the soil are to be compared, not only with regard to the particular vegetables it supports, but according to the nature of the subsoil, the declivity, and the humidity and temperature of the climate. When there is an excess of argil or clay, water is imbibed slowly, but is strongly retained; and in drying, the mass hardens and contracts. A larger proportion of silex, in a state of division more or less fine, gives a greater degree of porosity; lime corrects an excess of either quality; and much of the excellence of the soil probably depends, not only on the proportions, but on the intimate and uniform mixture of the ingredients, and the degree of comminution to which they are reduced. A fertile soil, analysed by Mr Davy, was found to be composed in 100 parts of 11 of carbonate of lime, 25 of siliceous sand, 45 of finely divided clay, 9 of animal and vegetable matter, 4 of water, and a little phosphate of lime.

Lastly, in the process of vegetation, the influence of heat and light is conspicuous. Both operate probably by exciting the actions of vegetables connected with their vitality; and from the change to which solar light gives rise in the reciprocal action between the growing plant and the atmosphere, it is obvious, that it also in part acts as a chemical power. Its influence is well marked in the

changes which plants suffer when they are secluded from light; they become of a pale colour, which soon changes to green when the light is admitted. This action is principally exerted on the sap circulating through the leaves, and it is accordingly at the margin of the leaf that the change of colour first appears.

Such are the circumstances most materially influencing vegetation; and considering the operation of all of them, the following may be presented as the theory of the process which the present state of our knowledge suggests. Regarding germination as its first stage, the seed exposed to atmospheric air expands; and the farinaceous matter, by the action of the oxygen of the air, is converted into sugar, which serves as food to the infant plant. Its organs are gradually unfolded, and its nourishment received from a different source; water, pure, or holding vegetable and animal matter in solution, is absorbed by the roots; and, in a soil containing decomposing vegetable and animal matter, different aërial fluids are received, and mingled with the sap. This, in its progress through the root, dissolves even part of the vegetable matter; and from this, the plant, in the first stages of its growth, is better enabled to form its products. It is brought to the leaves of the vegetable, and presented under an extensive surface, covered with a very thin membrane, to the action of the air and light; part of its water transpires; carbonic acid, and other elastic fluids from the atmosphere, are perhaps absorbed; and, by the action of the vessels, assisted by the chemical agency of light, new combinations are established, and the proper juice of the plant is formed. This is

conveyed by the footstalk of the leaf, and by vessels proceeding downwards through the bark, or between it and the wood: it is deposited in different parts, or is still farther changed in its progress,—changes from which the peculiar vegetable products are formed.

From the substances conveyed to the plant from the air, water, and soil, must no doubt be derived all the elements of which its products are formed. But in the uncertain state of our knowledge with regard to what principles are truly elementary, it is perhaps in vain to attempt to trace with certainty the source of those ultimate principles which the vegetable analysis affords. There are found in the products of the vegetable kingdom, though in very different proportions, oxygen, hydrogen, nitrogen, carbon, sulphur, phosphorus, the fixed alkalis, lime, magnesia, argil, and silex, and several metals, particularly iron, manganese, and, as it has likewise been affirmed, gold. With regard to oxygen and hydrogen there is no difficulty, as these are abundantly supplied from water. From a common soil, containing always vegetable and animal matter, carbon may be derived, but in plants growing merely in water and air, there is the difficulty, as has been already stated, if we do not admit of the absorption of carbonic acid from the atmosphere, of accounting for the oxygen of the carbon necessary to their growth, and still more for the larger quantity disengaged in the state of carbonic acid, when the plant is not under the action of light. Nitrogen, if it is not a compound body, may be derived from the atmosphere. With regard to the other substances present in more sparing quantity, little can be said with

precision; they may in general be derived from the soil; and the researches of Saussure have established some important facts in proof that the saline, earthy, and metallic ingredients have this origin; at the same time it is sufficiently possible that all these principles may be compounds of elements more subtle, at present unknown to us, and may be formed in the processes of vegetation; or the opposite supposition is equally probable, that, whether simple or compound, they may be evolved from the decomposition of others, which our imperfect knowledge has ranked as elementary.

CHAP. II.

OF THE PROXIMATE PRINCIPLES OF VEGETABLES.

The products of vegetation are extremely diversified; but in submitting them to chemical arrangement, they are reduced to a few species, named the Proximate Principles of Vegetables. These are distinguished entirely by chemical characters; the substances arranged under each species, may differ somewhat in their sensible qualities, but if they have that agreement in chemical properties which fixes the species, these less important differences are disregarded, as indeed they do not fall under the investigation of the chemist.

These proximate principles exist in the different parts of plants, and in their products, either insulated, or in states of mixture or combination; and, in the latter case, are separated by processes founded on their chemical relations, as by the action of different solvents, or by the application of heat. If the leaves of a plant, for example, are macerated with water, its entire substance is not dissolved, but it may yield a matter soluble in water; if distilled, a volatile principle may be obtained; if macerated in alkohol, a portion of matter may be extracted, which the water had not dissolved; and by multiplied operations of this kind, a number of distinct substances are obtained.

The diversities of properties in these principles, and from which the discrimination between them is established, arise from differences in their chemical constitution. Still they have all the general characters of vegetable matter, and in their analysis afford similar products, diversified principally in the proportions.

This analysis is effected in various modes. The most general is the analysis by heat, and this has been much prosecuted by chemists. When a vegetable substance is exposed to a temperature superior to 212°, after the superfluous water is dissipated, its decomposition commences, from the re-action of its elements, and the new combinations into which they pass. A dark-coloured empyreumatic oil distils over with a portion of an acid liquor; carbonic acid, carbonic oxide, and carburetted hydrogen gases are disengaged, and a quantity of charcoal remains, frequently containing portions of saline, earthy, or metallic matter. These products are not those which existed

in the vegetable matter, but are compounds, arising from the decomposition of the proximate principle, and the union of the elements in new modes and proportions. The oil is produced by the union of part of the hydrogen with part of the carbon of the vegetable matter; the acid, from the combination of another portion of carbon and hydrogen with oxygen; the carbonic acid, oxide, and carburetted hydrogen, are similar products; and the remaining charcoal arises from the excess of carbon not spent in the formation of these compounds.

From such an analysis, however, little is learned of the nature of the matter subjected to it; for although the products can be collected, and their composition may be ascertained, yet experiments of this kind are liable to sources of error nearly inappreciable. From slight variations in the state of the matter analysed, with respect to humidity, or from still slighter variation of temperature in conducting the experiment, important differences in the results will be produced; and we are likewise unable to ascertain what quantities of the products of the analysis have preexisted in the vegetable matter, or have been actually formed. We acquire, therefore, only some general information. If much acid has been afforded by the analysis, we conclude that the matter analysed has contained a large proportion of oxygen, as this principle enters so largely into the composition of acids. If much oil has been obtained, we conclude, by a similar mode of reasoning, that hydrogen has been an abundant element of the matter analysed. From the production of ammonia or prussic acid, we infer the existence of nitrogen: from the

quantity of charcoal, we draw some conclusion as to the quantity of carbon existing in the vegetable; and by burning this charcoal, we discover the quantities and kinds of earthy and metallic mater which it has contained.

Sometimes vegetable substances are analysed, by heating them in contact with atmospheric air, so as to excite combustion; and from the products, determining the nature and proportions of the constituent principles. Certain principles can likewise be analysed by subjecting them to spontaneous decomposition, as saccharine matter, for example, by the process of fermentation: and, lastly, vegetable analysis may in some cases be effected by the agency of the nitric acid, which produces oxygenation of the vegetable matter, and by the product indicates the principles of which it has been formed.

The proximate principles of vegetables, or those compounds of their ultimate principles which, by mixture or combination, form every kind of vegetable matter, have been reduced to the following species: Mucilage or Gum, Fecula, Sugar, Gluten, Albumen, Jelly, Fixed Oil, Volatile Oil, Camphor, Wax, Resin, Extract, Cautchouc, Tannin, Acids, and the Ligneous Fibre. To these have been added some principles more subtle, or more doubtful, as the Aroma-Narcotic Principle, and Colouring Matter.

Sect. I.—*Mucilage, or Gum.*

This is one of the most abundant proximate principles of vegetable matter, and it seems to be the first product of the changes which the sap suffers from the action of the vessels. It is found in all young plants, in their roots, stalks, and leaves, and particularly in their seeds; and it is often present in such large quantity in their vessels as to be discharged by spontaneous exudation. It is also frequently combined with other proximate principles, from which it may be separated; but its characters are best taken from those varieties of it in which it exists in a pure form.

Pure gum is usually in small fragments, brittle, and semi-pellucid, of a white, yellowish, or reddish colour. It is inodorous and insipid, neither fusible nor volatile, and not inflammable in the strict sense of the term, for although it is charred when heated under exposure to the air, it scarcely burns.

Gum is soluble in water, either cold or warm, in every proportion, forming a thick viscid solution, which is named Mucilage, and from which the gum may be obtained by evaporation in its original state.

A chemical character serving to distinguish gum, is its perfect insolubility in alkohol; it is even precipitated by this re-agent from its watery solution. It is likewise insoluble in ether, or in oils; but triturated with oils, it diffuses them in water.

Gum suffers decomposition from the more powerful acids. Sulphuric acid chars it, causing at the same time a forma-

tion of water and acetic acid. Nitric acid causes the formation of oxalic, malic, and saccho-lactic acids, in proportions varying according to the concentration of the acid. Oxy-muriatic acid converts it almost entirely into citric acid. Muriatic acid dissolves it without forming from it any new product.

The alkalis and alkaline earths, in solution in water, dissolve gum without producing on it much change. Some of the earthy and metallic salts give rise to changes which serve to distinguish it; in particular, the acetate of lead throws down a copious white precipitate from its solution, while the super-acetate has no sensible effect on it, and a solution of silicated potash renders it quite opaque.

Gum is decomposed by heat, affording a large quantity of pyro-mucous, or empyreumatic acetic acid, with empyreumatic oil, carbonic acid, and carburetted hydrogen gases, ammonia, and a residuum of charcoal, which affords a little phosphate of lime. The principal elements of these products are carbon, hydrogen, and oxygen; and from the large quantity of acid produced, the proportion of oxygen may be inferred to be large. The production of ammonia indicates the presence of nitrogen, and the lime of the residual charcoal is capable of being discovered by tests in gum, being precipitated in particular from its solution by oxalic acid. It is from the presence of lime that gum appears to be incapable of passing into the vinous fermentation, this earth counteracting that process; and it is this chiefly which distinguishes gum from fecula, another proximate principle of vegetables, to which it has a great resemblance.

The purest gums are obtained by spontaneous exudation, such are the gum-arabic and the cherry-tree, and plum-tree gum. Gum-tragacanth differs a little from pure gum, particularly in being imperfectly dissolved by cold water, though with boiling water it forms a very viscid solution. The mucilages extracted by the maceration of water on seeds and roots which abound in gummy matter, present also some appearances with re-agents different from pure gum,—differences, however, of little importance.

Gum, in the state of mucilage, can be extracted in considerable quantity from a number of indigenous plants, by maceration in water, and a supply of it has thus been procured for several purposes in the arts, particularly in calico-printing. By a slight preparation, too, it may be obtained from the greater number of the lichens, these being freed from the outer skin, and boiled strongly with water, to which a small quantity of carbonate of potash has been added, and the mucilaginous liquid being reduced by evaporation to the requisite consistence.

Gum is used in pharmacy to suspend oils, balsams, and resins in water; and in several arts is employed, from its adhesive quality.

Sect. II.—*Of Fecula, or Starch.*

The principle distinguished by this name, forms the principal part of the nutritive grains and roots, and is ex-

tracted from them by the action of water, the grain or root, after being cleansed, being bruised, and beat with the water; the fecula is extracted in the state of a powder, which is diffused through the water, and speedily subsides. Starch is the fecula of wheat, and is extracted by a process of this kind; and other varieties of it are obtained from rye, from the potatoe, and from the roots, stems, and seeds of a number of plants. It is sometimes extracted, even quite mild, from poisonous or acrid plants, the acrid matter being dissolved by the water, and thus entirely abstracted.

Fecula is usually in the form of a light white powder, very soft and smooth to the touch, and apparently composed of impalpable brilliant grains; it is insipid and inodorous, though it sometimes has colour and taste, from other principles which adhere to it.

The property characteristic of this principle is insolubility in cold water, while it is perfectly soluble in hot water, forming a solution viscid or gelatinous. The solution of it takes place when the temperature is raised to 160° or 180°; and if the water is dissipated by evaporation, the solid matter is soluble as before. It is insoluble in alkohol and ether, and alkohol precipitates it from its watery solution, like gum.

Fecula is capable of passing into the vinous fermentation, and of undergoing the previous change of conversion into saccharine matter. This happens in the process of the germination of seeds, and it is from this property that the different nutritive grains form fermented liquors.

It is decomposed by heat, blackens, and forms at length a spongy charcoal, and if heated strongly, burns. The

products of its decomposition in close vessels are an acid liquor, which is diluted empyreumatic acetic acid, a little empyreumatic oil, carbonic acid, and carburetted hydrogen, and a residuum of charcoal. From these products it may be inferred to be a compound of carbon, hydrogen, and oxygen.

The acids decompose fecula with results somewhat similar to those which they produce on gum. Sulphuric acid chars it, and forms water and acetic acid. Nitric acid converts it into malic and oxalic acids.

The alkalis appear to dissolve it, as their solutions reduce it to the consistence of a jelly, even without the aid of heat. It is precipitated from its solution in water by acetate of lead, and nitro-muriate of tin, but not by silicated potash,—a property in which it differs from gum.

Fecula, in a number of its properties, bears a resemblance to gum, and still more to the mucilages extracted by maceration from the seeds and roots of plants, and it is probably formed from mucilage in the process of vegetation. It forms the principal part of the nutritive seeds and roots, and is itself highly nutritious; hence it is used in its pure state as an article of diet, salop, sago, arrow-root powder, and cassava, being varieties of it. Wheat affords it in larger quantity than any other vegetable, and in a state of perfect purity. The potatoe also affords a large quantity of it, and the starch of both these vegetables is used for the adhesive property of its gelatinous solution.

A substance obtained in the form of a powder from the root of elecampane, (Inula helenium), and distinguished as a peculiar principle, appears to be merely a variety of fecula, distinguished by inferior solubility in water, so that, although dissolved by boiling water, the greater part of it separates as the water cools.

Sect. III.—*Of Jelly.*

The juices of certain fruits, as the currant, if not too watery, concrete into a kind of tremulous jelly. The substance communicating this property is very sparingly soluble in cold water, while it dissolves easily in boiling water, the solution as it cools becoming gelatinous. In this leading character, therefore, it resembles fecula. As an acid usually accompanies it, it is not improbable it may owe to this the slight modification of its properties.

When procured by evaporation in a solid state, Vauquelin found it to be transparent. It is dissolved by the alkalis, and in the dilute acids. Nitric acid converts it into oxalic acid, without disengaging from it any sensible proportion of nitrogen. It is precipitated by infusion of galls. Decomposed by heat, it affords, along with the elastic fluids usually disengaged in the decomposition of vegetable matter, much empyreumatic acetic acid, little oil, and scarcely any ammonia.

It is from the presence of this principle, that the juice of the currant and other fruits form a jelly when prepared with sugar. To form the gelatinous consistence, it is necessary that there should be a certain proportion between it and the water; by long boiling, too, the property is lost. Hence the reason, as Vauquelin has remarked, that in preparing the preserved jellies of these fruits, if the juice is too watery, or the proportion of sugar not sufficiently large, so that it is necessary to continue the boiling long, the gelatinous consistence is not acquired.

Sect. IV.—*Of Sugar.*

Sugar is an abundant vegetable product, mixed frequently with other principles, but frequently also secreted in a more pure form. It thus exists as the chief constituent part of the sweet juices of many fruits; and there are plants, as the sugar-cane and the sugar-maple, which afford it in large quantity. From both of these it is extracted, and even from other plants, for the numerous uses to which it is applied.

The juice of the sugar-cane, at a certain state of maturity, is highly saccharine. It is expressed and boiled, a quantity of lime being added, the operation of which appears to be that of neutralizing a portion of oxalic acid in the juice, which prevents the concretion of the sugar. The juice, after the proper decoction is allowed to remain at rest until it become clear, is boiled down in another

vessel, until, on cooling, the sugar separates in a concrete state, a sweet liquor remaining, Molasses, which is drained off. The saccharine matter thus obtained, being not altogether pure, is purified by boiling its solution in lime water, with the addition of a quantity of blood; the lime neutralizing any acid that may be still present, the blood coagulating, and the coagulum entangling the impurities. The liquor, after being sufficiently concentrated, is drawn off, and run into inverted conical moulds of clay, in which it becomes concrete; the base of the inverted cone is then covered with clay which is moistened with water, and this filtrating slowly through the mass, removes any saccharine liquor; the mass is afterwards strongly dried. By a similar process, sugar is obtained from the juice of the sugar-maple; and from the juice expressed from the roots of the Beet, Parsnip, and some similar plants.

Sugar, when pure, has a sweet taste, free from any peculiar flavour; it is of a white colour, and appears in the mass to consist of brilliant grains; it also assumes, in becoming concrete from its watery solution, a regular crystalline form, that of a rhomboidal prism; the crystals are transparent.

Sugar is soluble in water; at the temperature of 50 of Fahrenheit it does not require much more than an equal weight. Boiling water dissolves nearly any quantity of it. Its solution is more or less viscid.

Sugar is also soluble in alkohol; and this solution, when concentrated by evaporation, likewise affords crystals.

When exposed to heat, sugar is blackened, swells up, and burns to a coal; if the heat is strong, its combustion

is attended with flame. The products are carbonic acid and water. Exposed to heat in close vessels, it yields a considerable quantity, rather more than half its weight, of weak empyreumatic acetic acid, a small quantity of empyreumatic oil, with carbonic acid, and carburetted hydrogen gases, the residuum being charcoal. These products into which the sugar is resolved, consist of carbon, hydrogen, and oxygen; and these may be stated as its ultimate constituents. From the large quantity of acid which its analysis affords, it appears to contain more oxygen than any other vegetable substance that is not acid.

By the abstraction of oxygen, sugar is converted into a substance somewhat similar to gum, a change produced in it, in some experiments by Cruickshank, by the action of phosphuret of lime.

Sugar is decomposed by the acids. Sulphuric acid causes an evolution of charcoal. Nitric acid is rapidly decomposed by yielding oxygen, and an acid is formed, the same with one which exists native in vegetables, the oxalic acid, a smaller portion of another, the malic being also frequently produced. Liquid oxy-muriatic acid converts it into citric acid.

The alkalis form combinations with sugar, in which the sweet taste is lost, though it is restored when the alkali is neutralized by an acid. The compound, it is singular, is not soluble in alkohol, though both its ingredients are. The action of the alkaline earths is similar, and both lime and strontites are rendered more soluble in water by the combination. The compounds have a bitter astringent taste, and their solutions are viscid and tenacious.

Sugar being highly nutritious, is, independent of its sweet taste, of some importance as an article of diet. Its solution, syrup as it is named, is employed in pharmacy; and sugar itself enters into the composition of ink, and of some pigments and varnishes, to give to them a degree of lustre.

Honey is another vegetable product, similar in many of its properties to sugar; nor has any essential difference been pointed out between them, except the natural fluidity of honey, and perhaps its viscosity. A species of sugar can be obtained from honey by the action of alkohol, or by clarifying it by a moderate heat, and the action of carbonate of lime. This sugar does not crystallize so readily as common sugar, and it suffers changes somewhat peculiar from the alkalis and earths, effervescence being produced, and a brown or black colour acquired. Some have supposed it to be a compound of sugar and mucilage.

Honey is formed in the flowers of plants, and is always exposed, frequently by a very complicated organization, to the atmospheric air. It has been supposed to be designed in the vegetable to receive and retain the fecundating pollen from the male parts, as its secretion diminishes or ceases when the fecundation is completed. A number of insects feed upon it, and it is collected in large quantity by the bee.

The saccharine matter formed in certain morbid states of the animal economy, giving rise to the disease named Diabetes, is very similar in its properties to the sugar o honey.

Manna is a concrete juice, which, from its sweet taste, may be judged to be highly saccharine. It has similar properties, and appears to owe any peculiar qualities belonging to it, to a portion of extractive or mucilaginous matter with which the sugar that is its basis is mixed.

Sect. V.—*Of Gluten, Albumen, &c.*

In the analysis of the flour of wheat by the affusion of water on the paste kneaded in the hand, the saccharine and mucilaginous matter is dissolved, and the fecula is carried off diffused in the water; there remains a viscuous, elastic substance, which, from its resemblance in some properties to an animal product named Gluten, has obtained the name of Vegetable Gluten. It amounts, apart from the water combined with it in its extraction, to a twelfth part of the weight of the flour, and is equal, in the humid state in which it is obtained, to from a third to a fifth of the weight. In the other nutritive grains, it is contained in much smaller quantity, and in some of them, as well as in the nutritive roots, there are no traces of it. It appears, however, to be contained in the expressed juices of some plants.

Gluten, combined with water in the state in which it is obtained from the flour of wheat, is soft and ductile, distinctly fibrous in its texture, and highly tenacious and elastic, so that it can be stretched out to great length; but when the stretching force is withdrawn, speedily

shrinks into its former dimensions. It is of a greyish colour, and has scarcely any odour or taste.

By a moderate heat, the water contained in gluten in this state is dissipated; it becomes hard and brittle, and is then not liable to much change. But soft gluten soon passes into a state of putrefaction similar to that which animal matter suffers, and there is a formation of ammonia, acetic acid, and an oily matter. Under water it does not putrefy so readily, the formation of acetic acid apparently preventing this, and dissolving a small portion of gluten; the decomposition, however, gradually proceeds, and is at length marked by the offensive odour which distinguishes putrefaction.

Gluten is not soluble in water, unless it has undergone a certain degree of change by spontaneous decomposition, and even then the portion dissolved is very inconsiderable. It is likewise insoluble in alkohol, unless when it is in a similar decomposed state.

The action of the acids on gluten affords different results, according to their state of concentration, and the facility with which they yield oxygen. The weaker acids, particularly the acetic, dissolve it without producing in it much change. Muriatic acid acts in a similar manner; oxy-muriatic acid changes it into a yellowish flocculent substance. Sulphuric acid chars it, and causes an evolution of carburetted hydrogen, and formation of ammonia and acetic acid. Nitric acid disengages from it nitrogen gas, and forms oxalic and malic acids.

Gluten is dissolved by the alkaline solutions, aided by

heat, suffering at the same time a change in its properties from partial decomposition.

This principle is decomposed by heat, and the products yielded by this decomposition are very similar to those from animal substances. A large quantity of carbonate of ammonia is formed, with empyreumatic oil, and a little prussic acid; carburetted hydrogen gas is disengaged, and there is a residuum of charcoal. The production of ammonia indicates the predominance of nitrogen in its composition; and this is shewn by the disengagement of this gas when gluten is acted on by nitric acid: the large quantity of oil farther indicates the presence of hydrogen in considerable proportion, while, from no acid being produced, it may be inferred to contain little oxygen. Phosphorus appears to exist in it in small quantity.

Gluten thus appears to be strictly analogous in composition to animal matter. Hence it adds to the nutritive quality of the grains in which it exists, and to this, in part at least, is to be ascribed the superiority of wheat. It communicates also that superiority which the bread prepared from wheat has to that from the other grains; as the flower of wheat made into a paste with water, forms from the presence of gluten a ductile mass, which, when rendered porous by the disengagement of carbonic acid, from the slight fermentation excited by the action of the leaven, remains after being baked, light and spongy, while the flower of other grains does not undergo this change, but forms rather friable pastes.

From the juices of certain plants, those generally of the cruciform kind, a flocculent substance separates by coagulation when they are exposed to heat; and it is also separated by the action of acids. This property of being coagulated by heat, and by acids, being characteristic of the animal principle named albumen, the matter thus separated has been considered as approaching to this, and has received the name of Vegetable Albumen. Rouelle long ago regarded it as analogous to gluten; and from the more recent observations of Proust, it appears to be merely a variety of it, deprived of the elasticity, and some of the other physical properties of gluten in its common state, from the nature of the process by which it is obtained. It not only exists in the cruciform plants, but likewise in the grape, apple, and other fruits, in the acorn, horse-chesnut, and other beans; and it is supposed to form the base of the green fecula which subsides from the expressed juices of a number of herbs.

Though this principle is probably a variety of gluten, the singular fact has been established, that there does exist in the vegetable kingdom a principle which has almost all the properties of animal albumen, and which, of all the varieties of vegetable matter, approaches most nearly in its character to animal substances. It exists in the juice of a plant, the carica papya, a native of the Isle of France. This juice, when it issues from the tree, is white as milk;

in a few minutes it coagulates, and a flocculent substance separates, which floats in the liquid now become transparent. If the juice be inspissated, it affords a solid brittle matter, which attracting humidity from the air, soon becomes soft. It is dissolved easily by cold water, and still more abundantly by water moderately warm. When the solution is made to boil, it becomes turbid, and coagulates; alcohol added to the cold solution, forms a flocculent precipitate; the acids coagulate it abundantly, and a precipitation is occasioned by a number of metallic salts. The solid matter exposed on burning fuel burns, diffusing an odour similar to that from animal substances. Subjected to destructive distillation, it affords carbonate of ammonia, a thick black oil, carbonic acid, and carburetted hydrogen, a charcoal remaining, difficult of incineration, and which affords phosphate of lime. So far, this substance has all the characters of animal matter; it is farther liable to putrefaction; and, subjected to the action of nitric acid, it affords a large quantity of nitrogen and carbonic acid gases, prussic and oxalic acids being also formed.

The liquid part of the native juice, after the coagulum has separated, appears still to retain a portion of the same principle dissolved; hence it is coagulated by acids and alkohol, and the matter separated is similar in appearance to the white of an egg. Infusion of galls, too, throws down from it an abundant precipitate, properties characteristic of animal albumen. We cannot, observes Vauquelin, by whom this juice was examined, regard without interest a substance produced by a vegetable presenting all the characters of animal matter; and we perceive that na-

ture has given to some plants the power of forming combinations similar to those produced in the animal system.

To the same family with the substances which have been considered under this section, probably belongs the principle denominated CAOUTCHOUC, or Elastic Gum. In physical properties it has resemblances to them, and it agrees with them in approaching in composition to animal matter.

This substance is usually imported from Spanish America in hollow balls; is the inspissated juice of a tree belonging to the family of Euphorbia, the Hævea Guianensis; the juice obtained from incisions is applied in successive layers over a mold of clay; is dried by exposure to the sun, and to the smoke from burning fuel; and when perfectly dry, the mold is broken, leaving the hollow ball. Caoutchouc is not, however, exclusively the product of this vegetable, but is afforded by a number of other plants, natives of the torrid zone, either perfectly the same, or with qualities little different. The juice from which the common caoutchouc is obtained, previous to inspissation, is white; it coagulates speedily from exposure to the air, the coagulum being soft and elastic; alkohol likewise coagulates it, and oxy-muriatic acid throws down an elastic precipitate.

Caoutchouc, in its solid and dry state, is of a close texture, distinctly fibrous, of a light brown colour, or sometimes nearly colourless; its elasticity is such that it can be stretched to a great extent; and on removing the stretch-

ing force, it recovers its original dimensions; its softness and pliancy are increased by heat; and by the heat of boiling water it is rendered so soft, that two slips newly cut and pressed closely together may be firmly united.

Caoutchouc is insoluble in water; even when the water is boiled on it, it suffers no change but that of becoming softer from the effect of temperature. It is also insoluble in alkohol. Sulphuric ether, however, when highly rectified, dissolves it, and by evaporation the caoutchouc may be recovered unchanged; the solution takes place more readily when it has been previously softened by maceration in warm water. Nitric ether also dissolves it, but produces partial decomposition, probably from the action of the portion of acid usually contained in nitric ether. From the action of the essential oils, aided by heat, solutions are obtained, which remain viscid when inspissated. Even the fixed oils dissolve it when boiled on it.

By the action of the more powerfnl acids, caoutchouc is decomposed. Sulphuric acid acts very slowly on it, however, unless heat be applied. Nitric acid corrodes and dissolves it, rendering it yellow, and changing its properties. Muriatic or dilute nitric acid has scarcely any sensible effect on it. The alkalis scarcely affect it in the cold, but it suffers corrosion when boiled in an alkaline solution.

Caoutchouc, exposed to heat, softens and swells, emitting an odour similar to that from animal substances; by an increase of heat, it becomes nearly liquid; if the air is admitted, it takes fire and burns with a bright light, and much smoke. Decomposed by heat in close vessels, it af-

fords ammonia with empyreumatic oil, shewing its analogy in composition to animal matter; this is likewise shewn by its affording nitrogen gas and prussic acid when treated with nitric acid.

Caoutchouc, from its softness, elasticity, and impermeability to water, is applied to the formation of catheters, bougies, and tubes for conveying gases. Its solution in oils forms a flexible varnish.

Birdlime is a vegetable product, analogous in its properties both to gluten and caoutchouc, and which may, without impropriety, be associated with them, as not improbably varieties of one species. It resembles gluten in its tenacity, its insolubility in water, and its relations to the alkalis and acids; but it is less animalized, and is therefore not liable to putrefaction. It is still more analogous to caoutchouc in tenacity and elasticity, fusibility, inflammability, insolubility in water, and solubility in ether; and there are varieties of this principle obtained from different plants, less elastic and more viscid than that from the Hævea, which approach therefore very closely to birdlime.

Birdlime exudes from different vegetables, but it is usually prepared from the inner bark of the holly, by boiling the bark in water until it is softened, and then laying it in layers covered with earth and stones; it thus suffers a slow change, and becomes viscid; it is afterwards kneaded and beat, any extraneous matter being removed by washing; and the paste is kept humid for several days to complete the change.

This substance has a greenish colour and slight smell; it is extremely viscid and tenacious, and can only be handled when thoroughly wet; its texture is fibrous, and has such an elasticity that it can be drawn to a great length, from which, when the external force is withdrawn, it immediately contracts. It loses its viscosity when dried, but receives it on the addition of water.

Exposed to heat, it softens and undergoes an imperfect fusion. Placed on burning fuel, it burns with a bright flame, and with a dense smoke.

It is insoluble in water. Alkohol does not dissolve it in the cold, but when boiling a solution is formed, which becomes turbid as it cools, and from which a substance is separated having properties similar to those of wax. Sulphuric ether dissolves it still more abundantly; the solution is decomposed by water, and a quantity of oily matter is obtained.

The acids, if diluted, partly soften, partly dissolve birdlime. Concentrated sulphuric acid chars it, and causes a formation of acetic acid and ammonia. Nitric acid heated on it dissolves it, and as the evaporation proceeds, deposites a hard brittle mass, which, by being subjected anew to the action of the acid, is converted into oxalic and malic acids. Oxy-muriatic acid renders it white, and destroys its viscosity; acetic acid softens and dissolves it. The fixed alkalis decompose it, causing an evolution of ammonia, and the formation of a saponaceous compound, soluble in water and in alkohol, and decomposed by the acids.

Sect. VI.—*Of Wax.*

Wax, though usually obtained as collected by the bee, is a vegetable product. It is secreted by a number of plants, and the wax of the bee was supposed to be collected merely by that insect from the pollen of flowers,—an opinion rendered doubtful perhaps by the experiments of Huber, which prove that bees form wax when all supply of this is excluded, and when they are confined, and fed with honey or sugar alone. Still the existence of wax as a principle of vegetables is fully established. It forms the silvery down sometimes conspicuous on their leaves, flowers, or fruit. The Myrica Cerifera, or Wax Tree, affords in large quantity a product having all its qualities, forming a covering on its seeds; other species of myrica afford the same product, and a number of other plants afford by decoction a similar inflammable concrete.

Wax is solid and brittle, easily softened, however, and acquiring tenacity from a very moderate heat; its colour is usually yellow or greenish, but it can be rendered white by exposure to the air and sun, with a slight degree of humidity, without any change in its qualities.

It melts at 142° of Fahrenheit; myrtle wax is rather more fusible, melting at 109°. It cannot be volatilized without decomposition. The products of this when it is heated in close vessels, are a thick empyreumatic oil in large quantity, a portion of acidulous water, carburetted hydrogen, and a residuum of charcoal, indicating

carbon, hydrogen, and oxygen, as its constituent principles. It burns with a clear and bright flame, affording water and carbonic acid; and from the quantities of these, Lavoisier inferred, that it consists of 80.28 of carbon, with 17.72 of hydrogen.

Wax is insoluble in water. Alkohol scarcely acts on it in the cold; but if boiled on it, dissolves about a twentieth of its weight, the greater part of which is precipitated as the temperature falls. Ether also dissolves it when boiled on it. Myrtle wax is rather more soluble than bees wax in both fluids.

The alkalis, when boiled in solution on wax, dissolve a portion of it, and form an imperfect saponaceous compound, soluble in warm, but sparingly soluble in cold water. Ammonia exerts a similar action. These compounds are decomposed by acids, and the wax recovered from them with its original properties. The myrtle wax is rather more easily dissolved than bees wax.

The acids do not exert much action on wax. Sulphuric acid, when aided by heat, converts it into a mass of a black colour; nitric acid whitens and hardens it.

Wax combines by fusion with the volatile and fixed oils, forming compounds of intermediate consistence. It approaches to the fixed oils in almost all its properties, differing principally in its firmer consistence, its solubility to a certain extent in alkohol, and forming with the alkalis less perfect saponaceous compounds.

Sect. VII.—*Of Fixed Oil.*

There exist two species of oil in vegetables, agreeing in the common properties of unctuosity and inflammability, but essentially different in many of their chemical qualities and relations. The one, from being capable of being volatilized without decomposition, is named Volatile Oil; the other is denominated Fixed Oil. The history of the latter is the subject of this section.

Fixed oils are generally contained in the seeds and fruits of those vegetables of which they are the products, and only at the period of maturity. They are extracted by mechanical pressure,—whence they are named Expressed Oils,—or in some cases by decoction with water. They are frequently impregnated with the mucilaginous or extractive matter of the vegetable, whence they acquire colour, odour, and taste; and if heat has been employed to favour their extraction by expression, they acquire acrimony, and suffer even a change in some of their chemical properties. The purest oils are those expressed from the fruit of the olive, or the seeds of the almond; others less pure are extracted from lintseed, hempseed, and the seeds of other plants.

Fixed oils are usually fluid, but of a thick consistence, and they congeal at very moderate colds; some are even naturally concrete; when fluid, they are transparent, colourless, or of a yellow or green tinge, inodorous and insipid; they are lighter than water; they are incapable of com-

bining with water, and are scarcely sensibly soluble in alkohol.

Expressed oil cannot be volatilized by heat unchanged. At temperatures below 600° of Fahrenheit, they remain fixed; nearly at that temperature, they are converted into vapour; but the oil thus condensed is altered in its properties; it has lost its mildness, and has become more limpid and volatile, a portion of carbon being likewise deposited. Transmitted through an ignited tube, oil is converted into carbonic acid and carburetted hydrogen, with a small portion of acid liquor, and a residuum of charcoal.

Exposed to a warm atmosphere, expressed oils gradually acquire a sharp taste and disagreeable smell, and become thick. This change, named Rancidity, is owing to absorption of oxygen; and hence it takes place sooner when the oil is exposed to oxygen gas, and a large quantity of the gas is frequently absorbed. Drying oils, as those expressed with the aid of heat are named, do not become rancid, but by absorbing oxygen, are rather converted into a resinous kind of matter. By these drying oils the absorption of oxygen is under some circumstances so rapid as to give rise to spontaneous combustion.

At the temperature of ignition, at which it is converted into vapour, oil burns in atmospheric air; a large quantity of light and heat being extricated by its combustion. When the access of the air to the vapour of the oil is not complete, it burns with a black smoke; and a quantity of carbonaceous matter, which has escaped the combustion, is deposited. Hence the utility of a slender wick, which draws up the oil by capillary attraction, and,

when kindled, converts it into vapour; and still more of a hollow cylindrical wick, as in the argands lamp, through which an internal circulation of air is established, and the whole oil is consumed; though in this case there is some loss of illumination, from the light from the internal surface having to pass through the flame.

The products of the combustion of oil are water and carbonic acid. 100 parts of oil produce 140 of the former, and 281 of the latter, combining with 321 of oxygen; whence Lavoisier inferred, that oil consists of 79 parts of carbon and 21 of hydrogen, a conclusion which cannot be regarded as more than an approximation; oxygen probably enters into the composition, though in small proportion.

Expressed oil is oxidated by a number of the acids. Sulphuric acid soon renders it black; the oxygen of the acid attracting part of the hydrogen of the oil, and causing the deposition of charcoal; and if heat is applied, a large portion of sulphurous acid is disengaged, and even sulphur is evolved. Nitric acid renders the oil thick and white; if heat is applied, the action is more rapid, and a yellow colour is communicated, the oil being rendered concrete. The drying oils are even inflamed. Muriatic acid exerts little sensible action; oxy-muriatic acid thickens the oil, and renders it white.

Expressed oil combines with the alkalis, and when the combination is perfect, it forms soap. If one part of oil be mixed with half its weight of a strong solution of pure potash or soda, a thick white mass is formed, which can be diffused in water, forming a milky-like mixture. If the

oil and the alkaline solution be boiled gently together, a more intimate combination is effected, and on cooling, a solid compound separates from the liquor. The soap thus prepared, differs according to the purity of the ingredients. Common soap is made of animal oil, or fat, or the coarser vegetable oils with resin; the finer soaps are prepared from olive or almond oil. Potash forms a soap which always remains soft, soda forms one that is more solid and firm. Hence either a solution of carbonate of soda, from which the carbonic acid is abstracted by lime, is employed in the preparation; or if a solution of potash, rendered caustic by the same operation, be used, there is added towards the end of the boiling, a quantity of sea-salt, the soda of which, being in part evolved, has the same effect. The cleansing property of soap depends on its alkali; and although the detergent power of this is weakened by the combination with the oil, advantage is gained from its softness and smoothness, and acting less on the cloth.

Soap is soluble in water, the solution being opaque, from the intermixture of particles of uncombined oil. It is also soluble in alkohol, forming a transparent solution. It is decomposed by all the acids, and by the greater number of the earthy and metallic salts, the acid combining with the alkali, and separating the oil. Hence spring waters often decompose it, from the quantity of sulphate of lime they contain. The oil separated by these decompositions is soluble in alkohol, a proof that, by its combination with the alkali, it has undergone some chemical change. Soap,

decomposed by heat, affords water, empyreumatic oil, and ammonia.

Ammonia forms with expressed oil a less intimate combination than the fixed oils do, as heat cannot be employed to favour the combination. The addition of a small quantity of it is employed in pharmacy to suspend oil in water. By adding an ammoniacal salt to a solution of soap, an ammoniacal soap is obtained by double affinity. It is less soluble in water than common soap, and suffers decomposition from exposure to the air.

The combinations of expressed oil with the earths and metallic oxides may be obtained by adding their salts to a solution of soap, when a double decomposition takes place. These compounds have a saponaceous quality, but are in general much less soluble in water than the soap of potash or soda.

Expressed oil, when boiled on sulphur, combines with it, and forms a compound of a brown colour, an extremely fœtid smell, and acrid taste. It likewise dissolves phosphorus with the aid of heat, forming a liquid which becomes luminous when exposed to the air.

Expressed oil promotes the oxidation of some of the metals, as copper or mercury, by the action of the air. It also combines with a number of the metallic oxides. Boiled with oxide of lead, it forms a compound of a firm consistence, what is named in pharmacy Common Plaster.

A mutual action is exerted between expressed oils and several of the other vegetable principles, as gum or resin. Triturated with mucilage, it forms a milky mixture,—a

mode of suspending oil in water which is sometimes employed in pharmacy. It melts easily with resin.

Expressed oils, besides their use in pharmacy and medicine, form the basis of paints, being triturated with oxide of lead and the colouring matter. Combined with resins and turpentine, they form varnishes, and printing-ink is a composition of them with lamp black. For some of these uses the drying oils are employed.

Sect. VIII.—*Volatile Oil.*

Volatile, or Essential Oil, is contained in the flowers, fruits, leaves, wood, or bark of many vegetables, generally in inconsiderable quantity, the proportion varying, however, according to the age and vigour of the plant. The oil sometimes exists in distinct vesicules, and may therefore be obtained by expression. But the usual method to procure an essential oil, is to subject the vegetable matter containing it to distillation with water. The oil is volatilized with the aqueous vapour, and is easily condensed; a small portion of it is retained in solution by the water; but the greater part separates, and may be obtained pure from the difference in their specific gravity. Being usually lighter, it collects on the surface.

Essential oil is odorous, sapid, and generally pungent, the taste and smell of the oils obtained from different vegetables being very different, and the odour at least is always that of the plant from which they are procured. They

are generally lighter than water, but some have a greater specific gravity. They are also usually fluid, and remain so even at a low temperature; but others congeal even at a very moderate degree of cold, and some are naturally concrete. They are volatilized by a very moderate heat. By a strong heat suddenly applied, they are partially decomposed.

Essential oils are soluble in water in minute proportion. The water acquires the taste and flavour of the oil. This impregnation is commonly obtained by distillation, the distilled waters of pharmacy being thus formed. They are much more soluble in alkohol; some of them unite with the alkohol in every proportion, others in limited quantities; and there are even some which are sparingly dissolved. By distilling ardent spirit from vegetables containing much essential oil, distilled spirits are formed.

Exposed to atmospheric air, these oils lose their smell, are thickened, and become concrete, frequently depositing at the same time crystals of an acid nature. These changes are owing to the absorption of oxygen. The acid is similar to the benzoic, and the thickened oil approaches in its properties to resin.

When heated in contact with atmospheric air, they are more easily inflamed than the expressed oils, and burn with a brighter flame, probably from their greater volatility; the products of the combustion are water and carbonic acid, and the water is in larger quantity than from the combustion of the fixed oils. Hence they differ from the fixed oils in containing a larger proportion of hydrogen,

to which, probably, their greater volatility and inflammability are owing.

The essential oils are oxidated by the acids. Sulphuric acid renders them black, producing at the same time considerable elevation of temperature, and frequently a violent effervescence from the disengagement of sulphurous and carbonic acid gases. Nitrous acid communicates oxygen with such rapidity as frequently to inflame the oil. By a more slow action it forms prussic, malic, and oxalic acids, and converts the remaining oil into a kind of resinous substance. Oxy-muriatic acid produces a similar resinous matter.

With the alkalis these oils combine with difficulty, and the combination can indeed only be effected by long trituration; the compound is slightly saponaceous. Liquid ammonia distilled with the oil combines with it, but very sparingly.

Sulphur dissolves with the aid of heat in any of the essential oils; the solution has an offensive smell. Phosphorus is also soluble in them, and some of these solutions; that, for example, in oil of cloves, is highly luminous.

These oils unite with mucilage or sugar; and by the medium of either, may be suspended in water. They dissolve resin, camphor, and several other vegetable principles.

In general they are used as perfumes, or in the practice of medicine. Some of them enter into the composition of varnishes.

Sect. IX.—*Of Camphor.*

This principle exists in comparatively few vegetables, principally in the aromatic plants. The camphor of commerce is extracted from the *Laurus Camphora*, a native of Japan; the wood of the trunk and branches being exposed to a moderate heat in close vessels, by which the camphor is sublimed. It is at first impure, but is purified by a second sublimation. Camphor is likewise deposited from essential oils when they are long kept, and from some of them, as those of lavender, marjoram, and peppermint, in considerable quantity.

Camphor is solid and tenacious, of a white colour, and semi-transparent; having a strong fragrant odour, and a very pungent taste. It is so volatile, that it quickly loses weight when exposed to the atmosphere; and at a very moderately increased temperature, it sublimes unchanged. If heated under compression, it may be fused.

It is highly inflammable, and burns with a dense light, much smoke, and with a strong smell. Carbonic acid is formed, and a portion of what has been named Camphoric Acid.

Camphor is very sparingly soluble in water, so much being dissolved as merely to communicate a sensible taste and smell. It is abundantly soluble in alkohol; this solution is decomposed by the affusion of water; and if the water be added very slowly, the camphor appears in capillary crystals; a proof that it can assume the crystalline

form. It is also dissolved by the essential and expressed oils; and from these solutions the camphor is sometimes deposited in slender crystals.

The alkalis exert no sensible action on camphor. Among the earths, magnesia appears to act on it, as, when they are rubbed together, the camphor becomes smooth, and easily diffusible in water.

The more powerful acids decompose camphor. Sulphuric acid digested on it renders it brown, and dissolves it. When heat is applied, sulphurous acid gas is disengaged; and if the solution is diluted with water and distilled, it affords a little oil, a portion of tannin, which had been formed in the process, remaining in the residual liquor. Nitric acid dissolves camphor, and the solution separates into two liquids, one of an oily appearance, which floats over another more watery; the former contains a portion of camphor, which may be precipitated by water; the latter is acid. When a large quantity of nitric acid is repeatedly distilled from camphor, the decomposition is complete, and a peculiar acid, the Camphoric as it is named, is obtained in crystals, amounting to half the weight of the camphor. Liquid muriatic, fluoric, and acetic acids, dissolve camphor, forming solutions which are decomposed by water; and water, impregnated with carbonic acid, dissolves a larger portion of it than pure water.

When camphor is mixed with any substance which opposes its volatilization, it is decomposed by exposure to heat. Thus, if one part of it be mixed with six parts of pure clay,—if the mixture be dried gently, and reduced

to a very fine powder, and then made into small balls with water; when these are completely dried, and are exposed to heat in a retort, a decomposition of the camphor ensues, a volatile oil distils over, a portion of charcoal remains, and a quantity of carburetted hydrogen and carbonic acid gases are disengaged, together with a small portion of camphoric acid. This decomposition points out the nature of camphor: as it is resolved principally into a product having the properties of an essential oil, and into charcoal, or carbonaceous compounds, it may be inferred, that its composition is similar to that of the volatile oils, and that it differs from them principally in containing a larger proportion of carbon.

The Oil of Camphor, obtained by this process, is of a golden yellow colour, has an aromatic odour, somewhat different from that of camphor, and an acrid burning taste. It is volatile and inflammable, entirely soluble in alkohol, and separated from this solvent by the affusion of water.

The acid named the Camphoric, obtained in this process, and also by the action of nitric acid on camphor, appears, from the examination of it by Lagrange, to differ from any known acid. It is obtained in slender crystals, which are sparingly soluble in cold water, but more soluble in hot water. It has no odour of the camphor; its taste is slightly acrid and bitter, and it reddens the infusion of litmus. By a gentle heat it is fused and sublimed, and by a stronger heat is decomposed. It is soluble in alkohol, and likewise in the mineral acids. It combines with the alkalis and earths, forming salts named Camphorates, so

unimportant, however, as in an elementary work to require no enumeration.

Camphor appears, in common with some other vegetable proximate principles, to be capable of being artificially formed. By transmitting muriatic acid gas through oil of turpentine, a large quantity of a concrete matter, indistinctly crystallized, is obtained. This, which is at first of a brown colour, becomes perfectly white when washed with water; its odour and taste are the same as those of camphor, with a little of the turpentine flavour, which is, however, removed by sublimation from charcoal and lime. It is volatile, inflammable, soluble in alkohol and in oils, and precipitated by water. The only differences observed between it and natural camphor are in their relations to the acids, artificial camphor not being so easily dissolved. A portion of this substance is obtained from oil of turpentine alone, by a very gentle heat; whence it might be concluded, that, as obtained even by the action of muriatic acid, it pre-exists in the oil; but this is refuted, and the actual formation of it established, by the largeness of the quantity in which it is obtained, seven ounces and a half being procured from a pound of oil.

Sect. X.—*Of Resin.*

This principle, as it exists in vegetables, is often combined with gum, or with essential oil. From some plants,

however, it is obtained by exudation nearly pure; or if combined with a portion of essential oil, this may be removed by volatilization, and its characters, in its insulated form, can thus be determined.

Resins, if at first liquid as discharged by the plant, soon become concrete. They are brittle, and have a smooth conchoidal fracture, with peculiar lustre, are more or less transparent, and usually of a yellow or brown colour. Frequently they are odorous and sapid, though others have neither taste nor smell.

They melt at a moderate heat, but cannot be volatilized unchanged. When heated to ignition with the admission of the air, they burn with a dense flame. Heated in close vessels, they suffer decomposition, water, with a portion of empyreumatic acid, much carburetted hydrogen and carbonic acid, and charcoal, being the products. They appear to consist, therefore, of carbon, hydrogen, and oxygen, and probably differ from the essential oils in the inferior proportion of hydrogen.

Resins are insoluble in water, and they suffer no change from the action of the air; hence their adaptation, under the form of varnishes, to prevent substances from being acted on by air and humidity. In a very humid atmosphere, however, they become soft.

They are soluble in alkohol, and likewise in ether, these solutions being decomposed by the affusion of water. They are also dissolved by essential and expressed oils, and the chemical action of camphor on them is marked by its rendering them quite soft, and nearly liquid.

The fixed alkalis dissolved in water, digested on resins,

dissolve them, and even in the state of carbonate, or in that of compound salts, with a slight excess of alkali, exert this solvent power. The action of ammonia is more weak.

The more powerful acids decompose resinous matter. Sulphuric acid at first dissolves it, but, continuing to act upon it, progressive changes of composition take place, tannin is formed, and ultimately the residual matter is carbonaceous. Nitric acid produces at first decomposition, the resinous matter being converted first into a substance having characters intermediate between resin and extract, and by farther changes into a variety of artificial tannin. Acetic acid dissolves resins, apparently without altering their composition.

A number of resinous substances are employed in medicine, or in the arts,—such are copal, mastich, sandarach, animi, and the resins from the juice of the different species of pine. These have the same chemical properties, or with differences comparatively so unimportant, as not to require particular enumeration. A peculiarity of mastich is, that it is not entirely soluble in alkohol, and the part which remains undissolved approaches in its characters to caoutchouc, being glutinous and elastic. Copal, too, is more sparingly soluble in alkohol than the others, forming rather a kind of viscous mass; camphor renders it completely soluble. Sandarach and elemi are partially soluble in oils.

Resins are employed in the formation of varnishes, being dissolved either in alkohol, or in essential or expressed oils. The former are named Spirit Varnishes; they dry

quickly, but have the disadvantage of being liable to scale; and to obviate this, by giving a degree of tenacity, a portion of an essential oil, as that of turpentine, is often added. The latter dry more slowly, and are liable to remain a considerable time clammy. The essential oil employed is usually that of turpentine; the expressed oil that of lintseed, rendered drying by having been expressed by heat; and these are often mixed together. Copal forms the basis of the finer varnishes, but there is considerable difficulty in dissolving it; the addition of a little camphor best promotes its solution, either in oils or in alkohol.

The name of GUM-RESIN has been applied to a number of substances which have long been employed in the practice of medicine, and which, from the action of solvents on them, appear to be compounds of gum and resin, in different proportions;—such are, aloes, assafætida, ammoniac myrrh, and others. They are solid and usually brittle, have often a strong taste and smell, and exert considerable activity on the animal system. Their chemical properties appear to be those of their immediate principles, gum and resin, slightly modified; they are usually insoluble either in water or alkohol; those in which gummy or extractive matter predominates, as aloes, are more completely dissolved by water; and those in which resin is more abundant, as myrrh, are dissolved more easily by alkohol; they are in general dissolved by alkohol diluted with one or two parts of water. Alkaline solutions dissolve them; acids decompose them; and in these decom-

positions they are not so easily converted into artificial tannin, as the pure resins. They are decomposed by heat, and with the usual products of the decomposition of vegetable matter, afford a portion of ammonia.

A substance which used to be ranked as a gum-resin, GUAIAC, appears, from the observations of Mr Brande, to have some peculiar properties. It displays in particular striking changes of colour from the action of oxygen, and of the acids; its solution in alkohol yielding, when decomposed by oxy-muriatic acid, a precipitate of a beautiful pale blue colour; when decomposed by sulphuric acid, one of a pale green colour; and from the action of diluted nitric acid a liquid is obtained, which is at first green, afterwards blue, and brown, and affords precipitates of the same colour, on the addition of water. In the direct action, too, of the acids on guaiac, changes of colour are produced,—sulphuric acid forming a solution of a deep-red colour, and nitric acid producing a deep green tint; the nitric acid is rapidly decomposed, and oxalic acid, with a substance more completely resinous, are obtained.

BALSAMS are vegetable products, which consist chiefly of resinous matter, with essential oil, but which afford, also, when submitted to different processes, a portion of a peculiar acid, the Benzoic; and the presence of this acid gives the peculiarity of composition which is hence supposed to constitute a balsam.

Their chemical properties are, of course, derived from

the principles of which they consist. They are insoluble in water, but abundantly soluble in alkohol, their solutions being decomposed by the addition of water,—from the precipitation of their resinous matter. By distillation with water, they afford, in general, a small quantity of essential oil. The acid is extracted from them, either by applying a gentle heat, when it is volatilized; or by maceration in water, when it is dissolved; or, lastly, by boiling them with an alkali or earth with which the acid unites, and from which it may be afterwards separated by the addition of another acid.

The principal balsams are those of Tolu and Peru, as they are named, Storax and Benzoin, the latter being concrete, the former fluid, but thick, and even becoming solid from age; they are odorous and pungent, and are regarded principally as articles of the materia medica.

Sect. XI.—*Of Extract, or Extractive Matter.*

By expressing the juices of recent herbs, or by boiling the leaves, bark, or wood of vegetables, and evaporating, in either case, the liquor to a thick consistence, preparations are obtained, which, in pharmacy, have been long known by the name of Extracts. It is obvious that these may consist of various proximate principles, which the water has dissolved. But it has likewise been supposed, that a peculiar principle generally forms the basis of them.

This has accordingly been distinguished by the appellation of Extract; and distinctive properties have been assigned to it. Of these it is necessary to take notice, though the existence of this as a peculiar principle, I shall have to remark, is liable to much doubt.

Extract is said to be soluble in water, but to become gradually insoluble from exposure to the air, especially at a high temperature. Vauquelin has remarked, that the juices containing it are colourless, as they exude from the plant, but that they become yellow or brown from exposure to the air. If evaporated, pellicles soon form on its surface, and the solid matter procured by continuing the evaporation, cannot be again entirely dissolved in water. Fourcroy likewise has observed, that the decoction of a vegetable which affords extract becomes turbid as it boils; the precipitated matter cannot be dissolved by an addition of water; and the longer the boiling of it is continued, and the more freely the air is admitted, the larger is the quantity of it formed. He concludes, therefore, that the insolubility is the consequence of the oxygenation of the extractive matter, and the facility of combining when it is in a humid state with oxygen, has been assigned as a character of this principle. Saussure, in exposing solutions of extractive matter to atmospheric air in close vessels, found the oxygen of the air to be consumed, and an equivalent portion of carbonic acid formed, while precipitates had been deposited from the liquors. He inferred, that in thus losing a portion of carbon by combination with the oxygen of the air, part of the oxygen and hydrogen of the extractive matter likewise combine to form water,

and that the residual matter has thus an enlarged proportion of carbon. It is quite insipid and inert, and the loss of power which many active medicinal plants sustain by boiling in water, without any volatile principle being dissipated, has been ascribed to these changes in the extractive matter in which their powers are supposed to reside.

Extract is soluble in alkohol, and the solution is not decomposed by water. This property of equal solubility in water and alkohol, and that which follows from it, of the solution in the one fluid not suffering decomposition from the other, has been assigned as another character of this principle not belonging to any other—gumresin, which approaches nighest to it in this respect, being only partially soluble in either, and its solution in the one in which it is most largely dissolved being decomposed by the other.

Oxy-muriatic acid converts extractive matter into a concrete substance of a deep yellow colour, insoluble in water, but soluble in alkohol, and in alkaline solutions.

Argil exerts an affinity to it, and forms an abundant flocculent precipitate with it from infusions in which it is dissolved. Several metallic salts have a similar effect, in consequence of the affinity between extractive matter and metallic oxides.

Extractive matter, in the spontaneous decomposition which it suffers in a humid state, exhales ammonia, and this alkali in part saturated by acetic acid, is afforded by it when it is decomposed by heat.

In reviewing the characters assigned to this principle, and the facts connected with its chemical history, there is room to doubt if its existence is fully established. There

is no process by which we can be certain of having obtained it in an insulated state; as it exists either in vegetable juices, or as obtained by decoction from any of the parts of plants, it necessarily must be in a state of intermixture, and the properties assigned to it, therefore, may merely arise from modifications produced by such intermixture in other known principles. Some of these properties, too, such as that of absorbing oxygen when in a humid state, or of exerting an affinity to argil or metallic oxides, belong to other principles. And what further throws doubt on the opinion which regards it as a distinct principle, is that even the properties assigned as characteristic of it are not uniform, the facility of decomposition, when in a humid state, from the action of oxygen, being sometimes for example possessed by a variety of extractive matter, without the equally distinctive quality of equal solubility in water and in alkohol.

Sect. XII.—*Of Tannin.*

The property of astringency in vegetables is indicated by a peculiar styptic taste, and by the power of corrugating the animal fibre, displayed in the operation of tanning. A peculiar chemical phenomenon had also been discovered to be connected with it, which hence came to be regarded as its test, that of producing a dark purple colour with the salts of iron, the power of producing this

belonging to all the vegetable astringents, and nearly in proportion to their astringency. It was afterwards discovered that a peculiar acid exists, in the more powerful vegetable astringents, and which in particular being abundant in galls, received the name of Gallic Acid. This acid, it was further found, struck the same dark colour with the salts of iron; hence it was concluded to be the principle common to astringents, and that on which their astringency depends.

An evident objection, however, to this opinion was, that the acid itself has no great degree of astringency; it was further found, that the colour it produces with the salts of iron is much less deep than that produced by the infusion of a vegetable astringent, a proof that some other substance exists in the infusion, on the action of which the production of the colour, in part at least, depends. Another principle has been accordingly discovered, which is rather to be regarded as the principle of astringency. Being the chief agent in the operation of tanning, it has received the name of Tannin, and for its discovery we are indebted to Seguin. The experiments by which he established its existence, consist in adding to the infusion of a vegetable astringent, as of galls or oak-bark, a solution of animal gelatin, as of glue or isinglass. A copious precipitate is immediately formed, which consists of the gelatin in combination with tannin; the gallic acid, mucilage, or any other principle contained in the astringent, remaining in the liquor above.

By this process tannin is not obtained in an insulated state; and though various methods have been employed,

it is not very certain if any of them afford it perfectly pure. The simplest is to add lime-water to an infusion containing tannin; a precipitate is formed which consists of the tannin combined with lime; and if this be treated with diluted nitric or muriatic acid, the lime is abstracted, and the tannin remains. Another is, to add sulphuric acid to a strong infusion; a precipitate is thrown down, consisting principally of tannin combined with the acid; it is dissolved in boiling water, and the acid is abstracted by the addition of an alkaline carbonate, the tannin being precipitated if an excess of water is not present.

Tannin, by evaporation of its solution, may be obtained in the solid form. It is friable, has a resinous-like fracture, is of a brown colour, or, according to Lagrange, a white colour, which becomes brown from the action of the air; its smell is peculiar, and its taste rough and bitter.

It dissolves in cold water, but more abundantly when the temperature is raised. It dissolves in alkohol of the usual strength, but, according to Richter, is insoluble in alkohol highly rectified.

From the observations of Seguin and Lagrange, it appears in its humid state to be very susceptible of oxygenation. When its solution is exposed to the air, pellicles form on its surface from this cause, and a similar change is produced by exposure to oxygen, or to oxy-muriatic acid gas. By oxygenation it acquires, according to Lagrange, the power of reddening infusion of litmus. It is little liable, however, to spontaneous decomposition, and is even a powerful antiseptic.

Tannin is precipitated from its solutions by the acids, combinations of the acid, and the tannin being established in different proportions, one forming an insoluble compound, and another one which is dissolved. Nitric acid, after precipitating the tannin, if concentrated, re-acts on it, and decomposes it. Oxy-muriatic acid, according to Lagrange, converts it into gallic acid.

The alkalis combine with tannin; a solution of potash or soda, first precipitates it, but soon re-dissolves it, and suspends its powers of combining with gelatin. Ammonia forms apparently a less soluble compound. The alkaline carbonates have nearly similar effects. Lime, barytes, strontites, and magnesia, form with it compounds of sparing solubility; and similar combinations are established even when the carbonates of these earths act on an infusion containing it, so that the tannin is entirely precipitated.

Tannin appears to exert strong attractions to the metallic oxides. Precipitates are thrown down from the greater number of metallic salts by the infusion of galls, which appear in general to consist of the oxide, the base of the salt united with tannin. These combinations are even established by boiling the infusion on the pure oxide; and by oxide of tin or zinc the whole tannin is thus abstracted. The most important combination of this class is that with oxide of iron. It is in consequence of its formation, that the infusions of the vegetable astringents strike so deep a colour with the salts of iron; for although the gallic acid is often associated with tannin, and gives a similar colour, it does so much more faintly, and the intensity of the co-

lour depends chiefly on the tannin. The iron requires to be in a certain state of oxidation for its production, the colour being faint when it is at the *minimum*, while, if more highly oxidated, it is deep; a difference owing partly perhaps to the relation of the oxide itself in these different states to tannin, but partly also, as has been already explained, to the difference in the force of affinity with which it is retained in combination by the acid of the salt, the affinity being weaker at a high than at a low state of oxidation, and hence the combination of the oxide with the tannin being more easily effected. The acid of the salt re-acts on this compound, and in some measure retains it dissolved. This combination is the basis of writing-ink, and of the black dyes. The essential ingredients of the former are infusion of galls and sulphate of iron; by their mutual action the compound of tannin and oxide of iron is formed, which the gallic acid of the infusion, and the sulphuric acid of the salt, contribute to hold suspended or partially dissolved; a portion of gum is added, to give sufficient consistence to the liquid, and frequently a little sugar to give the ink lustre. The decay of ink from age is probably owing to the decomposition of the tannin from the slow but continued action of the metallic oxide and the sulphuric acid on it. In the formation of the black and purple dyes, different astringents are employed, besides the gall-nut, particularly the bark of some species of willow, logwood, and sumach.

The most important and characteristic chemical property of tannin, is that displayed in its relation to animal gelatin. They combine with much facility, forming from a

state of solution a soft flocculent precipitate, which on drying becomes hard and brittle. The tannin of different vegetables combines with different proportions of gelatin. The combination is influenced, too, with regard to the relative quantities that combine, by the concentration of the solution of gelatin, the quantity of precipitate being greater when the solutions are mixed in a concentrated state; and also by the quantity in which one is added to the other, an excess of gelatin re-dissolving part of the precipitate, or rather forming with the tannin a more soluble compound.

On the formation of this combination depends the art of tanning. The skin of an animal, when freed from the hair, epidermis, and cellular fibre, (which is done in the manipulations of the art, principally by the action of lime), consists principally of indurated gelatin. By immersion in the tan-liquor, which is an infusion of oak-bark, or other powerful astringents, the combination of the tannin with the organized gelatin, which forms the animal fibre, is slowly established, and the compound of tannin and gelatin not being soluble in water, and not liable to putrefaction, the skin is rendered dense and impermeable, and not subject to the spontaneous change which it would otherwise soon undergo. To render it equal throughout the whole substance of the skin, the action of the tan-liquor must be gradual, and hence the tanning is performed by successive immersion of the skin in liquors of different strength. A portion of the extractive matter of the infusion appears also to enter into the combination. The skin increases in weight from one-fifth to one-third.

Tannin decomposed by heat affords an acid liquor, a brownish oil, and a considerable quantity of carbonic acid, a light spongy charcoal forming the residuum.

An important fact in the chemical history of this principle, is its artificial formation. It had been known to be developed by heat, in substances in which it did not previously exist. Mr Hatchet observed, that it is produced in the action of nitric acid on carbonaceous compounds; and extending his experiments, he has shewn, that it is formed in the action of sulphuric and nitric acid on resins, gum-resins, bituminous substances, and many other varieties of vegetable matter, and even from a number of animal substances. Those which were carbonaceous yielded it most readily; hence in many of them the previous operation of charring favoured the production of tannin; from the same action sulphuric acid produced it more readily than nitric acid, or the previous action of sulphuric acid favoured its production by the action of nitric acid; or, lastly, if nitric acid alone were employed, it required, with regard to a number of substances, to be used in large quantity, and to be repeatedly distilled from them. The product obtained by all these operations has the general qualities of tannin; its taste is astringent, it combines with gelatin, and its relations to other chemical agents are similar to those of this principle. Mr Hatchet observed, however, that it differs somewhat in its properties as produced in these processes, and he has marked three varieties of artificial tannin:—the *first*, formed by the action of nitric acid, approaching nearest to natural tannin, and differing from it only, indeed, in not being decomposed by

the continued action of nitric acid: the *second*, formed by the repeated distillation of nitric acid from vegetable resins, gum-resins, and balsams, and differing from the other in the colour of the precipitates it forms with gelatin: the *third*, produced by the action of sulphuric acid on the same substances, less energetic in its action on gelatin and skin, and therefore most remote from natural tannin. These differences probably depend on slight differences in the composition which constitutes this principle. Nitrogen does not appear to enter into the composition of the last variety, to which he supposes its less powerful action may be owing.

Proust remarked, that even natural tannin is not uniform in its qualities, but differs as afforded by different vegetables, whence he concluded that there are varieties of it, as there are of several other vegetable proximate principles. Mr Davy suggested, that such differences might arise from the presence of other principles capable of modifying the action of tannin, and stated some facts in proof of some of these peculiarities depending on this cause. It is not improbable, however, that slight variations in the composition may in natural, as well as in artificial tannin, produce diversities of properties.

The analysis of the principal astringents was undertaken by Mr Davy, with the view of determining the proportion of tannin they contain. Galls contain it in largest quantity. Oak-bark affords a less proportion, from the predominance of the ligneous fibre. Catechu yields about half its weight of it, and kino appears to contain even a larger proportion. In the greater number of these, the

tannin has been supposed to be combined principally with mucilage and extract, a supposition, however, which Dr Bostock has rendered doubtful. Tannin is generally accompanied with a portion of gallic acid, but this acid has been supposed to be often present in vegetables, without any sensible quantity of the tanning principle.

A principle exists in some vegetables, which appears to have some relation to tannin, the nature of which is not yet well understood. It has the character of forming with tannin an insoluble precipitate, whence Seguin supposed it to be analogous to animal gelatin, a supposition which has no probability, as Dr Duncan has shewn. From its existing in several of the species of cinchona, he has given it the name of Cinchonin.

Sect. XIII.—*Of Gallic Acid.*

There exist in the juices of many plants, at certain periods of their vegetation, peculiar acids, and the same or other acids are likewise found combined with some of the vegetable proximate principles, or united with alkaline or earthy bases, forming what have been named the Essential Salts of Plants. Of these native vegetable acids, seven have been usually enumerated, the Gallic, Malic, Citric, Oxalic, Tartaric, Benzoic, and Acetic. There

may be added to the number, the Moroxylic, an acid of later discovery, and the Prussic, though the latter has been more usually ranked among the substances belonging to the animal kingdom. These acids have a compound base of carbon and hydrogen, and differ principally in the proportions of their elements; hence they are convertible into each other. The oxalic appears to be the one most highly oxygenated, and it is it into which the greater number of the others are ultimately changed.

Gallic Acid, the first of these, and the history of which is to be given under this section, has an intimate connection with tannin; they are generally associated in the vegetable astringents, and they are similar in some of their most striking chemical relations. It derives its name from the gall-nut, in which it exists in large quantity, and from which it is usually obtained. Its presence is shewn by the power which the infusion of galls has in reddening litmus; and it may be procured by a process given by Scheele,—merely allowing a strong infusion to remain in a vessel imperfectly inclosed for some months; a sediment is deposited; this being washed with cold water, and dissolved in boiling water, crystals of a greyish colour are procured, which are acid. Scheele observed, too, that by distillation galls afford an acid liquor, and a portion of a concrete acid is condensed in a crystalline form. Other methods have been employed, such as abstracting the tannin and extract of the infusion of galls by the affinity of argil, or boiling in the infusion carbonate of barytes, and decomposing the gallate of barytes by sulphuric acid.

But it is not certain, if by either of these processes the acid is obtained in a state of purity, and in particular altogether free from tannin: this principle always adheres, too, to the acid procured by the first process of Scheele, so as to render it capable of precipitating gelatin. There remains, therefore, only the process of sublimation, and this probably gives the gallic acid in its purest state, a minute portion of oily matter only adhering to it, which gives it a slight aromatic odour; it gives no precipitate with gelatin, and therefore does not appear to have any intermixture of tannin. It is inferior, however, to the acid procured by the spontaneous decomposition of the infusion of galls in acid powers, a difference which Lagrange considers as owing to the latter having combined with it a portion of acetic acid. With regard to the different states of this acid, and its purity, there still remains, on the whole, considerable uncertainty.

The sublimed acid is procured in crystals of a white colour, if the heat has not been raised too high, or continued too long, so as to volatilize any vegetable matter, which gives it a brownish tinge. When purified too by solution and crystallization, the acid is white; its crystals are slender prisms, its taste is sour; it reddens, though not very deeply, the vegetable colours, and excites effervescence in the alkaline carbonates; it requires 24 parts of cold water for its solution, but dissolves in less than 2 parts of boiling water, this solution crystallizing on cooling. It dissolves in 4 parts of alkohol, at a medium temperature.

Exposed to heat it fuses, exhaling an agreeable odour;

a portion sublimes, and condenses in crystals, while a quantity of acid liquor is also produced, a large quantity of charcoal remaining in the retort. The concrete acid has nearly the same taste and odour as acid of benzoin. The products of its entire decomposition prove it to be a compound of carbon, hydrogen, and oxygen. By nitric acid it is converted into oxalic acid.

Gallic acid combines with the alkalis and earths. Its salts are named Gallates; they have been little examined: those, with the alkalis, are soluble; they throw down dark-coloured precipitates from metallic solutions, similar to those produced by the acid itself.

This property of forming dark-coloured precipitates with the solutions of metals, is the most important one belonging to gallic acid, as rendering it a re-agent of considerable delicacy. The observations with regard to these, however, are of less value, as the acid has been usually employed in that state in which it has an intermixture with tannin; and we have no accurate comparative experiments with regard to the effects from it in a purer form. Its action on the salts of iron has been principally examined, and this is similar to that exerted by tannin. It strikes a violet or purple colour, more or less deep; but for the production of the colour, the iron requires to be in a high state of oxidation; hence, if added to a solution containing the iron at the minimum of oxidation, no colour is immediately produced; but it soon appears from exposure to the air, probably from oxygen being absorbed. It can also be rendered apparent, however, by causes which cannot change the state of oxygenation, as by dilution

with water, or the addition of a little alkali; and hence probably the reason of its not appearing when the salt contains the iron imperfectly oxidated, is, that the oxide in that state is retained by a stronger attraction in combination with the acid with which it is united, than when the oxidation is more perfect. The colour, from the action of gallic acid, is less deep than that from tannin; and the precipitate is much finer, and remains longer suspended. Perhaps there is some reason to suspect, that the colour is always produced by tannin adhering to the acid, and that the acid, only by its re-action on the precipitate, brings the compound more nearly to a state of solution.

From this relation subsisting between gallic acid and tannin on oxide of iron, arises the advantage derived from their combination, in the formation of writing ink, or black dyes, or the superiority of the infusion of a vegetable astringent, in producing the colour, to either of them in its separate state.

Sect. XIV.—*Of Malic Acid.*

The juices of unripe fruit are in general sour, and this is owing principally to the presence of an acid, which being abundant in the unripe fruit of the apple, has been named Malic Acid. It exists in many other unripe fruits, particularly in the plumb, sloe, barbery, gooseberry, and currant, mixed more or less with another acid, the citric. To obtain it pure, the juice containing it is neutralized by

carbonate of potash, to the saturated liquid acetate of lead is added; the malate of lead which is precipitated, is washed with water, and is then decomposed by sulphuric acid. This acid is also artificially formed in the action of nitric acid on fecula, sugar, and other vegetable principles, and is separated from the oxalic acid, generally formed in the same processes by the addition of lime-water, which forms with the oxalic acid an insoluble compound, with the malic acid one that remains dissolved.

Malic acid, however far its solution may be evaporated, does not crystallize, a property by which it is distinguished from the other vegetable acids. It acquires a brown colour, and becomes thick; its taste is extremely sour, and it reddens strongly the vegetable colours. It suffers spontaneous decomposition. It is also decomposed by heat, affording the usual products of the decomposition of vegetable matter, and in particular a large proportion of carbonic acid gas. It is charred by sulphuric acid. By nitric acid, it is converted into oxalic acid.

This acid combines with the alkalis and earths, forming salts denominated Malates. The alkaline malates are soluble and deliquescent, and even the earthy malates have more solubility than the salts formed by the earths with the other vegetable acids; by a slight excess of acid, they are in particular rendered quite soluble.

Malic acid acts on those metals which have a strong affinity to oxygen, and combines with the oxides of the others, and in consequence of this, decomposes several metallic salts.

Sect. XV.—*Of Citric Acid.*

This acid exists in the lime, the lemon, the tamarind, and many other sour fruits. It may be obtained from them by expression, the acid juice being diluted with alkohol, by which the mucilaginous matter is precipitated, and the alkohol being then evaporated; but the purification by this method is not complete. According to the process given by Scheele, the expressed juice of the lemon, after filtration, is neutralized by carbonate of lime. The citrate of lime thus formed is insoluble in water; it is washed to carry off any remaining mucilage, and is decomposed by adding half its weight of sulphuric acid, diluted with six parts of water, the action being promoted by a gentle heat. The sulphate of lime is precipitated, the citric acid remains dissolved, and by evaporation may be obtained in a crystalline form. The crystallization is more easily effected when a slight excess of sulphuric acid has been added. If the acid is coloured brown, it may be obtained white by a second crystallization.

Its crystals are rhomboidal prisms; they are permanent in the air, or slightly efflorescent; they are soluble at a moderate temperature, in little more than their own weight of water, and in half their weight of boiling water; the solution has a strongly acid taste, and reddens deeply the vegetable colours.

Citric acid, exposed to heat, is decomposed, affording carburetted hydrogen, carbonic acid, and empyreumatic

acetic acid, with a residuum of charcoal. Its constituents therefore are, carbon, hydrogen, and oxygen.

This acid is not, like several others, convertible into oxalic acid; but, when decomposed by the nitric or sulphuric acid, is changed partly into acetic, partly into carbonic acid.

Citric acid combines with the alkalis and earths, and metallic oxides; citrate of potash is soluble, deliquescent, and does not easily crystallize; citrate of soda is likewise very soluble, but crystallizes readily in six-sided prisms, which are efflorescent; citrate of ammonia also crystallizes, though with difficulty, in elongated prisms. The earthy citrates are much less soluble. The metallic citrates are not sufficiently important to require notice.

Sect. XVI.—*Of Oxalic Acid.*

This acid exists abundantly in the juice of the leaves of the sorrel, (oxalis acetosella), combined with a portion of potash not sufficient to neutralize it. This salt, the super-oxalate of potash, is obtained by expressing the juice, allowing the impurities to subside, and clarifying it more completely by boiling it with water, in which a small portion of fine clay is suspended. After due evaporation, the salt crystallizes, and is purified by a second crystallization.

From the super-oxalate of potash the oxalic acid may be procured, according to the process given by Scheele, by adding to its solution acetate of lime, as long as there

is any precipitation; the oxalate of lead, being washed, is decomposed by sulphuric acid, which combining with the oxide of lead, the oxalic acid is disengaged. This acid can also be formed by an artificial process; and as this is easily conducted, it is more frequently obtained by it than from the native salt. The process consists in oxidating sugar by nitric acid. One part of refined sugar in powder is put into a retort with three parts of nitrous acid; a strong mutual action is exerted, and nitrous acid vapours are disengaged; when this has ceased, an additional portion of acid is added, and a moderate heat applied; the liquor, on cooling, affords a large quantity of oxalic acid, crystallized in slender prisms. The uncrystallizable liquid, which contains malic acid, being removed, the crystals are purified by solution, and a second crystallization. The acid is in this process formed not merely from the oxygenation of the sugar by the nitric acid, but from more complicated changes of composition not well determined. It is obtained, by a similar process, from fecula, gum, and several other vegetable products.

Oxalic acid crystallizes in slender four-sided rhomboidal prisms; the crystals, when pure, are white and transparent. Their taste is sour, and they redden deeply the vegetable colours. They are soluble in twice their weight of cold water, and in an equal weight of boiling water. They are also soluble in alkohol.

Exposed to heat, oxalic acid suffers decomposition. The products are an acid liquor, with a quantity of concrete acid, which condenses in the neck of the retort, and which is the oxalic acid extremely pure; much carbonic

acid, and carbonic oxide, or carburetted hydrogen gases, are disengaged; there is scarcely any empyreumatic oil; it may be inferred, therefore, that there is little hydrogen in the composition of this acid, that it contains a large proportion of carbon, and, probably from its being formed from the other vegetable acids by processes communicating oxygen, that it contains also a considerable portion of this element. It suffers decomposition from the action of the more powerful acids.

This acid exerts affinities of considerable strength to the alkalis and earths. Its salts are named Oxalates. Oxalate of potash, if neutral, is not easily crystallized, but with even a slight excess of acid, readily assumes a crystalline form, and the native super-oxalate may be obtained in crystals of considerable size, white, permanent in the air, and abundantly soluble in water. Oxalate of soda, when neutral, is much less soluble; but with an excess of acid, is more soluble, and more disposed to crystallize. Oxalate of ammonia is abundantly soluble when neutral, and with a slight excess of acid, is obtained, by slow evaporation, crystallized in quadrangular prisms. The earthy oxalates, with the exception of oxalate of argil, are of very sparing solubility. The acid appears to exert a strong affinity to lime, attracting it from any other acid, as the lime, on the other hand, attracts the oxalic acid from any other salifiable base; and the compound being of very sparing solubility, its formation affords a very delicate test, either of lime, or of the acid itself. The metallic oxalates present no fact of any interest with regard to their history.

Oxalic acid is principally employed as a test of lime.

The native super-oxalate of potash, under the name of Salt of Lemons, is used to remove ink-stains, an effect which it produces by dissolving the oxide of iron, which, with tannin, forms the colouring matter of ink.

Sect. XVII.—*Of Tartaric Acid.*

This acid, as it exists in vegetables, is usually combined with potash, forming a salt with an excess of acid,—the super-tartrate of potash. This is deposited in considerable quantity from the juice of the grape during its conversion into wine, or rather from the wine during the slow fermentation it suffers in the cask. It does not appear to be a product of the fermentative process, but pre-exists in the juice of the grape, and is merely separated. It also exists in other fruits, as in the tamarind, of which it forms a considerable part. As first deposited from wine it is impure, having associated with it colouring matter, and tartrate of lime. In this state it forms the Crude Tartar of commerce, named White or Red Tartar, according to its colour. It is purified by boiling it in water, with the addition of a small quantity of fine clay, which attracts the colouring matter. By evaporation it is obtained crystallized, forming the Purified Tartar, Crystals, or Cream of Tartar of the shops.

From this salt the tartaric acid is obtained. The process of Scheele, which is the best, consists in adding to a solution of the super-tartrate of potash in boiling water,

carbonate of lime in powder, as long as any effervescence is excited; the tartrate of lime which is formed and precipitated, being well washed, is decomposed by adding sulphuric acid equal in weight to the chalk that had been employed, previously diluted with half its weight of water, digesting them with a moderate heat; the sulphuric acid combines with the lime, and forms the sulphate, which being of sparing solubility, is separated, while the tartaric acid is dissolved by the water, and by evaporation is obtained in a crystallized form.

The crystals of this acid are usually tabular, sometimes also prisms, white and nearly transparent; their taste is very sour, and they redden deeply the vegetable colours. They are very soluble in water, and form a solution so concentrated as to have an oily appearance.

Tartaric acid is decomposed by heat; it affords a large quantity of empyreumatic acetic acid, with a portion of empyreumatic oil, much aerial fluid, consisting of carbonic acid and carburetted hydrogen, and a bulky charcoal.

It combines with the alkalis and earths, forming salts, properly named Tartrates, though from this acid having the name of Tartarous given to it, they are often denominated Tartrites. The acid appears to have a peculiar tendency to enter into simultaneous combination with more than one base, and to form ternary salts, which crystallize with much regularity, and are of uniform composition.

Tartarate of potash is usually formed by neutralizing the excess of acid in the super-tartrate, by the addition of carbonate of potash. From its affinity to water, it is not easily obtained crystallized; by slow evaporation, how-

ever, in a dry atmosphere, crystals in the form of tetraedral prisms are procured. It is deliquescent in a humid atmosphere, and very soluble in water, whence its name of Soluble Tartar. It is very susceptible of decomposition, so far as relates to the abstraction of that portion of alkali which renders it neutral, and hence it is converted by the action even of weak acids into the super-tartrate. This super-tartrate is of more sparing solubility,—requiring 60 parts of cold and 30 of boiling water for its solution. It concretes from the latter solution in small irregular crystalline masses, white and semi-transparent. Its taste is sour. It consists of 57 of acid and 33 of potash, with 7 of water. It is decomposed by heat, and, from the decomposition of the acid, is converted into carbonate of potash.

Tartrate of soda is soluble and crystallizable; a triple salt, the Tartrate of potash and soda, formerly named Rochelle Salt, is formed by neutralizing the excess of acid in the super-tartrate, by adding carbonate of soda. It crystallizes in regular rhomboidal prisms. Tartrate of ammonia is a very soluble salt. The tartrates of barytes and lime are insoluble; those of magnesia and argil do not crystallize, their solutions becoming gelatinous on evaporation.

Tartaric acid acts on some of the metals, and it may be combined with the oxides of all of them by double affinity. From the excess of acid in the super-tartrate of potash, it dissolves several of the metals or their oxides; and from the tendency of this acid to establish ternary combinations, the compounds thus formed are often of uniform composition. The most important of them is that formed with

oxide of antimony, the preparation and properties of which have been noticed under the history of that metal.

Sect. XVIII.—*Of Benzoic Acid.*

This acid exists in the natural balsams, in combination with resin and essential oil, and is obtained from them by the application of a moderate heat,—from the one named Benzoin in largest quantity, whence its name; it rises in vapour, and condenses in slender prisms. It can also be extracted by boiling the benzoin in water, or in larger quantity, by boiling it with a portion of slaked lime, and decomposing the benzoate of lime which is formed, by adding to the liquor when cold muriatic acid; the benzoic acid is precipitated. In all these cases the benzoic acid appears to be merely extracted from the balsam in which it exists, and not formed, as some chemists have supposed; for it is not very probable that the formation of a substance perfectly uniform as obtained by these processes, should be determined by operations so dissimilar; and the chemical agency of some of them, of water for example, appears not to be sufficiently powerful to *cause* its formation. This acid is not only a vegetable product, but belongs also to the animal kingdom, being sometimes found in the urine of gramenivorous animals; also in that of children; and in general, indeed, when the phosphoric acid of that secretion is deficient.

Benzoic acid is, according to the usual method in which it is obtained, in soft light flakes, or in slender needle-like crystals; when pure, white and brilliant. Its taste is pungent, and slightly acidulous. It has a peculiar odour, somewhat aromatic, which becomes strong when it is heated and volatilized. This appears not to be essential to it, but to be derived from a small portion of oily matter derived from the balsam.

This acid is fusible; and when it has become solid after fusion, its surface exhibits a stellular radiated appearance. It is also volatile. Heated on burning fuel, it inflames. Urged with a strong fire in close vessels, the portion that is not immediately sublimed is decomposed, and affords an acid liquid, a quantity of oil more abundant than what is produced in the decomposition of any other vegetable acid: carburetted hydrogen is also disengaged in a considerable proportion, and charcoal is left in the retort. It consists, therefore, of the usual principles of vegetable matter, and, compared with the other vegetable acids, hydrogen predominates in its composition.

It is scarcely soluble in cold water, but is abundantly soluble in hot water. Its hot solution reddens the infusion of litmus. Alkohol dissolves it abundantly; and it is precipitated from this solution by the addition of cold water.

Benzoic acid is not easily decomposed by the mineral acids; they dissolve it, but it is precipitated again by water little changed.

This acid unites with the alkalis and earths, forming salts denominated Benzoates; their properties are not important,

have not been fully described, and scarcely require distinct notice. They are all soluble, even those with earthy bases, and in general crystallizable. The metallic benzoates are equally uninteresting. The acid itself, though retained in the materia medica, has no medicinal virtue, and is employed merely in some officinal preparations in which it has long been an ingredient.

Sect. XIX.—*Of Acetic Acid.*

This, like several of the other vegetable acids, is a native production, and is also capable of being artificially formed. It exists in the sap of vegetables, combined with potash and lime, and is discovered by evaporating the sap, and adding to the solid matter sulphuric acid; the vapours of acetic acid are then perceived by their smell. It is more peculiarly, however, the produce of fermentation; and the production of it even characterizes one stage of that process. It is under it, therefore, that its chemical history is best placed.

Sect. XX.—*Of Prussic Acid.*

Prussic Acid is usually obtained in the decomposition of certain animal substances by heat, from new combinations of the elements of animal matter. But it has lately

been discovered, that it exists as a product of the vegetable system. It had always been observed, that this acid has the peculiar fragrant smell of peach-blossoms; and it had also been observed, that the same smell is perceptible in the distilled waters from the leaves of the cherry-laurel, the seeds of the bitter almond, and some similar vegetables, all of which are more or less narcotic. Bohn at length found, that when potash is added to the water distilled from the bitter almond, it acquires the property of forming a blue precipitate with solutions of iron,—the sure indication of the presence of prussic acid. This has been confirmed by Vauquelin, Bucholz, and other chemists; and similar results have been obtained from the distilled waters of the peach-blossom and the cherry-laurel, even prussiate of potash being obtained crystallized, by distilling them from potash, and the acid being also abstracted from the oil of these plants. Prussic acid, therefore, may be classed with the vegetable acids; but as it is more peculiarly formed from animal matter, and is more analogous in composition to animal substances, its history will be afterwards delivered.

Sect. XXI.—*Of Moroxylic Acid.*

This name has been given by Klaproth to an acid which he extracted from a saline efflorescence, found on the trunk of the white mulberry (morus alba.) He regards it as a peculiar acid, though farther investigation may perhaps connect it with one or other of the acids already

known. In its properties it approaches nearest to the succinic acid.

The saline exudation consists of this acid in combination with lime, and mixed with a portion of extractive matter. The acid was obtained by two processes. In the first, to a solution of the salt a solution of acetate of lead was added; and the precipitate formed, consisting of the acid united with the oxide of lead, was decomposed by sulphuric acid. In the second, the salt itself was decomposed by sulphuric acid, the sulphate of lime being separated.

This acid is similar to succinic acid in its taste. It remains dry on exposure to the air, and is soluble both in water and in alkohol. When heated in a retort, a small quantity of acid liquor is first obtained; a concrete salt next rises, which condenses in the form of prismatic crystals, colourless and transparent; a little charcoal remains in the retort, the sublimed matter is the acid, free from the extractive matter which adheres to it when it is prepared in the humid way. In its pure state, it does not precipitate the metallic solutions; but the native salt from which it is extracted, throws down precipitates from nitrate of silver and acetate of lead.

Sect. XXII.—*Of Wood, Cork, and Suberic Acid.*

The wood of vegetables is the base to which the other principles are attached, forming the structure of the plant,

and the greater part of the substance of which it is formed. Its properties are sufficiently characteristic to give it a claim to be regarded as a distinct principle.

Wood is fibrous in its texture. It is inodorous, insipid, and generally free from colour, though it is also frequently possessed of colour, taste, and smell, from the presence of extractive matter, mucilage, resin, or essential oil, and it is only when these have been extracted by the action of water and alkohol, that the wood can, as a chemical principle, be regarded as pure. In this state it is insoluble in water; even when the water is boiled on it, it is not dissolved. It is equally insoluble in alkohol: and hence it forms the residuum, when any of the solid parts of plants have been acted on by these fluids. From the action of the air, if it is dry, it does not appear to suffer any change; but when humid, it is gradually decomposed, and passes through various intermediate states to that of a black mould, consisting principally of carbon. The oxygen of the atmospheric air is, during this change, consumed, and carbonic acid formed with a portion of water, and the latter, being derived from the combination of the oxygen, leaves carbon predominant. When the air is entirely excluded, wood decomposes with extreme slowness, even though humid, as, for example, when it is buried in the earth. When the action of water is favoured by a high temperature, it appears to produce, however, a decomposition of wood, whence, after the first action of the air, a portion of extractive matter is formed, which the water dissolves; and hence, as Saussure found, it is impossible to

reduce wood by repeated decoctions in water to that state in which it shall not yield by a new decoction with the aid of the action of the atmosphere, a portion of extract.

The alkalis act on wood, and stain it of a dark colour; with the assistance of heat, they soften, and partly dissolve and decompose it.

The stronger acids also act on it. Sulphuric acid chars it, rendering it speedily black and soft. Nitric acid gives it a yellow tinge; and when acted on in large quantity, disengages nitrogen gas, and converts it into oxalic acid, with small quantities of malic and acetic acids.

Wood suffers decomposition from heat, a large quantity of an acid liquor distils over, with a portion of empyreumatic oil; carburetted hydrogen, and carbonic acid gases are disengaged, and a portion of ammonia is produced, which is neutralized by the acid. A charcoal remains, which retains the figure, and even the texture of the wood. The acid procured in this process, was formerly regarded as a peculiar one, and named Pyro-ligneous Acid; but the researches of Fourcroy and Vauquelin have shewn, that it is diluted acetic acid, with an impregnation of empyreumatic oil.

When the air is admitted, and the heat raised to ignition, wood burns. Its combustion at first gives much light, from the extrication of the hydrogen in combination with a part of its carbon; but as this is dissipated, the light is diminished, and there is at length only the red glow of the charcoal. The products of the combustion are principally carbonic acid and water; and if nitrogen be a constituent principle of wood, as its analysis by heat ap-

pears to prove, ammonia will probably also be evolved. An ammoniacal salt is accordingly always found in the soot of fuel.

Wood, from the products of its combustion, or of its decomposition by heat, appears to consist of carbon, hydrogen, and oxygen. It is evidently, of all the vegetable principles, that which contains the largest proportion of carbon; since, independent of the quantity of this principle disengaged in its analysis, in the state of carbonic acid and other elastic products, the residual charcoal amounts to one fourth or fifth of the weight of the original wood. This charcoal always contains a portion of saline matter, which it affords by incineration, principally carbonates, sulphates, and muriates of potash and lime, and also earthy and metallic matter, principally silex, iron, and manganese. Some of these may be essential to the composition, but, from the researches of Saussure, it appears that they are often derived from the soil.

Cork, the external bark of the Quercus Suber, is analogous to wood. It is light, soft, spongy, and elastic; is inflammable; affords a little ammonia by distillation, and is acted on by chemical agents in nearly the same manner. The principal peculiarity with regard to it, and in which it differs from wood, is that, when acted on by nitric acid, it affords a peculiar acid, hence named the Suberic.

To obtain this acid, diluted nitric acid is distilled from cork with a gentle heat, the distillation being continued, until the production of red vapours ceases; the whole,

while warm, is poured into a porcelain bason, placed on a sand-bath, and a moderate heat is applied, stirring the matter constantly until it ceases to exhale white irritating vapours. A concrete soft substance is thus obtained, of a yellow colour, which is to be put into a matrass, and diluted with twice its weight of distilled water; it is heated so as to liquify it, and the solution is filtered from the part that is not dissolved by the water. The solution is coloured, but the colour is removed, either by saturating it with an alkali, and precipitating it by an acid, or by boiling it with charcoal.

Suberic acid is not crystallizable, but may be obtained by evaporation in pellicles, or by precipitation in powder. Its taste is slightly bitter and acid; it reddens the vegetable colours. Exposed to heat, it is volatilized, and forms crystalline flakes on the sides of the vessel. Heated by the blowpipe, it liquifies, then becomes pulverulent, and is sublimed. It becomes brown from exposure to light.

It is sparingly soluble in cold water; boiling water dissolves half its weight of it. Alkohol developes in it an aromatic odour.

Suberic acid unites with the alkalis and earths. Its salts are named Suberates. Those with alkaline bases are soluble, and have a bitter saline taste; those with earthy bases are in general of sparing solubility, but have also the same taste. The mineral acids in general precipitate the suberic acid from their solutions; and they are decomposed by solutions of almost all the metallic salts.

A character peculiar to this acid is, that when a few drops of it are added to a solution of indigo in sulphuric

acid, it causes the blue colour to pass to a green. Lagrange has pointed out other characters by which it is distinguished from the known vegetable acids; from the citric, by not crystallizing; from the gallic, by not precipitating iron black; from the malic, by being obtained in a concrete form; from the tartaric, by its volatility; from the oxalic, by not precipitating the solution of sulphate of copper, and by yielding to it lime. From these, and the phenomena presented in its combinations, he considers it as proved to be different from all the other acids, a conclusion which may be just, though it is to be remarked, that it does not appear to have ever been obtained pure, a portion of extractive matter adhering to it, which may give rise to some of its properties.

The Ligneous Fibre is probably the basis of other vegetable productions, as of the fibres of flax, cotton, and other vegetables which are dressed and wove in cloth. They agree with it in their natural production and texture, and in chemical qualities; particularly in inflammability, insolubility in water or alkohol, and in the changes they suffer from the alkalis, the mineral acids, and other re-agents. Any differences they do present, are probably to be ascribed to their state of aggregation, or to slight modifications of composition.

Sect. XXII.—*Of Colouring Matter, Aroma, Acrid Principle, Bitter Principle, Narcotic Principle.*

From the imperfections of chemical analysis, it has not been always found practicable to refer some important properties of certain vegetable products to any known proximate principles; and in cases of this kind the existence of peculiar principles, in which these properties reside, has been supposed,—a supposition apparently confirmed by the fact, that with the property itself certain peculiar chemical relations are connected. Thus, in vegetable substances possessed of deep or brilliant colours, the colour is frequently found to be capable of being abstracted from the vegetable matter by chemical agents, and transferred, apparently by the exertion of chemical affinities, to others; thus, indicating its existence in a principle, which, however, from its general properties, cannot be identified with any of the established principles. The same conclusion, it has been supposed, may be drawn with regard to the odour of plants. And there are even facts, whence it has been inferred, that bitterness, an acrid quality, and the narcotic quality, sometimes reside in a principle peculiar to each.

The justness of the reasoning on which this kind of classification has been established, may well be called in question; for all these properties, even in vegetables, reside in principles of different kinds. The colour, for example, does not belong to a principle of uniform properties; and there is not more propriety in admitting the existence of a prin-

ciple of colour or of smell than a principle of taste, all such qualities arising from modifications in the composition of any of the varieties of vegetable matter. Still, however, the chemical facts which have been referred to the operation of such principles, and which the present state of the science does not admit of being classed with more precision, require to be stated; they may therefore be so far generalized, keeping in view only the improbability of the assumption that such principles exist. As thus connected merely by an imperfect hypothesis, I place the consideration of them under this section, concluding the history of the individual vegetable products.

1. Colouring Matter.—Many of the vegetable substances used from the richness of their colours in the processes of dying, have chemical relations, whence there is some reason to infer the existence of a principle in which their colour resides. This colouring matter, too, appears analogous in several of its properties to the proximate principle denominated Extract. Still it is not uniform in its chemical characters; farther investigation must determine how far it is connected in its different varieties with any of the other proximate principles; and at present the general facts belonging to the subject only can be stated. They are interesting from their relation to the chemical arts of dyeing and pigment-making.

The colouring matter of vegetables is seldom found insulated. It is either mixed with other principles, or dif-

fused through the leaves, bark, or wood, and is extracted by the operation of certain solvents.

Water, cold or warm, often dissolves it; sometimes it is not soluble in water, but in alkohol; frequently its extraction is facilitated by the action of acids or of alkalis; facts which prove that the colour is in reality attached to principles which are far from being alike.

When dissolved, the colouring matter may often be abstracted from the solvent by substances which appear to exert an attraction to it. Argil and metallic oxides, in particular, exert actions of this kind. The former, if diffused or boiled in a coloured vegetable infusion, frequently attracts the principle in which the colour resides so completely, that the liquor remains colourless. Or if alum be dissolved in a coloured infusion, and it be decomposed by the addition of an alkali, the argil in the moment of its precipitation attracts the colouring matter with a similar effect, and also forms a coloured precipitate. In like manner, if a coloured infusion be boiled with a metallic oxide, or a metallic salt dissolved in the infusion is decomposed by an alkali, it often happens that the colouring matter is attracted by the oxide. It is apparently from similar affinities to the colouring matter that it is often attracted by linen, cotton, silk, or wool, from its solutions; and even where the affinities of these are not sufficiently powerful, they may be rendered capable of attracting it, or the combination may be rendered more permanent, by their being impregnated with another substance, which has towards it a still stronger attraction. Lastly, the shade, and even frequently the tint of colour, are altered by chemical agents.

The alkalis, acids, and various neutral and metallic salts, exert operations of this kind.

On these principles rest in a great measure the art of dyeing, the processes of which are arrangements founded on the affinities of colouring matter, in consequence of which colours are extracted, modified, transferred to the cloth, and rendered more permanent. For this view of the subject we are principally indebted to Bergman. In immersing pieces of wool and of silk, in a solution of indigo in sulphuric acid, largely diluted with water, he observed, that the wool was speedily dyed, and that if the proper proportions were observed, the solution in which it was immersed was deprived of colour. The silk was dyed more weakly; it only lessened the colour of the solution, but did not abstract it entirely. These phenomena he ascribed to the different forces of attraction exerted by these substances towards the colouring matter. In consequence of such an attraction, the sulphuric acid had dissolved the indigo; the silk exerted, however, to the particles of the indigo, a stronger attraction than the diluted acid did in which they were dissolved: it therefore abstracted them from the fluid. And the wool did this still more completely, as having to these particles a still stronger attraction.

Even where the substance to be dyed has little or no attraction to the matter on which the colour depends, so as either not to be capable of abstracting it from its solvent, or of retaining it with such force as to form a permanent dye, the colour may be communicated and rendered permanent by the intermedium of a substance which, having an attraction on the one hand to the colouring

matter, and on the other to the cloth or thread, shall serve to unite them. Such substances are named Mordants, and their use is essential in the processes of dyeing. The principal mordants are alum, acetate of argil, muriate of tin, sulphates of copper and zinc, acetate of copper, oxide of arsenic, tannin, and certain animal substances. Of those of the saline kind, it is not so much the entire salt, as its earthy or metallic base, that serves to fix the colouring matter; and in the course of the process it is often disunited from its acid. Hence the extensive application of alum, and of the solutions of tin, as mordants, from the powerful affinities of argil and oxide of tin to colouring matter. Sometimes mordants are employed rather to heighten the colour, or give it more brilliancy, or communicate a particular shade. With these different views, they are susceptible of a great variety of applications, with regard to the various dyes and the different cloths; and the proper management of them constitutes the principal part of the art of dyeing.

The art of cloth-printing, or calico-printing, in other words, of dyeing in certain colours particular spots of the cloth, or figures impressed on it, while the ground shall be of a different colour or entirely white, depends on the same principles. A mordant is applied by a stamp to the part on which the figures are to be impressed; it thus receives a permanent dye, while the colour of the rest of the cloth is easily discharged, thus leaving a coloured design on a white ground. The mordants principally used in this process, are the acetate of argil and acetate of iron,

these, with logwood, quercitron, and other colouring substances, giving different colours.

The formation of the vegetable pigments, or what are named Lakes, affords another exemplification of the affinities of colouring matter. The colour is extracted by its proper solvent, generally by water; and there is added to the solution some substance capable of attracting and combining with the colouring matter, so as to form a precipitate. Thus, if alum be dissolved in an infusion of brazil wood, and an alkaline solution be added, the argillaceous earth is precipitated, and carries with it the colouring matter, forming therefore a lake. Similar lakes are formed from other coloured vegetables; and the most beautiful of them, carmine, is prepared by a similar process from cochineal, a colouring substance of animal origin.

The vegetable substances used in dyeing are extremely numerous. The colouring matter of the greater number of them, such as all the woods and barks, logwood, brazil wood, weld, quercitron, &c. appears to approach in its characters to extract, and admits, therefore, of few observations as to their chemical history, farther than what have been already stated. Indigo is a substance more peculiar, and with regard to which there are some singular facts. It is in some measure an artificial preparation. The plant which affords it, being cut when ripe, is put into troughs with water, and pressed down. A species of fermentation is soon excited, and a quantity of aërial fluid is disengaged, partly inflammable. The water becomes turbid, and when the process has been sufficiently advanced, it is drawn off into another trough, where it is kept agi-

tated, to promote the separation of the colouring particles. Towards the end of this stage of the operation, a portion of lime-water is added, which still farther favours this separation. The liquor is withdrawn into another vessel, in which the deposition is allowed to go on; and the indigo, which forms its solid matter, is obtained by gentle pressure in the state of a paste, which is dried by exposure to the air, excluding the solar rays. The rationale of the process by which it is prepared is not well understood. The plant, by expression or infusion, affords only a green colouring matter previous to the fermentation; and we have no precise facts from which it can be determined how this fermentation is so easily excited, what are the changes it occasions, or how these are connected with the production of the colouring matter.

Indigo is of a rich blue colour; it is light and friable, has a smooth fracture, is tasteless, and has scarcely any smell. With its pure colouring matter it contains other principles, particularly a portion of gummy and of resinous matter, earth, and oxide of iron. It yields its mucilaginous part to water, but the colouring matter is not dissolved. It is equally insoluble in alkohol, or in ether, a small portion of the resin only being dissolved.

The action of acids on indigo is more energetic and important. Concentrated sulphuric acid dissolves it even in the cold; the solution appears black, from the deepness of its colour, and even when largely diluted with water, retains a deep blue colour. The colour is changed to a green, by the action of a number of substances upon it; as by sulphurous acid, vinegar, ammonia, alkaline sul-

phurets, sulphate of iron; and by some of these the colour is entirely destroyed. The alkaline carbonates throw down from the solution a blue powder, which Bergman named Precipitated Indigo.

The action of nitric acid on indigo, when the acid is concentrated, is even so violent as to inflame it; and when diluted, it still acts on it forcibly, and decomposes it; a substance is formed, which, freed from nitric acid by washing, forms a brown-coloured mass, of a strong bitter taste, requiring a large quantity of water for its solution, and more soluble in alkohol. This is the substance which has received the name of Bitter Principle, and which, as a product of the action of nitric acid on different varieties of animal matter, is afterwards to be noticed. A little oxalic acid is also formed, and a portion of tannin.

Muriatic acid does not act on the colouring matter of indigo, but dissolves the oxide of iron and the earthy matter. The greater number of the other acids act on it in the same manner. Oxy-muriatic acid destroys its blue colour.

The fixed alkalis extract a portion of matter from indigo, but not that in which its colour resides. They dissolve, however, precipitated indigo, but the blue colour gradually changes to a green, and is at length destroyed.

Indigo, when exposed to heat, swells, emits vapours, and burns slowly with a white flame. The residuum consists of earthy matter and oxide of iron. The colouring matter, by destructive distillation, affords carbonic acid, carbonate of ammonia dissolved in water, empyreumatic oil, and charcoal. It consists, therefore, of hydro-

gen, oxygen, nitrogen, and carbon, the proportion of carbon being unusually large.

The chemical properties of this substance are peculiar, and are evidently such as prevent it from being considered as a variety of any other known principle. The application of it to the art of dyeing presents, too, some singular phenomena; for although it is not soluble in alkaline solutions or in lime, yet, by the intervention of other substances, this solution is effected, so as to form a dye-liquor. These, which are in general metallic preparations, as sulphate of iron, or sulphuret of arsenic, appear to operate by abstracting oxygen, by which the indigo is rendered soluble. It at the same time becomes green, but the cloth dyed in the liquor becomes blue on exposure to the air, probably by regaining oxygen.

Woad is a substance produced by a process similar to that followed in extracting indigo from a different plant. It gives a blue colour, which is permanent, but has not the beauty of that from indigo. If this plant, however, be subjected to precisely the same process as that followed in preparing indigo, it affords a blue colouring matter the same; and there can be little doubt, therefore, that the colouring matter of woad is indigo less perfectly prepared.

Annota is prepared, by a process somewhat similar, from the seeds of the Bixa Orellana. It is of an orange colour, is not perfectly soluble in water, but the addition of an alkali renders it more soluble, and gives it a bright orange-yellow colour. Acids form with this liquor an orange-coloured precipitate. It is more soluble in alkohol than in water.

From different species of lichen, is prepared the colouring matter known under the names of Archil and Litmus, so useful to chemists, as the most delicate test of acidity. The plant is reduced to powder; a quantity of alkali is added to it, and it is kept moist; it ferments, and gradually acquires a blue or violet colour; it is then dried. Litmus, or Turnsole, is a similar substance, apparently in a more pure state. The colouring matter is extracted by water; if the solution be kept secluded from the air, the colour entirely disappears; but it is quickly renewed when the air is admitted. It is also soluble in alkohol, and exhibits the same phenomenon. It is instantly reddened by the weakest acid liquor; and hence the watery infusion of it, or paper stained with this, affords a very delicate test.

Aroma.—The odour of plants generally resides in their essential oil; but it has been observed, that there are plants smelling strongly, as the violet or the jessamine, from which either no oil can be procured, or, if obtained in small proportion, it has not that strength of odour which might be looked for, did this quality, as possessed by the plant, depend on it. These plants, too, lose their odour by exposure to a very moderate heat, not sufficient, it has been supposed, to volatilize the essential oil. And hence it has been concluded, that there exists an Aroma or Principle, in which their odour resides; that this is capable of being combined with their other principles, and that it is even

on its presence that the essential oils have usually the odour of the plant.

This hypothesis rests on very feeble grounds. The odour of plants may reside in any of their principles, arising, like other sensible qualities, from modifications of their composition; it does, in different vegetables, exist in principles of different kinds; there is no direct proof of the existence of any subtle principle of this nature; and all the facts supposed to be favourable to the hypothesis admit of explanation, on the supposition that the odour resides in the essential oil; that this is sufficiently volatile to be dissipated at a very moderate temperature; that it may be diffused in atmospheric air, or dissolved by it; and that, suffering chemical changes from long exposure to the atmosphere, it is deprived of much of its smell by age.

Acrid Principle.—There are a number of plants which, in their recent state, are extremely acrid to the taste, and display this acrimony in the irritation and inflammation which they occasion when applied to the skin: yet they lose this peculiar acrimony on being dried, while their more active powers frequently remain. From some of these plants, too, this acrimony is communicated to water or alkohol by distillation from them, though no other property, not even odour, is thus conveyed. It has been concluded from these facts, that there exists a peculiar volatile principle in these plants different from an es-

sential oil, in which their acrimony resides. If its existence shall be considered as probable, however, it has never been obtained in such a state as to be submitted to chemical examination, and all that relates to it is therefore uncertain and obscure.

Narcotic Principle.—The narcotic power belonging to some vegetables, it has been found, is impaired or lost by decoction in water, though, when the operation is performed so as to condense the water volatilized, it is not found to be impregnated with any essential oil; nor are essential oils usually possessed of such active powers. In some cases, the distilled water, as for example that from the leaves of the cherry-laurel, has a narcotic quality; in other cases it has none. From such facts, the existence of a narcotic principle has been inferred.

The loss of narcotic power by decoction, in those cases where it is not communicated to the water distilled from the vegetable which possesses it, is probably to be ascribed, not to the dissipation of any volatile principle, but to changes of composition. Where it is communicated to water, it appears now to be established, that it is the prussic acid. This acid has been discovered, as already remarked, in the cherry-laurel, the bitter almond, and other narcotic plants. It has also been found, that, in its pure state, it is narcotic; and there is therefore every probability in the conclusion, that that quality in these vegetables depends on its presence. But there is no reason

farther to infer that it is the narcotic principle; for there is none to presume that it exists in other narcotics, and it is itself inferior in narcotic power to some vegetable products. A substance has been said to be extracted from opium by the alternate action of water and alkohol, which has even been obtained in a crystalline form; and this matter having been found to be more powerfully narcotic than opium, it has been regarded as the principle on which the powers of that drug depend. The results, however, still rest on authority rather uncertain; if they were admitted, it does not appear that this substance is very powerfully narcotic, and there is no proof of its being contained in any other narcotic vegetable.

Bitter Principle.—It has been supposed, that a principle exists in some of the vegetable bitters, in which their bitterness resides. The properties, however, assigned to it, particularly its equal solubility in water and in alkohol, and its precipitation by certain re-agents, appear to prove, that what has been considered as such is a variety of extract. And were its existence established, the name that has been given to it, implying that it is the principle of bitterness, can with no propriety be assigned to it, since so many substances possess this quality, in which it cannot be supposed to exist. A product of the action of nitric acid on certain vegetable and animal substances has, from its intense bitterness, been distinguished by the name of Bitter Principle. There is no reason to believe, however,

that it is ever naturally formed; and it cannot therefore be regarded as a principle of vegetables. As a product of decomposition, it is afterwards to be noticed.

CHAP. III.

OF THE SPONTANEOUS CHEMICAL CHANGES AND DECOMPOSITION OF VEGETABLE SUBSTANCES.

Besides the peculiar chemical changes to which the individual vegetable products are liable, there is a series of changes of which they are more or less susceptible, arising from the spontaneous re-action of their elements at natural temperatures, which chemists have been accustomed to class together, as forming the general process they have named Fermentation. And of this process three stages have been distinguished, marked as well by the phenomena which attend them, as by the peculiar products they form;—the Vinous Fermentation, of which vinous spirit is the product,—the Acetous, from which acetous acid or vinegar is formed,—and the Putrefactive, in which the elements are disengaged in new combinations in the elastic form. These do not always succeed each other, as it is not every substance that is capable of passing through the changes which constitute each: but when they do, the vinous always precedes the acetous, and this again is terminated by the putrefactive.

Sect. I.—*Of the Vinous Fermentation.*

Saccharine matter is the principle more peculiarly liable to the vinous fermentation. Sweet vegetable juices pass into it readily, as do those substances which are capable of becoming sweet, such as the fecula of grain. When the fermentation commences, the liquor, if transparent, soon becomes turbid; a kind of intestine agitation of it takes place; a quantity of aerial matter is formed, and disengaged; the temperature rises, and this continues until the fermentation is completed, which requires a longer or shorter time, according to the quality of the fermenting liquor; it then becomes transparent, depositing a sediment, and its qualities are found to be wholly changed; it has lost its bland and sweet taste, and acquired a greater or less degree of pungency; and it is capable of acting more powerfully on the living system, producing an exhilirating or intoxicating effect. The elastic fluid disengaged during the process, is carbonic acid gas, accompanied sometimes, in the fermentation of fecula, with a portion of hydrogen gas. No peculiar agency is exerted by the atmospheric air, nor is its presence even necessary to the series of changes.

The process of vinous fermentation is, to a certain extent, dependent on external circumstances. Thus a due degree of temperature is required; it proceeds with most uniformity at a temperature from 50 to 55. At 32° it is checked, and at 60, or higher, it is too rapid, and is liable

to pass, before it is completed, into the acetous stage. A certain extent of dilution with water is also necessary. If the impregnation of saccharine matter is too great, the process is retarded; if, on the other hand, the liquor is too much diluted, it is liable to become sour as the fermentation proceeds. Lastly, the presence of a ferment is in general required. A solution of pure sugar scarcely passes into a state of fermentation, or does so very imperfectly, and rather forms a sour, than a vinous liquor. The substance by which fermentation is excited, is the scum collected on the surface of a liquor already in fermentation, or the sediment which is deposited, Yeast, as it is named. This added to any liquor capable of fermenting, causes the fermentation very soon to commence, and to proceed rapidly.

The nature of the matter in yeast, by which fermentation is excited, has been the subject of research, but is not perhaps altogether ascertained. Rouelle remarked, that it affords ammonia by destructive distillation; and Lavoisier inferred, that it contains nitrogen. From the experiments of Fabroni, Thenard, and Seguin, it appears to be analogous to gluten or albumen, and to be originally derived from those sweet vegetable juices which are capable of fermenting without any addition, as the juice of the grape. According to Fabroni, it is contained in this fruit, and also in the nutritive grains; it is deposited from the juice, or from the infusion of the grains, and if added to another sweet liquor, causes it to ferment; the gluten of wheat, with the addition of a little tartar by which its solubility in water is promoted, has a similar

effect. Thenard obtained from the juice of the gooseberry, by filtration, a substance slightly glutinous, which, added to a solution of sugar, caused it to ferment; and the same substance he found to be deposited from the juices of the grape, apple, and other fruits, during their fermentation. After drying, it is still capable, when added to a sweet liquor, of exciting fermentation; it is scarcely soluble in water, is decomposed by nitric acid, nitrogen gas being disengaged; it is liable to putrefaction, and affords, by destructive distillation, the same products as animal matter. This principle, on the whole, seems to be analogous to vegetable gluten.

Sugar, it has frequently been supposed, is the only vegetable principle susceptible of the vinous fermentation; the fecula of the nutritive grains passing into it, it was imagined, only after having been subjected to the process of malting, in which there is the transition into saccharine matter. It is now known, from the practice of the spirit-distillers of this country, that this preliminary process of malting is not indispensible; they always add a portion of unmalted to malted grain, the former is often even in larger quantity than the other; and the infusions of this pass into the vinous fermentation, on the addition of yeast. Fourcroy and Vauquelin have shewn by experiment, that unmalted grain alone can be made to ferment, and afford a liquor, which, by distillation, gives alkohol. As fecula consists of the same principles as sugar, differing only in the proportions, it is not difficult to conceive, that by the series of changes which fermentation establishes, it may afford the same product.

The theory of fermentation is still imperfectly understood. Its ultimate result is, the formation of a peculiar principle, volatile and inflammable, which can be obtained, by distillation, from the fermented liquor; diluted, and with some degree of intermixture, it forms the common spirituous liquors; and in its pure form, ALKOHOL. But there is still much uncertainty with regard to the changes by which saccharine matter, or fecula, is converted into this product.

Sugar being a compound of carbon, hydrogen, and oxygen, carbonic acid gas being disengaged during fermentation, and no oxygen being absorbed from the air, Lavoisier supposed that part of the oxygen and carbon of the sugar combine, and form this carbonic acid, and that its hydrogen, with the remaining carbon and oxygen, form the alkohol. But to this simple theory the objection is obvious, that the agency of the ferment or yeast, so essential to the process, is not explained. This has since formed a subject of investigation. Fabroni has supposed, that it operates by its carbon attracting part of the oxygen of the sugar, forming the carbonic acid, while its hydrogen and nitrogen combine with the remaining elements of the sugar, and form alkohol. Thenard has given a similar view, the yeast operating, as he supposes, by subverting the equilibrium of affinities established among the elements of the sugar, by the attraction which its carbon exerts to oxygen; it thus forms part of the carbonic acid which is disengaged, and gives rise to the new combinations, whence the remaining carbonic acid and alkohol are produced. A very different hypothesis is advanced by Se-

guin, founded on the supposition, that a portion of water is decomposed in fermentation; its oxygen, he infers, combines with the carbon of the ferment, forming carbonic acid, while the hydrogen combines with the saccharine matter, and converts it into alkohol,—an hypothesis to which there are the obvious objections, that the product of alkohol ought to exceed the quantity of sugar, and that the small quantity of ferment cannot afford the carbon necessary to form the large quantity of carbonic acid disengaged. The subject still requires investigation, particularly with regard to the agency of the ferment: but the ultimate result of the process appears to be, as Lavoisier supposed, the abstraction of much of the carbon and oxygen of the saccharine matter, and hence hydrogen predominates in the composition of alkohol.

From the saccharine juices of fruits wines are formed by fermentation, and by the same process liquors somewhat analogous are formed from the nutritive grains. These fermented liquors differ in their strength and flavour. The wines from the juice of the grape are superior to the others; those from other fruits are weaker, and are acescent, or liable to become so; and the fermented liquors from the nutritive grains, retain some mucilaginous and extractive matter: all these afford spirituous liquors by distillation, the wine of the grape yielding the purest and strongest product. The alkohol which forms the active principle of these varieties of ardent spirit, was usually supposed to pre-exist in the wine, or fermented liquor, and, from its volatility, to be separated merely by the distillation. Fabroni, finding that wine could not be produced by adding

the product to the residual liquor of the distillation, inferred that the alkohol is actually formed during the distillation from new combinations of the principles of the fermented liquor. But it is easy to suppose, that the changes of composition established by the high temperature, towards the end of distillation, may give rise to the circumstance from which this conclusion has been drawn; and the fact, that wine has the power of acting on the living system, peculiar to alkohol, and that with a force proportional to the quantity of this product which it yields by distillation, affords reason to conclude that it contains the alkohol fully formed, or at least in a state very analogous to that in which it affords it.

ALKOHOL is procured from spirituous liquors by repeated distillation; being volatile, it is thus freed from the water with which it is diluted. The process is usually facilitated, however, by certain additions. After the spirituous liquor has been once distilled, by which it is freed, not only from a considerable portion of water which remains in the still, but also from the oily or extractive matter, which gives it peculiar flavour, there is added to it a twelfth of its weight of the pearl-ash of commerce, previously exposed to a red heat. This attracts a considerable portion of water, which forms a dense solution that subsides; the spirit above is poured off, and distilled with the heat of a water bath, a small quantity of alum being frequently added, the acid of which, exerting an attraction to the portion of potash which the spirit may hold dissolved, prevents it from being brought over by its affinity to the

vapour, and thus gives to the spirit a more fragrant odour. The alkohol thus procured, has still water combined with it, and even to an extent which we have not the means of appreciating. It may be obtained, somewhat more concentrated, by repeated distillations, with a very gentle heat, from potash, or from muriate of lime.

Alkohol, as obtained by the usual process, is of the specific gravity of 0.835, in which state it is sufficiently adapted to many of the uses, depending on its chemical agency, to which it is applied. It has been brought, by concentration, to the specific gravity of 800, or 798, at the temperature of 60° : when of the usual specific gravity, 0.835, it contains above 10 of water, which may be abstracted in its higher rectification. The proportions of alkohol and water, at other degrees of specific gravity, have been determined by Gilpin, from a very extensive series of experiments.

Alkohol is colourless and transparent; its odour is fragrant, and its taste pungent; it acts powerfully on the animal system, producing exhiliration and intoxication. It retains its fluidity at the greatest degree of cold hitherto reached; it is highly expansible from heat, and volatile; it evaporates quickly under exposure to the air, and in close vessels boils at 165°. Its vapour transmitted through an ignited tube is decomposed, a large quantity of oxy-carburetted hydrogen gas with carbonic acid are formed, and charcoal is deposited.

Alkohol is highly inflammable. It kindles when the temperature is not much above 300°, when in contact with atmospheric air, and burns with a blue lambent flame,

without any sensible smoke, and, when pure, without any residuum, affording merely water and carbonic acid gas; and the quantity of water that is condensed, exceeds even the weight of the alkohol consumed, so large a portion of oxygen being consumed in the combustion. Lavoisier from this experiment inferred, that 100 parts of alkohol consist of 28.5 of carbon, 7.8 of hydrogen, and 63.5 of water,—a conclusion liable to the objection, that there are no grounds for determining how much of the water obtained in the combustion exists in the alkohol in its entire state, and how much of it in the state of its elements, forming part of the combination itself. The experiment has been more lately repeated by T. Saussure, and from the results, he has given as the proportion of the elements of alkohol, carbon 48.82, hydrogen 15.82, oxygen 41.36; a conclusion still liable to the same objection, that we know not how much of this oxygen and hydrogen exist as the elements of alkohol, or how much of them exist in it in the state of water. From the results of its analysis, by passing it through an ignited tube, he farther found that a little nitrogen (3.5 parts in 100) is contained in it; and Thenard had before found, that the nitrogen of yeast disappears in fermentation, and had inferred, that although not easily detected in the alkohol, it enters into its composition.

Alkohol combines with water in every proportion; and although the properties are not much modified, the combination is marked by the specific gravity of the compound not being the mean of the specific gravities of the two fluids. It is always greater from the condensation that takes place. This condensation is accompanied with a

diminution in the capacity for caloric, and hence, with a rise of temperature. Alkohol diluted with an equal weight of water, forms what is named Proof Spirit.

In consequence of its affinity to water, alkohol precipitates many of the neutral salts from their aqueous solutions. There are others which it does not precipitate, and which it even dissolves. It dissolves potash and soda in their pure form, and may be combined by distillation with ammonia. It also dissolves strontites and barytes in sparing quantities.

The acids combine with alkohol, and some of them decompose it; forming a particular order of compounds, the Ethers, as they are named, to be immediately considered.

Alkohol unites with sulphur, when the sulphur is presented to it in the state of vapour. The compound is a liquid of a reddish colour and fetid smell, resembling that of sulphuretted hydrogen: it becomes turbid on cooling, and sulphur is precipitated from it by the addition of water. Phosphorus is dissolved by alkohol: the solution is rendered turbid, and the phosphorus precipitated on the affusion of water; this being accompanied with a tremulous light. It does not dissolve carbon, nor does it combine with hydrogen.

Alkohol is the solvent of a number of the vegetable proximate principles, as sugar, resin, extract, camphor, essential oil, and several of the acids; hence it extracts the medicinal powers of many vegetables, and is employed in pharmacy, either in its pure form or diluted, to form tinctures. Solutions of resinous substances in it form varnishes.

THE action of the more powerful acids on alkohol is peculiar, and gives rise to an order of compounds, important from their chemical properties. These have been distinguished by the generic appellation of ETHERS. They differ in their qualities as produced by the different acids; but they also agree in the possession of certain general properties; they are highly volatile, odorous, pungent, and inflammable; miscible with water, and capable of combining with alkohol in every proportion. SULPHURIC ETHER, produced by the action of sulphuric acid on alkohol, is the one which has been longest known to chemists.

To prepare sulphuric ether, sulphuric acid is poured on an equal weight of alkohol in a retort; and after they are thoroughly mixed by a gradual agitation, heat is applied by the medium of a sand-bath, a large receiver being adapted to the retort, carefully luted, and kept cool by water. Distillation commences when the temperature is raised to 208°, and a colourless liquid condenses in the receiver. When the quantity of it amounts to about half the quantity of alkohol that had been employed, the heat is withdrawn. The residual liquid is of a dark brown or black colour. If a fresh portion of alkohol, not more than half of the first quantity, be added to it when it is cold, an additional portion of ether will be procured by a new distillation.

The ether condensed in the receiver by this process, is weak from the intermixture of water, and is usually also impure from the presence of a portion of sulphurous acid.

It is rectified by agitating it with sub-carbonate of potash, or muriate of lime, and distilling it a second time by a very gentle heat, putting into the retort from which it is distilled a small quantity of black oxide of manganese.

The theory of the formation of ether is still involved in some obscurity. Fourcroy and Vauquelin, from an experimental investigation of the process, inferred, that the sulphuric acid does not suffer decomposition; they supposed, therefore, that it acts merely by a resulting affinity, causing part of the oxygen and hydrogen of the alkohol to combine and form water; the balance of affinities among its elements being thus subverted, a portion of its carbonaceous matter is precipitated and diffused through the residual liquid, and the remaining elements entering into new combination from the ether.

The principal difficulty is to explain the agency of the acid, for the proof is not clear that no portion of it is decomposed; and the fact, that of the other acids, those form ethers most readily, which yield oxygen with greatest facility, rather favours the conclusion, that the communication of oxygen from the acid is necessary to establish the series of changes whence these products are formed. Still the series of changes themselves, which occur in the formation of sulphuric ether, appear to be sufficiently ascertained. There is evidently a formation of water, as the residual liquor is considerably diluted, and this appears to be derived principally from the combination of the oxygen and hydrogen of the alkohol; there is also a precipitation of a carbonaceous matter somewhat bituminous, which must equally be derived from the alkohol; its remaining elements

from the other; for no trace of the acid itself, or of its base, can be discovered in its composition. Hence sulphuric ether appears to differ from alkohol principally in the predominance of hydrogen; and to this its greater levity and volatility may be owing. It accordingly affords only water and carbonic acid in its combustion. From the quantities of these Cruickshank inferred, that the proportion of carbon to hydrogen is as 5 to 1, while in alkohol he supposed it to be as 8 or 9 to 1. Saussure has more lately stated the composition of sulphuric ether at 59 of carbon, 19 of oxygen, and 22 of hydrogen.

There are some other products disengaged in the process by which sulphuric ether is formed. Towards the end of the distillation, an oily-like fluid condenses, which the chemists have named Oil of Wine, and which some have supposed to be a compound of ether and sulphurous acid, while others have regarded it as of a composition analogous to ether, but containing a larger proportion of carbon. There is also disengaged at this stage of the process a considerable quantity of olefiant gas.

Sulphuric ether is a fluid extremely light; its specific gravity, when it is highly rectified, being so low as .716. It is colourless and transparent, has a pungent taste, and a penetrating, rather fragrant odour. It is highly volatile, evaporating rapidly at natural temperatures. It boils under the usual atmospheric pressure at 98°, and, *in vacuo*, boils at a temperature even below 32 . In its spontaneous evaporation, it absorbs a considerable quantity of caloric, so as to produce much cold. It congeals at —47°. It is inflammable, burns with a clear white flame, and without

smoke, producing by its combustion water and carbonic acid. Its vapour, diffused in atmospheric air or oxygen gas, explodes when kindled.

Sulphuric ether is soluble in water, requiring about 10 parts for its solution. It dissolves in alkohol in every proportion. On the fixed alkalis or earths it exerts no action; with ammonia it combines by distillation. It dissolves sulphur and phosphorus in small proportions; and it resembles alkohol in the solvent operation it exerts on a number of the vegetable proximate principles.

Nitric Ether is formed by the action of nitric acid on alkohol; but, from the violence of this action, the process is difficult, and requires to be conducted with much caution. Various methods have been employed; that of Woolfe is generally preferred. It consists in adding to four parts of nitre in coarse powder in a retort, by successive small portions, a mixture of four parts of sulphuric acid, and rather more than three parts of alkohol, connecting the retort with a range of receivers, kept cool; nitric ether is formed and volatilized without the application of heat, and is condensed by passing the gaseous product through water, or through a solution of muriate of soda in the receivers. It floats above the liquor, and is purified from any free acid by agitation with lime, and a second distillation with a gentle heat.

The theory of the formation of nitric ether is still more obscure than that of sulphuric ether. It is sufficiently ascertained, however, by the experiments of Pelletier and Bayen, that the acid is decomposed; the alkohol likewise

suffers decomposition, portions of oxalic and acetic acid with water are formed, but there is no deposition of carbonaceous matter, as there is in the formation of sulphuric ether. A considerable quantity of elastic fluid too is disengaged, which, according to the researches of Thenard, consists of nitrogen, carbonic acid, and nitrous oxide, holding a portion of nitric ether dissolved. This chemist has farther found, that after the free acid of the nitric ether at its first distillation is abstracted by lime, acidity is regained, when it is kept for some time either with or without the access of air; and this arises from the production of nitric and acetic acids, the elements of which must therefore exist in the composition of nitric ether. He hence concludes, that in the formation of this ether, a portion of the oxygen of the acid combines with much of the hydrogen, and part of the carbon of the alkohol forming water and carbonic acid; nitric oxide, nitrous oxide, and nitrogen, being disengaged; the elements of the remaining acid, he supposes, enter into combination with the remaining elements of the alkohol, and form ether. From the products of its analysis when it is decomposed by heat, he infers, that 100 parts of nitric ether are composed of 14.49 of nitrogen, 28.65 of carbon, 48.52 of oxygen, and 8.54 of hydrogen.

Nitric Ether has an odour strong, but less fragrant than that of sulphuric ether; it is light, volatile, and inflammable. When highly rectified, its levity is such that it floats on water; and its volatility is so great that it instantly evaporates when poured from a bottle, and it boils at 70° under the usual atmospheric pressure; it requires 50

parts of water for its solution, but combines with alkohol in every proportion.

When a smaller portion of nitric acid is added to alkohol than is sufficient to convert it entirely into ether, a product is obtained on distillation, having a fragrant odour, and somewhat acidulous, which has been named Spirit of Nitrous Ether, and has been regarded as nitric ether largely diluted with alkohol.

Muriatic Ether.—The action of muriatic acid in its common state on alkohol is so inconsiderable, that no product which can be regarded as a muriatic ether can be obtained from it. By the action of oxy-muriatic acid on alkohol, a liquid is obtained which has been regarded as etherial, but is rather of an oily nature. It appears, however, that when the acid is brought to act on the ether in a very concentrated state, a proper ether is formed; it is thus procured by distilling alkohol from concentrated muriate of tin, or by transmitting muriatic acid gas through alkohol, and afterwards distilling the impregnated liquor. Much of the success of the operation, Thenard finds, depends on the due regulation of the heat; and the process he has given consists in mingling equal parts by measure of alkohol and concentrated muriatic acid in a retort, exposing the retort, supported on a grate of iron, to the direct fire of a common furnace, there being connected with the retort a large bottle half-filled with water, with a tube of safety inserted, and to which a bent tube is adapted, terminating under an inverted phial filled with water: when the liquor is brought to boil the muriatic ether is disengaged in the gaseous form, and is collected in the phial.

In this state it is colourless, has a strong etherial smell, and a saccharine taste. At a temperature below 50°, it condenses into a liquid, which retains the same taste and odour, and is limpid. Its specific gravity is to that of water, at the temperature of 39°, as 874 to 1000. It evaporates rapidly, producing much cold. Cooled to —22°, it does not congeal.

This product has no sensible acidity; but, what is singular, when it is kindled, muriatic acid gas is immediately produced in large quantity; and this acid is also slowly evolved in it when it is kept for some time, as it is too by the action of sulphuric or nitric acid at a high temperature. From the products of its combustion, Thenard infers, that 100 parts contain 51.89 of carbon, 33.03 of oxygen, and 15.68 of hydrogen, with which are combined 41.72 of muriatic acid. Whether this acid exists in the combination fully formed, or only in the state of its elements, is not determined; the latter perhaps is more probable; as if it existed in the former state, the force of affinity by which it is retained can scarcely be supposed so energetic, but that it should be detected by the action of some of the re-agents which are tests of this acid.

Phosphoric Ether has been supposed to be formed by exposing to heat a mixture of alkohol, and concentrated liquid phosphoric acid. A portion of unchanged alkohol first passes over, but after this a liquid condenses, which has an etherial smell, somewhat fetid, and is slightly acidulous. On removing this by the action of lime or magnesia, and distilling it a second time, it assumes an odour more grateful, similar to sulphuric ether, has nearly the

same specific gravity, is soluble in water in limited quantity, and is highly volatile and inflammable, burning without any smoke. The theory of its formation has not been determined.

Fluoric Ether has been said to be obtained in decomposing fluor spar by sulphuric acid mixed with alkohol, applying heat so as to produce distillation. On distilling the product a second time from potash, an etherial liquid is obtained, resembling sulphuric ether, and which may perhaps have been formed by the action of the sulphuric rather than of the fluoric acid.

Acetic Ether is obtained by distilling repeatedly alkohol from concentrated acetic acid; it gradually acquires an etherial odour, and after the third distillation and rectification by an acid, it forms a proper ether. A similar product is obtained by distilling the acid with alkohol and a portion of sulphuric acid. Thenard found, that in the first process, if the distillation be repeated ten or twelve times, the acetic acid is almost entirely decomposed, and the alkohol is all converted into ether. In this conversion he supposes that the elements of the acid combine merely with those of the alkohol. The odour of acetic ether is grateful; its taste is peculiar; its specific gravity is 866; it evaporates on exposure to the air, and boils at 123°. It is soluble in water, requiring scarcely eight parts for its solution; if to this solution an alkali is added, the odour and taste of the ether disappear, the alkali is saturated, and diluted alkohol is obtained by distillation. In burning, too, acetic acid is deposited, though the ether itself is free from all sensible acidity.

Sect. II.—*Of the Acetous Fermentation.*

When the vinous fermentation is completed, if the liquor be kept under the same circumstances, with the admission of the atmospheric air, it begins to suffer another change. It loses its vinous fragrance and pungency, and becomes sour. When this is completed, an acid liquor is formed, Vinegar, the acid of which in its pure form is in chemical nomenclature denominated the Acetous, and the process by which it is formed, is named the Acetous Fermentation.

Every substance susceptible of the vinous, is susceptible also of the acetous fermentation, and this even without having previously become perfectly vinous; and there are substances incapable of the former, which undergo the latter, as vegetable infusions, or juices containing much mucilage with a little saccharine matter. Alkohol by itself is incapable of this change, and even to a certain extent counteracts it; hence strong vinous liquors do not so readily become sour as those that are weak.

The action of a ferment appears to be necessary to excite the acetous fermentation, and of this, vegetable gluten appears to be the base. The admission of the atmospheric air is indispensable; and its oxygen is absorbed, and appears to combine merely with carbon from the fermenting liquor, so as to form an equivalent portion of carbonic acid. Lastly, a due degree of temperature is required, the fermentation taking place slowly when the tempera-

ture is below 60°, and being accelerated when it is raised to 70°. When it is rapid, there is an intestine motion in the liquor, as there is in the vinous fermentation; it is turbid, its temperature rises, and there is a disengagement of elastic fluid. When it is complete, these appearances subside, and the liquor, depositing a considerable sediment, becomes clear.

There is still some obscurity with regard to the theory of the acetous fermentation. The strength of the acetous liquor which is formed being proportional to its previous vinous strength, and the vinous property being completely changed into acidity, while there is at the same time an absorption of oxygen, it was concluded that the change consists in the oxygenation of the alkohol of the vinous liquor, or as carbonic acid is at the same time disengaged, in the abstraction of carbon. But as alkohol alone does not suffer this change, and as the presence of mucilage, sugar, or other vegetable matter, is necessary, the theory is not complete; neither does it explain the operation of the ferment necessary to the process. Nitrogen appears to enter into the composition of vinegar, which the ferment probably affords.

Vinegar is of different degrees of purity and strength, according to the materials from which it is prepared; that from wine is purest and strongest; prepared from unrefined sugar, or from infusions of unmalted grain, it contains a portion of vegetable matter, which renders it liable to spontaneous decomposition. Along with the acid which is its base, vinegar always contains a portion of extractive

matter, which gives it colour, and frequently also portions of malic and tartaric acids.

To obtain the pure acid, the easiest method is by distillation. It passes over with a portion of water, and is thus freed from the vegetable matter, and from the other acids, care being taken not to continue the distillation too long, nor to raise the heat too high, as the vinegar is liable to acquire an empyreumatic odour. Distilled vinegar, though pure, is however extremely weak, and hence other processes are employed to obtain it in a concentrated state.

Its concentration can be effected by freezing, the water congealing, and the acid remaining uncongealed; and by repeating the operation with greater degrees of cold, a very strong and pure acid can be obtained. Another method is to expel the acid from its saline compounds. Thus, if acetate of potash or of soda, rendered as dry as possible, be exposed to heat with concentrated sulphuric acid, or with super-sulphate of potash, the sulphuric acid combines with the base of the salt, and the acetic acid is disengaged. It is also obtained from applying heat to a mixture of acetate of lead, and dried sulphate of copper or iron. Or if verdegris, which is a compound of this acid with oxide of copper, be exposed to a heat gradually raised, the acid is volatilized, and is obtained in a very concentrated state.

It had been remarked, that the acid obtained by this last process is more volatile and pungent than that obtained by the other methods, and displays also some differences in its combinations. It was hence concluded,

that it is different in composition, either containing a larger proportion of oxygen, which it receives from the metallic oxide in its preparation, or a smaller quantity of carbon, from a portion of this element being abstracted by the affinity exerted towards it by the metal. Hence the distinctive names were introduced, of Acetic and Acetous Acids, the former being applied to the acid procured from verdegris by heat, the latter to the acid existing in vinegar, and obtained from it in a state of concentration. The experiments of Adet, and more lately of Thenard, have shewn, however, that there are no grounds for this distinction; the acids obtained by these different processes, when brought to the same degree of purity and strength, having the same properties, and exerting the same chemical actions. There is, therefore, only one acid, and to this the name of Acetic is properly applied.

Acetic acid, highly concentrated, has an odour fragrant and penetrating; it is caustic, and, even when largely diluted, has a sour taste. It is capable of congealing, when exposed to intense cold. It is very volatile, its odour being quickly diffused when it is exposed to the atmosphere, and by a moderate heat it rises entirely in vapour: This vapour kindles on the approach of a burning body.

Acetic acid combines with the alkalis and earths, forming salts, which are named ACETATES. They are in general soluble in water, and, from their affinity to it, are not easily crystallized. It combines, too, with the metallic oxides. The greater number of these combinations present nothing interesting, and it will be sufficient, therefore, to take notice only of the more important compounds.

ACETATE OF POTASH, formed by saturating distilled vinegar with potash, is obtained by evaporation of its solution, in the state of a white foliated mass; or if the evaporation is carried to a less extent, small prismatic crystals form slowly. This salt is extremely deliquescent, is soluble in little more than its weight of water, at 60°, and is also soluble in alkohol. ACETATE OF SODA is obtained by evaporation, in slender prismatic crystals, which are deliquescent, and are soluble in less than three parts of water, at 60°. ACETATE OF AMMONIA can scarcely be crystallized, as, when its solution is submitted to evaporation, it is partly volatilized, partly decomposed: by evaporation, however, with a very gentle heat, it may be obtained in acicular prisms.

The Earthy Acetates are all soluble, and, by evaporation, afford either a gelatinous viscid mass, or acicular crystals.

The Metallic Acetates are likewise, in general, soluble and crystallizable; those applied to any use, are the acetates of quicksilver, copper, and lead.

Acetate of Quicksilver is prepared by decomposing a solution of nitrate of quicksilver by adding a solution of acetate of potash; the acetic acid combines with the oxide of quicksilver, and when the solution has contained the metal at a low degree of oxidation, the acetate is copiously deposited in scales of a white colour, and brilliant silvery lustre. This salt has been used as a mild mercurial preparation.

Copper forms different combinations with acetic acid. The verdegris of commerce is a sub-acetate, prepared by

stratifying copper plates with the husks of the grape, after the expression of the juice, and moistening them occasionally with weak vinegar. The copper is oxidated, and the oxide retains a portion of the acid combined with it; this forms a crust on the surface of the metal; it is scraped off and dried, and is of a light green colour. When it is dissolved in distilled vinegar, the excess of oxide is dissolved by the acid, and by evaporation of the solution, the neutral acetate is procured, crystallized in aggregated prisms, of a much deeper green colour; it is soluble in water and in alkohol, while the other is only partially dissolved. Both the acetate and sub-acetate are used as pigments, and also in the processes of dyeing, and in medicine, as escharotics.

Acetic acid forms, also, different combinations with lead. Cerusse, or white lead, which, triturated with oil, forms the common basis of paint, is prepared by exposing plates of lead to the vapours of vinegar; the lead is oxidated, and this oxide retaining probably a portion of acid combined with it, forms a crust on the surface. When this is digested in distilled vinegar, it is dissolved, and by evaporation of the solution, a mass is obtained, composed of a congeries of slender prisms, which, from its sweet taste, has been named Sugar of Lead; and which is used in medicine, and in several of the arts. This salt was regarded as acetate of lead, but it appears to be a super-acetate, or to contain always a slight excess of acid, which is necessary to its crystallization. Its crystals are acicular prisms, semi-transparent, of a white or yellowish colour, with a silky lustre; it is slightly efflorescent, is easily so-

luble in water, but appears to be partially decomposed, from the affinity of the water to the acid aided by its quantity. The neutral acetate is what has been known by the name of Goulard's Extract, prepared by boiling vinegar on litharge; it does not crystallize readily, and its crystals are plates; in its chemical relations, particularly to some of the vegetable and animal proximate principles, it differs considerably from the super-acetate.

Acetic acid acts on several of the vegetable products. It dissolves camphor, volatile oils, resins, and gum-resins, without materially modifying their properties.

The composition of acetic acid is not altogether determined. It obviously is composed, principally, of carbon, hydrogen, and oxygen, but the proportions are not ascertained; and from its affording ammonia, when decomposed by heat, it appears to contain nitrogen.

Sect. III.—*Of the Putrefactive Fermentation.*

The process of putrefaction, in animal matter, consists in the formation, from new combinations of its elements, of products offensive in their odour, which escape in the aerial form. Few vegetable substances can be said to be liable to it, yet they undergo a species of decomposition somewhat analogous, in which a similar evolution of gaseous products takes place, so that only the saline and earthy matter of the vegetable substance at length remains. To this the name of the putrefactive fermentation has been given.

Those vegetable products which are either soluble in water, or imbibe it, are those more peculiarly liable to this series of changes; and the same circumstances favour it which favour the other kinds of spontaneous decomposition, particularly a moderately high temperature, and the access of the air. The elastic products disengaged, are compounds of carbon and hydrogen, and carbonic acid; the former, according to the researches of Saussure, appearing principally when the action of the atmospheric air is excluded by the substance being immersed under water; the latter when the air is admitted, the oxygen of the air combining with the carbon of the vegetable substance, to form the carbonic acid, and with its hydrogen forming water. There is no sensible production of ammonia or of gases containing sulphur and phosphorus, the evolution of which more particularly characterises animal putrefaction, a difference arising from the absence of these elements, and of nitrogen, in the composition of vegetable matter. Those few vegetable products, however, which contain them, present results in their ultimate decomposition similar to those of animal substances.

Carbon being in general the basis of vegetable matter, it frequently remains, forming a kind of inert residuum after the decomposition has proceeded to a certain extent, constituting what is named Vegetable Mould. This, when the air is excluded, is scarcely liable to any farther change, there being no other principles to re-act on it with sufficient force. If the air is admitted, however, its oxygen acts on its carbonaceous base, and forms carbonic acid; this abstraction of carbon allows part of the oxygen and hydro-

gen of the mould to combine and form water, and by these progressive changes, the decomposition is at length rendered complete, and nothing remains but the saline, earthy, and metallic substances, originally contained in the vegetable matter.

It appears, however, that from the operation of circumstances, probably principally the exclusion of the atmosphere, and the presence of pressure, the decomposition does not proceed beyond the accumulation of this carbonaceous residuum; the former circumstance removing the agency of oxygen, the latter preventing the formation of elastic products; and from the process conducted under these circumstances, and on vegetable matter originally composed principally of carbon, as wood, have probably principally originated the different varieties of bitumens and coal, the origin of which from the vegetable kingdom, it has already been stated, can be clearly traced.

BOOK IX.

OF ANIMAL COMPOUNDS.

THE chemical history of animal substances may, like that of the vegetable products, be considered under three divisions;—the first comprising what relates to their formation; the second including the details of their individual chemical qualities; and the third embracing the few general facts connected with the compositions to which they are liable from the re-action of the constituent principles, either at high or at low temperatures.

CHAP. I.

OF THE FORMATION OF ANIMAL SUBSTANCES.

ANIMAL substances are distinguished by nearly the same general chemical characters as vegetable products. They are formed of a few ultimate principles, the diversities in their properties arising chiefly from the proportions and the modes in which these are combined. From this peculiarity of constitution, they have the same susceptibility of de-

composition as vegetable substances have, the balance of affinities among their elements being altered by slight variations of circumstances, and new combinations established. Hence, too, their analysis is always of the complicated kind, their principles not being disengaged insulated, but in new states of chemical union.

With regard to the distinction between the vegetable and animal compounds, the latter are more liable to decomposition from the re-action of their elements. The kind of spontaneous decomposition, too, which they suffer is different. They are scarcely susceptible of the vinous fermentation; they seldom even pass into the acetous, but undergo putrefaction, a process in which the principal products are ammonia, and certain compound elastic fluids having an offensive odour, by the formation and evolution of which the whole nearly of the original matter is dissipated. In their decomposition by heat, ammonia too is a principal product; prussic acid is usually formed, elastic fluids are disengaged, somewhat similar in chemical composition to thse evolved in putrefaction, and the residual charcoal affords phosphoric salts.

These differences arise from the peculiarities in the composition of animal matter. Being more complicated than that of vegetable matter, or derived from the union of a greater number of elements, the affinities these reciprocally exert are more nicely adjusted; hence they are more easily subverted. They not only contain carbon, hydrogen, and oxygen, the usual constituent principles of vegetable matter, but likewise nitrogen in considerable quantity, and sulphur and phosphorus in smaller proportions. From

the nitrogen existing in animal substances, is derived the abundant formation of ammonia which attends their decomposition, the nitrogen forming it by combining with hydrogen; and its predominance in their composition is very well shewn by its evolution when they are acted on by nitric acid. The presence of sulphur and phosphorus is discovered, by their being contained in the elastic fluids disengaged during the putrefaction, or decomposition by heat of animal matter; and it is the predominance of these principles which appears more peculiarly to give rise to the characters which distinguish putrefaction: the acids formed by their oxygenation are also found in the residual charcoal, combined usually with soda and lime. Carbon, it may be added, is contained in animal substances, in a proportion inferior to that in which it enters into the composition of vegetable products, and hence they give less carbonic oxide and carbonic acid in their decomposition; they afford, too, less empyreumatic acid, a proof that oxygen exists in them in inferior proportion; on the contrary, hydrogen appears to be predominant, from the large quantity of empyreumatic oil which they usually afford.

The animal products are ultimately derived from changes produced in the composition of vegetable matter, all animals living directly, or indirectly, on vegetable food; and even the present imperfect state of chemistry enables us to trace, in part, their formation,—the conveyance of their elements, and the processes by which these are brought into the combinations, whence the varieties of animal matter are formed. Vegetable matter is composed chiefly of

carbon, hydrogen, and oxygen; and can, therefore, furnish the whole of these elements which are required for the purposes of animal nutrition and growth. From the same source, or from the water with which the animal is supplied, may be derived the lime and iron, which are contained in small quantity in the animal products; at least the only supposed difficulty, with regard to these, is in the case of those animals by whom a large quantity of lime is secreted in the formation of their shells. There is a greater difficulty with regard to the source of the nitrogen, which is so abundant in animal matter; for although it is contained in some vegetable substances, it is not a common principle, and is usually in small proportion; and it does not appear that any portion of it is conveyed, as was once supposed, into the mass of blood, by respiration, from the atmospheric air. The present uncertainty, however, with regard to the nature of this substance, precludes nearly all satisfactory speculation on this subject. Phosphorus is another principle, the origin of which is not very obvious; it is always contained in animal substances, and even a considerable portion of it, in the state of phosphoric acid, is discharged as excrementitious; yet it is rarely found in vegetable matter. Still it has been shewn, that in those vegetables which are most nutritious, as in wheat, phosphorus is a constituent principle, the ashes of a pound of wheat-flour yielding 84 grains of phosphate of lime; and it is only in those animals who feed, in part at least, on animal matter, that the urine holds phosphoric salts dissolved. These facts lend probability to the supposition, that it is conveyed by vegetable food.

It is also sufficiently certain, that the vegetable analysis is not yet arrived at that state of perfection, that we can be certain that small portions of these principles may not exist in the composition even of every variety of vegetable matter; and that thus slowly introduced, they may accumulate in the animal system. And, with regard to the whole of this subject, it must farther be admitted, that the state of chemistry does not allow us to decide what substances are truly simple; and all those, with regard to which these difficulties have been supposed to exist, may either be compounds, or, if simple, it is equally possible, may exist in the composition of others, which our imperfect knowledge ranks as elementary.

The principles conveyed by the food, from which it is sufficiently evident, whatever difficulty we may have in tracing them minutely, animal nutrition is ultimately derived, are brought into those combinations productive of the several varieties of animal matter, by the united processes of digestion, respiration, and secretion; and the operations of these, so far as it can be done, it is satisfactory to trace.

In digestion, the food is submitted to the action of the gastric juice, or liquor secreted by the glands of the stomach, at a temperature, in the more perfect animals, above 90, and to the pressure, more or less forcible, arising from the contraction of the stomach itself. It is thus resolved into a soft pulpy mass, in which the previous texture or nature of the aliment can scarcely be distinguished. By facts, to be afterwards stated under the chemical history of the gastric fluid, it is proved, that it is principally

by the solvent power which it exerts, that this digestion of the food is effected. The nature of the change itself is not very well ascertained; but the food does not seem to be resolved into its ultimate principles; its soluble parts rather appear to be extracted without decomposition, and brought into intimate mixture, while there is also a partial animalization, by the intermixture of the saliva and gastric fluids. The digested food, conveyed into the intestinal canal, probably continues to suffer further changes, promoted by the temperature, and alternating pressure; and more directly produced by the action of the pancreatic juice and the bile; after the intermixture of the latter fluid, traces of the chyle are observed, and this milky fluid, in the progress of the food through the intestinal canal, is absorbed by the lacteals, and conveyed into the mass of blood. Chylification, therefore, is the last stage in the process of digestion; the precise nature of the changes which constitute it are not ascertained, but, from the opaque milky appearance of chyle, it is obvious that it is not a perfect solution; the more soluble principles of the food are, no doubt, dissolved in it; others less soluble, but probably nutritious, appear to be suspended in it; and the whole is so far animalized, as to contain a product approaching to one of the most important principles of animal matter, albumen, capable of being discovered in it by coagulation by heat. The chyle mixes with the blood, so that all traces of it are immediately lost.

There is a chemical change constantly produced in the blood by the process of Respiration, probably connected with the process of animalization. While it circulates

through the lungs, it is exposed, in the minute blood-vessels, under a very extensive surface, to the action of the atmospheric air, alternately taken in and thrown out in breathing. A portion of carbonic acid is formed, and discharged from the lungs, the quantity of oxygen necessary to form this, being abstracted from the atmospheric air inspired. The blood loses, therefore, a portion of carbon, with which this oxygen combines; and as this process is constantly carried on, it must be connected with the changes which the blood suffers in the system,—in other words, with the formation of the animal products. It is not improbable that a portion at least of this carbon is derived from the imperfectly assimilated chyle, and as animal matter contains a smaller proportion of carbon than vegetable matter, a portion of it probably remains redundant in the blood, after the formation of the principles of that fluid from the chyle, or of the other animal products in the course of the circulation; a principal office, therefore, of respiration, is probably to remove a principle which would thus otherwise become redundant.

Lastly, by Secretion the animal fluids and solids are formed. Either in the extreme blood-vessels, or in the minute and convoluted vessels which constitute the glands, the blood suffers changes of composition, whence the different products are formed. The nature of the process of secretion, by which this is accomplished, is extremely obscure; but it is evident, that however the actions of the vessels, whence the changes arise, may be dependent on their vitality, the changes themselves are strictly chemical. And it may perhaps be proposed, as no im-

probable hypothesis of the nature of secretion, that the cause productive of the new combinations to which it gives rise, is merely the approximation of the elements of the blood, by the contraction of the vessels through which it is transmitted. It is urged, by the contractile force of the heart and arterial system, through vessels extremely minute, and even the diameters of these vessels are alternately diminished and enlarged by their alternate contraction and relaxation. By this, an approximation and change in the relative positions of the particles which compose the principles of the blood must be produced. There can now remain no doubt, that the force of attraction between the minute particles of matter is materially modified by the distances at which they are placed; by such a cause, therefore, changes in the exertion of attraction in the principles of the blood may be produced, and be productive of all the new combinations to which secretion gives rise.

By secretion a variety of products are formed,—as the bile, milk, &c.; and by an analogous process, carried on without the intervention of glands, in the extreme blood-vessels, are probably formed the principles of the blood itself, and the greater number of the animal solids. The process of animalization is thus completed, and, from the progressive operation of these general processes, Digestion, Respiration, and Secretion, the formation of animal matter is traced.

CHAP. II.

OF THE ANIMAL PRODUCTS.

The different varieties of animal matter may probably, like vegetable substances, be comprised under a certain number of well-defined species. This, however, is as yet imperfectly attained; we therefore consider merely the principal animal fluids and solids, introducing under their history those specific distinctions which can be established, and the notice of those principles which are characterised by these distinctions. The blood may first be considered as the source of the others; and its history is farther of importance, as it contains those proximate principles of which the other varieties of animal matter are principally formed.

Sect. I.—*Of the Blood.*

The blood, or common fluid which circulates in the vessels of the animal system, and is the source of the various secreted products, differs in the different tribes of animals. It is from its properties in the more perfect, or warm-blooded animals as they are named, that its chemical history is drawn.

While in the vessels of the animal system, it appears to be homogeneous. The microscope discovers it, however,

to consist of globules diffused through a liquid; and when it has been drawn for a short time, it separates into two parts, one solid and firm, of a red colour, the other liquid, of a slight yellowish tinge. The former is named the Crassamentum, the latter the Serum. By a farther simple analysis, that merely of washing with water, the crassamentum is resolved into two parts, a firm white elastic substance, insoluble in water, which has been named Gluten or Fibrin, and the colouring matter of the blood, which is carried off in a state of solution. The cause of the coagulation of the blood is not well determined. It takes place more readily when the temperature is allowed to fall, and when the blood is at rest; but it also happens when it is agitated, and when the temperature is not reduced. Neither is it dependent on the access of the air. It probably arises from a property belonging to the fibrin, the operation of which is counteracted by the circumstances under which the blood circulates in the animal system.

This coagulation affords the most simple and direct mode of discovering the immediate constituent principles of the blood.

The liquid portion, or Serum, is of a pale yellowish colour, somewhat tenacious, and has a slightly saline taste. It is perfectly miscible with water; a little free soda exists in it, whence it changes the blue colour of violet to a green.

It coagulates from the application of heat, raised to 160°, forming a mass more or less firm, but tremulous, with a portion of liquid diffused through it. It is also coagulated by the action of a number of the acids, by salts with an excess

of acid, by alkohol, and by some metallic oxides. The substance which coagulates exists in many of the animal products, besides the blood. It is named Albumen, and is the first immediate principle existing in this fluid, the properties of which are to be pointed out.

Albumen is soluble in cold water, but is separated from it by coagulation when its temperature is raised, and also by the action of those re-agents which separate it from the serum. After its coagulation it is not soluble as before. The coagulation by heat does not take place when its solution has been previously much diluted. The alkalis dissolve albumen; ammonia dissolves it very slowly, the solution forming a kind of viscid porous pulp: potash and soda, while they dissolve it, partially decompose it, causing an exhalation of ammonia, and the separation of a grey powder. Acids likewise dissolve it, but at the same time re-act upon it, producing decomposition to a greater or less extent. It is decomposed by heat, and in this decomposition affords the usual products of the decomposition of animal matter. Sulphur appears peculiarly to exist in it; hence, when it is triturated with nitrate of silver, the sulphuret of the metal is formed.

The chemical test by which the presence of albumen can be recognised with the greatest delicacy and accuracy, is the corrosive muriate of mercury, a few drops of its solution detecting, by the milkiness it produces, albumen dissolved in 2000 parts of water. Goulard's Extract, and nitrate of silver, also precipitate it; but they are of little utility as tests, as they act on other principles of animal matter.

Albumen exists not only in the blood, but in many of the soft solids. Mr Hatchet's experiments prove that it forms the base of cartilage, shell, horn, and hair, and it enters into the composition of membrane, muscular fibre, and bone.

If the liquid diffused through the coagulum of the serum be pressed out from the albumen, and if it be made to boil gently, it has been said to become gelatinous on cooling. This being the distinguishing property of a principle existing in various animal solids, and denominated from it Gelatin, it has been inferred, that it is one of the constituents of the blood. The fact, however, has been more lately rendered doubtful by Dr Bostock's experiments. When the albumen of the serum is coagulated by heat, the separation is not perfect, a portion still being dissolved in the remaining liquid. But if this be removed by precipitation by oxy-muriate of mercury, it does not afford a jelly, and it gives no precipitate with infusion of tannin, a test by which gelatin is discovered in very minute quantity. Hence he concludes, that gelatin does not exist in the serum of the blood. There is a small quantity of an uncoagulable matter, however, different from albumen, which he considers as the principle denominated Mucus, the characters of which are not being coagulated by heat, nor concreting by cold, and not being affected by corrosive muriate of mercury, or tannin, but being copiously precipitated by acetate of lead.

The serum, besides these varieties of animal matter, holds dissolved some saline substances,—pure soda, muriate of soda, phosphate of soda, and phosphate of lime.

The Crassamentum of the blood is of a soft consistence, and a dark-red colour, which becomes florid at the surface from exposure to atmospheric air or oxygen gas, while it is rendered of a darker hue by other gases. Though apparently homogeneous, it is resolved, by the mere affusion of water continued sufficiently long, into two parts; the colouring matter is carried off in solution in the water, and there remains a white fibrous substance denominated Fibrin.

The colouring matter appears from microscopical observations to be in the form of round globules. It is soluble in water, retaining its colour; but when the solution is heated to 170°, it becomes brown, and a flocculent precipitate is formed. It is this matter on which the gases act more peculiarly; and substances capable of communicating oxygen to it, as oxide of mercury, when diffused through its solution, communicate to it a florid hue.

This colouring matter appears partly to consist of albumen as it is coagulated by heat, and by acids, while alkalis dissolve it. The matter communicating colour appears to have iron for its basis, either the pure colouring matter itself, obtained by evaporation of its solution, or the entire crassamentum, affording a considerable quantity of that metal in the residual matter obtained in its decomposition by heat. This is, according to the experiments of Fourcroy and Vauquelin, oxidated, and probably in the state of a sub-phosphate. The colouring matter obtained by evaporation of its solution, they found, afforded phosphoric acid and oxide of iron. Sub-phosphate of iron, according to these chemists, is of a brownish-red

colour, and soluble in alkalis; and the pure soda of the blood, they suppose, maintains it in a state of solution. They accordingly affirm that sub-phosphate of iron is soluble in the serum of the blood, or in the white of an egg which is albumen nearly pure, and that it forms a deep red colour, the addition of a little pure alkali both promoting the solution, and rendering the colour more lively. Hence they conclude, that the colouring matter of the crassamentum consists of albumen with sub-phosphate of iron.

The Fibrin, which is its other constituent part, remains when the colouring matter has been removed by the affusion of water; it is also obtained by agitating the mass of blood itself with a rod, the serum and colouring matter being mixed by the agitation, while the fibrin adheres to the rod. It is sometimes found concreted in the large blood-vessels after death, forming what have been named Polypi; and in inflammatory diseases, it is more peculiarly disposed to separate from the blood when it is drawn from the vessels, and gives rise to the appearance named the Inflammatory Crust, or Buffy Coat of the Blood. The same principle exists in other animal products; it is in particular the basis of the Flesh, or Muscular Fibre.

Fibrin is a solid elastic substance, of a distinctly fibrous texture, of a white colour, inodorous and tasteless; it shrinks when dried and exposed to heat; it is quite insoluble in water, except at a very high temperature, obtained by applying heat under compression. In a humid state it is liable to spontaneous decomposition, softening, and at length becoming putrid. It is dissolved by the alkalis, but is at the same time decomposed, ammonia being

exhaled when it is acted on by potash or soda. Pure ammonia scarcely acts upou it, unless heat be applied; it then dissolves it. The acids decompose it,—sulphuric acid charring it, and forming acetic acid,—nitric acid disengaging from it nitrogen gas, and forming other products which vary according to the concentration of the acid, the principal of which are, acetic, malic, and prussic acids, an oily substance, and a peculiar yellow bitter matter,—muriatic and acetic acid dissolving it, but so far changing its composition, that when it is precipitated by the alkalis, it no longer has its original properties. It is decomposed by heat, and affords the usual products of the decomposition of animal matter.

After this enumeration of the constituent proximate principles of the blood, the properties of the entire compound itself, which in a great measure result from these, will be better understood.

The blood, when newly drawn, appears homogeneous; it is soluble in water, and this dilution prevents its spontaneous coagulation. If it be heated, however, the albumen is partially separated in flakes. Acids added to blood immediately decompose it, rendering its colour dark, and producing coagulation. Alkalis render it more thin, and prevent its spontaneous coagulation. The metallic salts in general decompose and coagulate it. It soon passes into putrefaction; but if the watery part be dissipated by evaporation, and the solid matter be rendered perfectly dry, this change takes place very slowly. Decomposed by heat, it affords all the products of animal matter; the elastic fluids disengaged are extremely offensive, and the char-

coal which remains is brilliant, and of difficult incineration; when burnt, it affords a considerable portion of iron.

In concluding the history of the blood, it is necessary to remark, that there is an important difference in it, as it exists in the arteries and in the veins of an animal; and this difference from the known operation of the cause by which it is produced, must depend on a chemical change. The venous blood returned from the extreme vessels to the heart, is brought by the pulmonary arteries to the lungs, through which it circulates, exposed to the air received in respiration, under a very extensive surface, and with the interposition of a very thin membrane, which appears not to prevent the reciprocal action of the air, and blood. Part of the oxygen of the inspired air, is consumed, and a portion of carbonic acid gas is formed, which is expired with the residual air; the blood at the same time loses its dark purple colour, and acquires a vivid vermilion hue; it is returned to the left side of the heart, is conveyed by the arteries to the different parts of the system, and again converted to the venous state. These reciprocal changes are so necessary to life, that their interruption by the suspension of respiration proves almost immediately fatal: they are obviously connected with changes of composition, and are hence subjects of chemical investigation.

Many experiments have been made to determine the relation between the consumption of oxygen by respiration, and the formation of carbonic acid, and the extent of these changes. These have presented very discordant

results, particularly with regard to the proportion of oxygen consumed, to that of carbonic acid formed. By the late accurate experiments of Allen and Pepys, it appears to be established, that there is no excess of oxygen consumed above that which is necessary to the formation of the quantity of carbonic acid gas which is produced, as had been supposed, but that the one is equivalent to the other. The absolute quantities vary from circumstances, but on an average, they estimate the production of carbonic acid gas, in natural respiration, at 26.6 cubic inches in a minute; and as oxygen gas occupies exactly the same space, when converted into carbonic acid gas, which it does in its pure form, this of course gives the quantity of oxygen consumed in the same time. There appeared, in some prior experiments, to be also a consumption of nitrogen in respiration; they found, however, that this is not the case, and the apparent consumption is owing to fallacy from the effect of respiration rendered laborious in the course of the experiment; by which, at the end of it, the full proportion of air is not thrown from the lungs. A portion of watery vapour is also expired: its quantity amounts to between two and three grains in a minute, and its source is probably evaporation from the humid surface of the lungs.

The chemical changes which occur in respiration, are considerably influenced by various circumstances. Thus the consumption of oxygen is greater at a low, than at a high temperature; during digestion, its consumption is also increased, as it is by muscular exertion. When oxygen gas is respired, more of it is consumed than in the

respiration of atmospheric air; and there is some reason to infer, that a portion of it is in this case absorbed by the blood.

Different views have been presented of the manner in which the chemical changes that occur in respiration are produced. Crawford advanced perhaps the first explanation that could be considered as precise. He supposed, that in the course of the general circulation, and more especially in the extreme vessels, the arterial blood receives a supply of the compound of carbon and hydrogen, which in its elastic form constitutes the heavy inflammable air of the older chemists, the hydro-carbon, or carburetted hydrogen of the modern nomenclature; by receiving this, it is converted to the venous state; this principle escapes from the venous blood during its circulation through the lungs, permeates the thin membrane in which the blood is inclosed, and combines in its nascent state with the oxygen of the inspired air, forming carbonic acid gas and watery vapour, which are expired. And the blood, losing this hydro-carbon, resumes its arterial state.

Lavoisier presented a similar view; at the same time he remarked, that the phenomena of respiration may be explained in another mode,—that the oxygen which disappears in respiration may be supposed to be absorbed by the blood; it may, in the course of the circulation, combine with carbon to form carbonic acid, and this acid conveyed by the venous blood, may be discharged in the lungs, while a new portion of oxygen is taken in. This explanation was adopted and illustrated by Hassenfratz and Lagrange.

Both these hypotheses are extremely defective. There is no proof in that advanced by Crawford, of carbon and hydrogen being communicated to the blood in the extreme vessels, or of the existence of such a compound as carburetted hydrogen in venous blood. And there is an equal deficiency of proof in the first principles of the opposite hypothesis, that oxygen is absorbed, or exists in arterial blood in a state of loose combination, or that carbonic acid is present in venous blood in a similar state: the last supposition seems even to be precluded by the fact, that when blood has absorbed carbonic acid, it is not rendered florid by subsequent exposure to oxygen. An objection to both hypotheses, not less important, is, that the changes which they suppose, are not analogous to the usual chemical changes which take place in the animal system; and that they are not sufficiently connected with the purposes which the blood serves in its circulation. When the general facility of combination in the principles of animal matter, and the tendency which the actions of the vessels have to form them into ternary or quaternary principles, are considered, it is improbable that oxygen should be absorbed by the blood in the lungs, without immediately altering its composition; that without being attracted by any of the other principles, it should be merely combined with carbon, or with carbon and hydrogen, in the proportions necessary to form carbonic acid and water; and that this carbonic acid, without affecting the ultimate composition of the blood, should be carried the whole length of the venous circulation, and thrown out at the lungs. It is equally improbable, that carbon and hydrogen should be

brought into a state of binary combination in the extreme vessels, and should be held dissolved by the venous blood, till acted on by the oxygen of the air in respiration. Still less are the changes which these explanations suppose connected with the changes which the blood suffers. Its principles are expended in the formation of the different secretions, and in the nourishment of the solid fibre. But no connection is traced between these known changes, and the supposed communication of hydro-carbon, or the combination of carbon and oxygen, in the extreme vessels.

The conversion of arterial into venous blood ought to be considered as the result of the changes carried on in the extreme vessels, and this conversion, as well as that of venous into arterial blood, as arising from changes in the ultimate composition of the known proximate principles of the blood, and not from the alternate communication and abstraction of a principle which it holds dissolved in a state of loose combination. According to this view of the subject, the following may be considered as an explanation of these phenomena.

The blood is the source whence the products of the animal system are formed. Its expenditure is constantly supplied by the chyle, a fluid less completely animalized than the blood itself. The peculiar character of animal matter, with respect to composition, is a large proportion of nitrogen, and a diminished proportion of carbon. It may therefore be inferred, that in the extreme vessels, where the animal solids and fluids are formed, the general process will be the separation from the blood of those elements of which animal matter is composed; and that, of

course, carbon, which enters more sparingly into their composition, will exist in the remaining blood in an increased proportion. This may be considered as the general nature of the conversion of arterial into venous blood. The oxygen of the inspired air acting on the extensive surface of blood in the lungs will abstract a portion of carbon, forming carbonic acid; and this gives rise to the conversion to the arterial state. The accumulation of carbon is thus prevented, and the due proportion of the elements of the blood preserved.

From the chemical changes which occur in respiration, has been derived the explanation of that uniform temperature which animals preserve, in general superior to that of the medium in which they live. It had been observed, that in different animals, the superiority of their temperature to that of the surrounding air, is greater according to the greater size of their lungs; whence it had been inferred, that respiration is the source of animal heat,—a conclusion which Dr Black confirmed by observing the analogy between this process and combustion, in the changes which are effected in the air.

Dr Crawford first explained this doctrine with precision, and established it by accurate experiments. He had previously shewn, that in general, when inflammable bodies combine with oxygen gas, a diminution of capacity takes place, whence there must be an evolution of caloric; and that in the combustion of charcoal, when carbonic acid is formed from the combination of oxygen with carbon, a large quantity of caloric is rendered sensible. It is evident, that since in respiration a similar consumption of oxygen and production of carbonic acid take place, there

must be a similar evolution of caloric. He further ascertained by experiment, that the capacity of the blood changes when it passes from arterial to venous; and of course from venous to arterial; that of arterial being larger than that of venous blood, in the proportion of 1.030 to 0.892. On these facts he founded his admirable theory of Animal Heat. In respiration, a quantity of oxygen is combined with carbon, and carbonic acid is formed. Caloric must be evolved in consequence of this combination. But the blood is at the same time changed from venous to arterial, and by this change acquires a greater capacity for caloric. It therefore takes up the caloric which has been extricated by the combination; so that any rise of temperature in the lungs which would be incompatible with life is prevented. The arterial blood, in its circulation through the extreme vessels, passes to the venous state. In this conversion, its capacity for caloric is diminished, as much as it had been before increased, in the lungs: the caloric, therefore, which had been absorbed, is again given out; and this slow and constant evolution of caloric in the extreme vessels over the whole body is the source of its uniform temperature.

Besides the experiments from which this theory was directly deduced, it has been confirmed by others, in which the quantity of caloric rendered sensible by an animal is measured. Dr Crawford, and Lavoisier and La Place, found, that when an animal is confined in a vessel, contrived so as to measure the quantity of caloric which it gives to the surrounding medium in a certain time, and the quantity of oxygen consumed by the animal in that

time, this quantity of caloric corresponds nearly to the quantity evolved from the combustion of carbonaceous matter, such as wax or oil, in the same quantity of oxygen.

This explanation is altogether independent on any particular theory of respiration. Whatever may be the nature of the differences between venous and arterial blood, it is proved by experiment, that the blood in these two states has different capacities for caloric; and on this fact the explanation of the origin of animal temperature depends. It is likewise the same, whether the combination of oxygen with carbon be supposed to take place in the lungs or in the course of the circulation, since from this combination the carbonic acid expired is derived; and whenever this takes place, there must be an evolution of caloric.

Transpiration is a function analogous to respiration, and gives rise to similar changes, though to a much less extent. Carbonic acid gas is exhaled from the skin with watery vapour, and oxygen is consumed. A small portion of acid, too, appears to be secreted by the cutaneous vessels.

Sect. II.—*Of the Chyle.*

Chyle is the fluid taken up by the lacteals from the food which has been digested in the stomach, and conveyed into the intestinal canal. It is conveyed by the

thoracic duct into the mass of blood, and is obviously the source whence the expenditure of matter in the formation of the animal products is supplied.

The chyle is of a white colour; its taste is sweetish. It is, from its milkiness, evidently heterogeneous; and, on standing, a portion of a thicker consistence, it is affirmed, separates and collects on the surface. After exposure for some time to the air, it becomes gelatinous, and at length presents a firm coagulum, semi-transparent, and of a light red tinge, under which is a portion of liquid, thin, and of the colour of milk. Besides this matter, which coagulates spontaneously, it contains a fluid that coagulates by heat.

The properties of this fluid have been, however, very imperfectly examined, owing, in a great measure, to the difficulty of procuring it in quantity sufficient to admit of an experimental investigation. It probably differs, too, according to the substances received into the stomach, these being frequently discernible in it in an unchanged state. Thus the colouring matter of indigo is discerned by the blue tinge it communicates, and musk by its strong and peculiar odour.

Sect. III.—*Of Milk, Sugar of Milk, Saccho-lactic Acid.*

Milk, the secreted liquid designed for the nourishment of young animals, though it differs somewhat in its properties in different species, appears to contain the same

proximate principles, and, on the whole, to be essentially the same.

It is white and opaque, bland and sweet to the taste; its consistence is somewhat thick, and its specific gravity a little greater than that of water. On remaining at rest after it has been drawn, it soon suffers a slight decomposition; a thick bland fluid, the cream, rises to the surface, and the portion beneath remains rather more watery. This separation facilitates the examination of its proximate principles.

The Cream is of an oily nature. By agitation it is resolved into a fluid and solid part, the latter having the properties of expressed oil. This substance, Butter as it is named, is a constituent part of the milk, and appears to be in a great measure mechanically diffused through it.

Milk, after the separation of the cream has taken place, soon suffers another change; it becomes acescent, and then coagulates, apparently from the re-action of the acid on the principle that separates, as acids, even the weakest, have the same effect. It is also produced by a number of neutral salts, by alkohol, by the gastric fluid of animals, the juices of a number of plants, and even by heat; the matter which separates in films, when milk is heated, being the same as that separated by the action of these other substances. The gastric fluid taken from the stomach of young animals, or the liquid prepared from the maceration in water, with the addition of a little salt, of the membrane of the stomach itself, is usually employed to afford this matter in its least altered state.

The substance thus separated is the Cheese of milk, a

principle having very peculiar properties. The cause of its separation is not ascertained, and it is rather singular that it should be occasioned by re-agents so different. The effect of the gastric fluid in separating it, does not depend on its acidity, as had been supposed; as, when it is not sensibly acid, or is even rendered alkaline, it retains the coagulating property.

The Cheese, or Caseous Matter of Milk, is white or greyish, somewhat elastic, insipid when fresh, though it acquires taste when kept. It is insoluble in water. Exposed to the air in a humid state, it soon passes into a state of putrefaction; but if rendered dry, it can be preserved long unchanged.

The fixed alkalis dissolve it, when their action is aided by a moderate heat, ammonia being at the same time exhaled from partial decomposition; and when an acid is added, sulphuretted hydrogen is evolved. The acids likewise dissolve it, but with more or less decomposition; nitric acid disengages from it nitrogen gas. Decomposed by heat, it affords empyreumatic oil, ammonia, and carburetted hydrogen; its residual charcoal affords small portions of fixed alkali and of phosphate of lime. These are the properties of cheese in its pure state. As usually prepared, it generally contains a portion of the oily matter of milk.

The Serum or Whey that separates from the coagulum of cheese, is a liquid of a yellowish colour and slight tenacity, and of a sweetish taste. When purified by filtration after the perfect separation of the cheese, it affords on evaporation a substance of a granulated appearance,

sweet taste, and yellowish colour, which, dissolved in water, yields, on evaporation, rhomboidal crystals of a white colour. This substance, named the Salt or Sugar of Milk, is a very peculiar one. It is soluble in seven parts of cold, and four of boiling water. Decomposed by heat, it affords products the same as those from the decomposition of vegetable saccharine matter. Submitted to the action of nitric acid, aided by heat, nitric oxide is disengaged, and, as the mutual action proceeds, a copious deposition of a white substance takes place. The residual liquid contains oxalic acid.

The substance separated in this process has acid properties. It is named Saccho-lactic Acid. Scheele, by whom it was discovered, concluded that it pre-exists in the sugar of milk, combined with saccharine matter, and that the nitric acid merely developes it, by decomposing the sugar combined with it;—an opinion which, although it does not appear very probable, has been acceded to by Parmentier and Deyeux, in their researches on milk.

Saccho-lactic acid is in the state of a white granular powder; its taste is slightly sour; it is sparingly soluble in water, requiring 60 parts at 212° to dissolve it. This solution has an acid taste, and reddens the vegetable colours; it deposites small crystals on cooling. This acid forms, with the different salifiable bases, salts named Saccholates, of which those with the alkalis are soluble and crystallizable, those with the earths and metallic oxides of sparing solubility. This acid is likewise formed by the action of nitric acid on gum.

The whey of milk, from the quantity of saccharine

matter it contains, can be made to pass into the vinous fermentation, so as to afford a weak vinous liquor. It passes more readily into the acetous fermentation; the acid which is formed when it becomes acescent, was once supposed to be a peculiar one, and was named the Lactic Acid. Later researches have shewn, that it is the acetic acid disguised by the presence of a little extractive matter, and of the small portion of saline matter contained in the whey. This matter consists of muriates of lime, potash, and soda, and phosphates of lime, magnesia, and iron.

The union of the saccharine and oily matter of milk, with the more animalized product, the cheese, render it a fluid at once nutritive and easy of digestion, and the presence of the phosphoric acid with the lime and iron adapt it to the formation of blood.

Sect. IV.—*Of Lymph.—Of Mucus.*

Lymph is a pellucid fluid taken up by the absorbents from the internal surfaces, or conveyed from the extremities of the arterial branches, and appears to be analogous to the serum of the blood. It is slightly viscid, is miscible with water, and coagulated by heat, by acids, and by alkohol.

The mucus, which covers the passages and internal cavities of the body, appears to be the lymph in an inspissated state, its watery portion having been absorbed. The term Mucus has been used, however, in a more appro-

priate sense, to denote a principle existing in the fluid which has usually received that name, as well as in other animal fluids. The characters assigned to it are solubility in water, its solution neither coagulating nor becoming gelatinous when heated; but by evaporation it can be obtained solid, and be again dissolved. It is not precipitated by tannin, or by corrosive muriate of mercury, but gives a copious white precipitate with Goulard's extract. It is insoluble in alkohol.

This principle appears to form the mucus of the nostrils,—a fluid which, as it is first secreted, is liquid and clear, but, from exposure to the air, becomes thick and viscid; and, by the continued action of oxygen, becomes nearly concrete, a change that is at once produced in it by oxy-muriatic acid. In this state it is not soluble in water, nor easily diffused in it; the acids thicken it, but in larger quantity re-dissolve it. The alkalis do not exert on it any solvent power. It contains a quantity of saline matter, principally muriate and carbonate of soda, and phosphates of soda and lime.

The liquid which forms the tears, Fourcroy and Vauquelin have observed, is nearly the same, and, like it, contains carbonate of soda, so as to change the colour of violet to green, with muriate of soda, phosphate of soda, and phosphate of lime. The latter, when it accumulates, forms the basis of the concretions sometimes found in the lacrymal glands.

Sect. V.—*Of the Saliva, and the Pancreatic Fluid.*

The Saliva, or liquor secreted by the salivary glands, and designed to facilitate the mastication of the food, is slightly viscid, and has a taste very slightly saline; it does not mix uniformly with water; exposed to the air, it becomes more thick and turbid. When the liquid, formed by triturating it with water, is exposed to heat, it is slightly coagulated, and it suffers the same change from alkohol, and the stronger acids, denoting the presence of albumen. The fixed alkalis dissolve it, and disengage a small quantity of ammonia, by decomposing the ammoniacal salts it contains. Lime-water throws down from it a precipitate of phosphate of lime, and oxalic acid detects lime in its composition. Acetate of lead, and other metallic salts, produce a copious precipitate from their action partly on the mucus, partly on the saline matter it contains. Evaporated by a gentle heat, it affords crystals of muriate of soda, and crystals similar to those of muriate of ammonia; and when decomposed by heat, its residual charcoal yields, by incineration, muriate of soda, phosphate of soda, and phosphate of lime.

The concretions which sometimes form in the salivary glands, consist of phosphate of lime with animal matter, probably inspissated mucus, or albumen. The incrustation which forms on the teeth, is of a similar nature.

The liquor secreted by the Pancreas, and apparently designed, like it, to facilitate the changes which the food

is to undergo, is similar, in its sensible qualities, to saliva; and, on evaporation, affords, like it, crystals of muriate of soda, and a colourless mucus, partially soluble again in water. It is colourless, and has a taste slightly saline.

Sect. VI.—*Of the Gastric Fluid.*

The liquid secreted by the glands of the stomach, and subservient to the process of digestion, operates probably by its chemical agency; and hence the importance of the investigation of its properties;—an investigation rendered difficult, however, from the difficulty of obtaining it pure in any considerable quantity. Spallanzani, by whom the operation of the gastric fluid, as connected with the process of digestion, has been laboriously investigated, observed that this fluid, whether procured from the stomach of gramenivorous or carnivorous animals, appeared to be the same in physical qualities. If unmixed with any of the food, it was clear, its taste was slightly saline; it gave no indication of acidity, except sometimes when obtained from animals feeding on vegetable food, from changes in which, the acid was probably derived. Neither was it sensibly alkaline. On adding nitrate of silver, it gave a precipitate of muriate of silver. Vauquelin found in it phosphates, and free phosphoric acid, and a small quantity of albumen was separated from it by the action of acids. Spallanzani observed, that it is liable to putrefaction, that it preserves other substances from becoming soon putrid, and even re-

stores the sweetness of animal matter which had become putrid,—observations to a certain extent confirmed by Stevens, though Vauquelin observed that the gastric fluid which he examined became corrupted in a few days.

The most remarkable property of this fluid, and one which must be regarded as depending on its chemical agency, is the solvent power which it exerts on the food. Reaumur observed, that if the food on which an animal naturally subsists be inclosed in metallic tubes, so as to protect it from any muscular action of the stomach on it, but perforated so as to admit of the action of the gastric fluid, it is dissolved, in those animals particularly who have a membranous stomach, and live on flesh; but in those who have a muscular stomach, susceptible of strong contraction, the solution was much less complete, or even frequently scarcely effected. This obviously might arise from the trituration produced in the food by the muscular action of the stomach in those animals, facilitating the solvent action of the gastric fluid; and, accordingly, Spallanzani found, that when the food was previously bruised, and introduced into the stomach inclosed in tubes, it was dissolved. The solvent power, however, he found to be exerted in a much shorter time in those animals who have a membranous, than in those who have a muscular stomach; and in some of the former this power is very great, the hardest bone, for example, inclosed in a tube, being speedily dissolved in the stomach of the eagle, or of the dog. He likewise found, that the same solvent power was exerted by the gastric fluid out of the body, at a temperature not higher than that of the animal system. His

experiments are confirmed, in general, by those of Stevens. The only discordance is, that Stevens found those kinds of food on which animals do not naturally subsist, are not dissolved by the gastric fluid of their stomach; while Spallanzani found, that in animals who feed naturally on flesh, grain previously bruised is dissolved, and in those who feed on grain, flesh undergoes solution. The animals, however, on whom he made these experiments, do not appear to be naturally much limited with regard to the food on which they subsist; and some animals, birds of prey for example, Spallanzani admits, were incapable of digesting vegetables. It appears on the whole, therefore, that the solvent power of the gastric fluid is in a great measure exerted only on the food natural to the animal; though in many species the stomach appears to be capable of adapting itself, to a considerable extent, to the substance which it receives, so that an entire change can at length be effected in the habits of many animals, with regard to the food on which they can subsist. In those who feed both on animal and vegetable substances, both are dissolved by the gastric fluid.

The solvent power of this fluid is very well shewn in its action on the stomach itself, which, in carnivorous animals especially, who die suddenly, and in a state of vigour, is sometimes found, a few hours after death, to be partially dissolved in its depending part,—a fact, too, which well shews how far the presence of vitality suspends the usual laws of chemical action, since it protects the stomach from the action of a liquid thus capable of dissolving it. Stevens, however, has, from some observations, supposed

that this is to be received with some limitation, and that animals, even when alive, are in some cases subject to the powers of digestion.

These properties of the gastric fluid cannot be traced to any obvious chemical property of which it is possessed, or to the known, or even the probable agency of any principle which it contains, and are therefore, with regard to our knowledge of it, altogether anomalous.

Sect. VII.—*Of Bile, and Biliary Calculi.*

Bile, the liquor secreted by the liver, is probably in part excrementitious, and in part designed to promote the process of digestion, or rather of chylification, no traces of chyle being discoverable in the digested food, until after its intermixture with the bile. It has the singularity of being secreted from venous blood, and with this is probably connected its peculiar composition, in which carbon and nitrogen appear to predominate. It has even been supposed to convey the excess of these principles from the system, and its secretion therefore has been considered as subservient to the process of respiration.

As first secreted, it is liquid, and in this state it in part flows into the intestinal canal. A portion of it is received into the reservoir named the Gall Bladder, in which it suffers a degree of inspissation; and it is this Cystic Bile, as it has been named, which has been usually submitted to chemical examination. It is thick, and of a specific gra-

vity greater than that of water; its colour is greenish-yellow; its odour faint; its taste intensely bitter. It suffers, in a short time, spontaneous decomposition, and acquires an offensive odour.

Bile, evaporated by a gentle heat, affords a large quantity of water, having its smell, but not its taste. The residual matter, Extract of Bile as it is named, is thick, of a dark-brown colour, deliquescent, and soluble in water. It cannot be rendered concrete without decomposition, and when decomposed by heat, affords a liquid brown and fetid, sulphuretted hydrogen, carbonate and acetate of ammonia, empyreumatic oil, and carburetted hydrogen, with carbonic acid; its residual charcoal affording much carbonate of soda.

Bile is soluble in water in every proportion, and its solution changes the colour of violet to a green, indicating the presence of a free alkali.

It is decomposed by the acids, a precipitate being thrown down of a greenish colour, and the bitter and inflammable matter of the bile remaining in solution. Alkohol produces a similar effect more completely, and affords the most direct mode of separating the proximate principles of this fluid. The coagulum which it forms, when collected on a filtre and washed, is a white viscid substance, having scarcely any bitterness, very putrescible, and approaching very nearly in its properties to albumen. The same substance is separated, though less perfectly, by heat. The filtered liquor retains the colour and the bitterness of the bile. By evaporation, it affords a concrete substance, inflammable, fusible at 120, soluble in alkohol, and preci-

pitated from this solution by the affusion of water. From these properties it has been named the Resin of the Bile, and is evidently the principle in which its chief properties reside. The solution contains, likewise, a portion of soda; and this soda is equally discovered in the coagulation of bile by acids, the salt which soda forms with the acid employed in the experiment remaining in the liquor from which the albumen has been precipitated.

Besides these principles, there exists in bile a species of saccharine matter, approaching in its properties to Sugar of Milk. Cadet obtained it by the simple process of decomposing bile by muriatic acid, and evaporating the residual filtered liquor, so as to cause it to crystallize. Along with crystals of muriate of soda, crystals of a different form of this peculiar matter were obtained. Thenard having obtained it by a more complicated process, in what he supposes to be a state of greater purity, found it to be soluble in water and in alkohol; it does not ferment with yeast, gives no ammonia by distillation, and is not affected by infusion of galls. It contributes, he supposes, with the portion of soda which bile contains, to the solution of the resinous matter; these three principles forming a ternary compound, which, with a little albumen and some saline matter, constitute bile. The salts are muriate, sulphate, and phosphate of soda, and phosphate of lime, with a little oxide of iron. The proportion of resinous matter in 1000 parts is, according to Thenard's analysis, about 43, of saccharine matter 41, of albumen 4, soda 4, of the above neutral salts 5.5, oxide of iron 0.5.

There are often found in the receptacle of the bile, the gall-bladder, concretions, or Biliary Calculi. These are not always uniform. Those most common are of a lamellated structure, and are composed of a substance analogous to the animal fat, named Spermaceti, or rather to the substance which has been named Adipocire, and of which spermaceti is a variety. This matter is fusible by heat; it is soluble in alkohol, when a boiling heat is applied, but precipitates in brilliant scales as the solution cools: It is also soluble in ether, when heat is applied; and potash and soda dissolve it, forming a kind of saponaceous compound. It forms the substance of the biliary calculi, in which it exists, disposed usually in crystalline laminæ, more or less mixed with a yellowish or greenish matter, which is probably inspissated bile; in some this matter predominates, so that the adipocire is discovered only by its deposition, when the concretion has been dissolved in boiling alkohol. And sometimes the calculus consists of alternate layers, formed of mixtures of these in different proportions.

Sect. VIII.—*Of Urine, Urée, Uric Acid, Urinary Calculi.*

The fluid secreted from the kidneys, contains more saline substances than any other secreted fluid; these it is probably designed to convey from the system: there is

also dissolved in it an animal principle, which gives to it peculiar characters.

When newly secreted, its colour is pale, its odour peculiar, but not fetid; it is transparent, but usually becomes turbid as it cools. It is sensibly acid, reddening the infusion of litmus. But, from the spontaneous changes it suffers producing ammonia, this acidity is soon neutralized, and it even becomes alkaline. These changes continue to proceed, mucous flakes are precipitated, the ammoniacal odour becomes strong and fetid, and the whole of the animal matter is at length decomposed, being converted principally into ammonia, combined with carbonic and acetic acids.

When urine is exposed to a gentle heat, its watery portion is dissipated, and with this carbonate of ammonia is formed and disengaged, the quantity increasing as the temperature rises. The liquid becomes turbid and deep-coloured; and when it is reduced to the consistence of thin syrup, it passes, on cooling, to the state of a confusedly crystallized mass; a liquor remains, very dark-coloured, holding the peculiar animal matter of urine dissolved.

The free acid existing in urine newly discharged, is principally the peculiar acid named Lithic or Uric Acid; it is often so abundant, as to be in part deposited, forming the reddish sediment deposited as urine cools; with this there is generally present a portion of phosphoric acid, and, as Thenard states, of acetic acid. A small quantity of benzoic acid is also often present, particularly in the urine of children, and of gramenivorous animals, in which case the uric and phosphoric acids are usually deficient.

All these acids, by the generation of ammonia, are speedily neutralized, and exist in the state of the salts which they form with that alkali, together with carbonate and acetate of ammonia, formed by the spontaneous decomposition of the urine.

Besides these, several neutral salts exist in urine. These are obtained by evaporation in a crystallized state, forming a saline matter, named by the older chemists Microcosmic Salt. This consists of a number of salts, phosphate of soda, phosphate of ammonia, phosphate of magnesia, phosphate of lime, muriate of soda, muriate of potash, muriate of ammonia, and the triple compounds of phosphate of soda and ammonia, and phosphate of magnesia and ammonia. These exert mutual affinities, which modify their properties, and render their entire separation difficult. They probably do not all pre-exist in the urine; those in particular which contain ammonia, derive a portion of it at least from what is formed by the combination of its elements during the evaporation. The quantities of them are of course liable to be varied according to the state of the secretion, and the time during which the urine has remained in the bladder. According to Mr Cruickshank's experiments, 36 ounces of urine yield an evaporation from one ounce to one ounce and a half of solid matter, consisting, on an average, of muriates one drachm, of phosphates nearly four drachms, uric acid and super-phosphate of lime twenty-five grains, animal matter three drachms and forty grains.

When the entire matter obtained by the evaporation of urine is urged by a strong heat, it affords a large quantity

of carbonate of ammonia, accompanied with a fetid oil, and with elastic products. Muriate of ammonia is sublimed, and towards the end of the distillation, a small portion of phosphorus disengaged from the decomposition of the phosphoric salts is volatilized.

The action of re-agents on urine affords some information with regard to the principles it contains, which renders its analysis more perfect. The acids have not much effect on it in its healthy state; they sometimes coagulate or render it milky, an effect indicating the presence of albumen, from a morbid state of the secretion. Oxalic acid gives a precipitate by combining with the lime it contains. If much loaded with the animal matter named Urée, nitric acid throws down a scaly pearly precipitate. The fixed alkalis precipitate phosphate of lime; the solutions of lime, barytes, and strontites, or of any of their soluble salts, produce more copious precipitates, as they decompose all its phosphoric salts, and form with the phosphoric acid insoluble compounds. The nitrates of silver, and of lead, form precipitates, from the metallic oxide combining both with the muriatic and phosphoric acids of urine. Infusion of tannin generally occasions a cloudiness in urine, indicating the presence of a little gelatin, and in some morbid affections, produces even a copious precipitate.

Besides the saline substances contained in urine, there exists in it a peculiar principle, which giving it some of its most characteristic properties, has been named Urée. It remains in a great measure in solution, when the saline matter has been separated by crystallization; and some of its properties had been observed by Rouelle. His obser-

vations had been neglected until its existence and properties had been again pointed out by Mr Cruickshank, who gave the process for obtaining it in its crystallized form, by the action of diluted nitrous acid on the extractive matter of urine. Fourcroy and Vauquelin observed its production in the same experiment, and they gave also another process, by which it is more directly obtained, and without any ground for the suspicion that it is formed in the process. To the crystallized mass obtained by the evaporation of urine, there are added four times its weight of alkohol in successive portions, heating them gently. The solution contains the urée; it is distilled until of the consistence of syrup; and in cooling, this deposites the urée crystallized in quadrangular plates of a brilliant yellowish-white colour.

This substance exhales a strong urinous odour; it has a smooth greasy feel, attracts humidity from the air, and becomes liquid; dissolves readily in water, and dissolves also, though more sparingly, in alkohol; if its solution has been made with the aid of heat, it crystallizes on cooling. So susceptible is it of decomposition from the re-action of its principles, that its watery solution passes quickly into a kind of fermentation, analogous to the acetous, a disengagement of carbonic acid gas takes place, and acetic acid with a portion of ammonia are formed. If the solution is submitted to distillation, the urée, by adding fresh quantities of water, and repeating the distillation, is almost entirely converted into carbonate of ammonia. If the solid urée be exposed to heat, it melts quickly, carbonate of ammonia sublimes, and this continues without any condensation

of water, or production of empyreumatic oil, farther than a minute portion that tinges the salt brown, and gives it a fetid odour. The carbonaceous residuum, after it has been urged by a strong fire, gives by lixiviation a liquor containing prussic acid, and when burnt in the open fire, yields a saline matter, principally carbonate of soda. Carburetted hydrogen, carbonic acid, and nitrogen gas, are disengaged. During this decomposition, urée is thus by the new combinations established among its principles by an elevated temperature, converted almost entirely into carbonate of ammonia; these elements must of course be carbon, oxygen, nitrogen, and hydrogen; the proportions it can scarcely be possible to estimate with any precision.

The acids act peculiarly on urée. Sulphuric acid diluted decomposes it when aided by heat, forming from its elements a portion of oil, acetic acid, and ammonia, and precipitating charcoal. Nitric acid, parting with oxygen so readily, might be expected to decompose rapidly a substance so susceptible of decomposition; yet what is singular, it appears rather merely to combine with it. When the acid is added to a strong solution of it, there is an instant deposition of crystalline scales, white and brilliant, which augments rapidly; this, when heated gently, softens and melts, an effervescence takes place, and it is converted principally into nitrate of ammonia. Hence Fourcroy and Vauquelin concluded, that it is a compound of nitric acid and urée. If heat is applied, however, to favour the action of the acid, or if the strong acid is poured on concrete urée, decomposition takes place, nitric oxide, nitrogen, and carbonic acid gases are disengaged,

with prussic acid; and a white or yellowish concrete matter remains, consisting principally of nitrate of ammonia. Muriatic acid has little effect on urée, precipitating it only from its solution in alkohol in brown flocculi; oxy-muriatic acid decomposes it, disengaging nitrogen and carbonic acid gases, and forming a concrete oily matter. The results of all these decompositions prove the predominance of nitrogen in the composition of this principle.

The alkalis dissolve urée; the fixed alkalis at the same time cause an evolution of ammonia, partly from the decomposition of ammoniacal salts mixed with it, and partly from the decomposition of the urée itself; carbonic acid and acetic acid are at the same time formed, and a concrete oily matter is separated.

Urée so far modifies the properties of a number of the neutral salts, as to cause them to crystallize, under a form different from that which their crystals usually assume. Its solution decomposes several of the metallic salts. Tannin changes the colour of its solution, but does not form with it any precipitate.

The tendency of this principle to pass to the state of ammonia, is probably occasionally the cause of morbid changes in the urine, and perhaps gives rise to the formation of urinary calculi, by neutralizing the acid which holds some of the substances usually contained in the urine dissolved. The predominance of nitrogen in its composition is a singular fact, and proves the developement of this element by the processes of the animal system, since its excess is thus discharged by an excrementitious fluid.

Uric Acid is a substance peculiar to urine and urinary calculi, and with these therefore its history is best connected.

Scheele discovered this acid as the principal ingredient of urinary calculi; he found, too, that it is always contained in urine, forming the reddish-coloured sediment which it often deposites. From forming the basis of stone of the bladder, it received the name of Lithic Acid; as a common ingredient in urine, it is named Uric Acid.

It is difficult to procure it pure. The process given by Dr Henry is to dissolve a calculus composed of it in a solution of potash; this solution is decomposed by muriatic or acetic acid; the uric acid is precipitated, and is washed repeatedly with distilled water, a few drops of liquid ammonia having been added to the first portion of water, to remove more completely any foreign matter from the acid. It is thus obtained in the state of a white powder, rough to the touch, and tasteless. It is so sparingly soluble in water, as to require nearly 2000 times its weight at 60° to dissolve it; at 212° it is soluble in little more than 1000 parts, and this solution, on cooling, deposites minute pellucid crystals. It reddens infusion of litmus, decomposes soap, and precipitates the alkaline sulphurets,—properties sufficient to characterize it as an acid, though some chemists have been inclined to rank it as an oxide. It is so weakly acid as to be incapable of decomposing the alkaline carbonates, nor is it dissolved by their solutions.

Uric acid combines with the alkalis and earths, forming compounds in general of sparing solubility, tasteless, and scarcely to be distinguished in external appearance

from the acid itself. The urate of ammonia is most soluble, and even of it an ounce of distilled water does not dissolve more than 2 or 3 grains at 60° ; next to it in solubility is the urate of potash. The alkaline urates become more soluble with an excess of base; and hence they are dissolved by boiling in an alkaline solution. These compounds, whether neutral or with an excess of base, are decomposed by all the acids, even the weakest, as the carbonic or prussic; they are decomposed, too, by almost all the neutral salts.

Uric acid is decomposed by the mineral acids; sulphuric acid chars it. Nitric acid has a singular effect upon it, affording a test which serves to distinguish it. It produces with it, when not added in excess, a red colour; this is deep when the mixture is concrete; it is also communicated to water in solution, but is destroyed both by alkalis and by acids. When nitric acid is repeatedly distilled from uric acid, it decomposes it, carbonic acid and nitrogen gases are disengaged, and prussic acid and nitrate of ammonia formed. Muriatic acid has little effect on uric acid; oxy-muriatic acid decomposes it, producing principally ammonia and carbonic acid.

Uric acid is decomposed by heat, affording carbonate of ammonia, carbonic acid, carburetted hydrogen, prussic acid, and a peculiar matter which sublimes and condenses in a concrete form. This substance has the properties of an acid, but is different from the uric acid. Its taste is slightly sour and bitter; it is much more soluble in water; it is volatilized by a moderate heat without decomposition, and it does not give a red colour with nitric acid. It is

sparingly soluble in alkohol. Its solution in water reddens infusion of litmus. By evaporation it affords minute crystals; it combines with the alkalis, and is not precipitated from these solutions by the acids; neither does it precipitate the earthy salts. In some of its properties it is analogous to succinic, in others to benzoic acid; but still it differs from either, and from every known acid. When decomposed by the application of a strong heat, it affords products similar to those from the decomposition of uric acid, and is no doubt formed from an alteration in the state of combination of these elements, produced by the heat by which it is sublimed.

The composition of the urine varies in the different species of animals. In those who feed on grass, the uric acid is wanting, while benzoic acid is generally present; and this is also frequently the case in the urine of children. The urine of the horse, cow, and camel, contains no phosphates, but muriates, sulphates, and carbonates, with urée.

Urinary Calculi owe their formation to deposition from the urine, or morbid changes in its secretion; and the investigation of their chemical constitution and properties is therefore connected with its history. It is one of much importance, from its relation to the discovery of the means by which their formation may be prevented, or by which they may be removed.

These concretions are not uniform; they differ much in their physical qualities, and it has been discovered that they differ not less in their chemical nature. The follow-

ing substances enter into their composition; uric acid, urate of ammonia, phosphate of lime, phosphate of ammonia and magnesia, oxalate of lime, silex, and animal matter; these substances being more or less pure, or mixed, and being often diversified by mechanical structure, so as to render it difficult to reduce these concretions to well-defined species.

Dr Wollaston has reduced them to four species; 1*st*, that composed chiefly of uric acid; 2*d*, what has been named the Fusible Calculus, composed chiefly of phosphate of ammonia and magnesia; 3*d*, The Mulberry Calculus, as it has been named by surgeons, consisting of oxalate and phosphate of lime; and, 4*th*, The Bone-Earth Calculus, formed almost entirely of phosphate of lime. Fourcroy and Vauquelin have given a classification more minute and complicated, but not strictly chemical, calculi being admitted as species, from mere differences in mechanical structure.

1*st*, Uric Acid Calculus. This is by far the most common. These calculi are of a brown or yellowish colour, smooth, displaying internally a fibrous or radiated structure, and often in fine layers of different shades, rather soft and brittle, with a specific gravity from 1.276 to 1.786. They are not melted by heat, but charred, exhaling an empyreumatic odour. They are insoluble in cold water, but dissolve when boiled in water. Alkaline solutions dissolve them readily in the cold, and a white precipitate is thrown down by the addition of an acid. Lime-water dissolves them more sparingly. Nitric acid produces the red colour characteristic of uric acid; the other acids act

weakly on them. In many the uric acid is nearly pure, in others it is intermixed with other ingredients. A calculus has been supposed to exist of urate of ammonia; but, from Mr Brande's observations, the ammonia which it exhales under certain trials arises from the decomposition of urée, or of phosphate of ammonia. It is less sensibly striated, and its colour is lighter than the pure uric acid calculus; and it is distinguished by the chemical character of dissolving in alkaline solutions, and exhaling a smell of ammonia, two properties which are not found together in any other species.

2d, Calculus of Phosphate of Magnesia and Ammonia. Fusible Calculus of Wollaston.—Phosphate of magnesia and ammonia seldom forms an entire calculus. It is either, if pure, discharged under the appearance of a white sand composed of minute crystals, or it is intermixed with other ingredients, particularly with uric acid and phosphate of lime, and frequently forms alternate layers of these, or covers a nucleus of uric acid. It is distinguished by its softness and smoothness, its white colour, its lamellated texture, and its giving a fine powder of brilliant whiteness. Before the flame of the blowpipe it melts into a white enamel; is charred when placed on burning fuel, and emits an ammoniacal smell; on raising the heat it melts. It dissolves very sparingly in boiling water. The acids, even those that are weak, dissolve it easily, leaving any animal matter mixed with it undissolved. The fixed alkalis disengage its ammonia, combine with its acid, and precipitate the magnesia.

3d, Calculus of Phosphate of Lime. This sometimes

composes the entire substance of a concretion, though more frequently it is mixed either with uric acid or with phosphate of magnesia and ammonia, or disposed with them in layers. When pure or little intermixed, the concretion is of a pale brown colour, and so smooth as to appear polished; its texture is laminated. It dissolves slowly, but entirely, in muriatic or diluted nitric acid, and it is little affected by alkaline solutions. Before the flame of the blowpipe it is at first charred, but soon becomes white; and, if the heat be raised as high as possible, is fused.

4th, Calculus of Oxalate of Lime. This has been long known by the name of Mulberry Calculus, from its colour and its rough painted surface. Dr Wollaston shewed that it consists chiefly of oxalate of lime, with animal matter. It is of a dark brownish or purplish colour externally, often grey within; its surface is usually uneven, often covered with protuberances: it is the hardest and the heaviest of the urinary calculi. It is also less affected than any of them by the usual re-agents. The alkaline solutions do not affect it, and the stronger acids,—the nitric and muriatic dissolve it only with great difficulty. The solutions of the alkaline carbonates decompose it, precipitating carbonate of lime. It is also decomposed by heat, leaving, when urged by a strong fire, pure lime amounting to about one third of its weight.

In all these calculi, besides the saline matter of which they chiefly consist, there is present a portion of animal matter, which appears to give them colour and induration; it is found even in those which are white and crys-

talline; in the mulberry calculus, it is present in larger quantity than in the others. According to Fourcroy and Vauquelin, it is analogous to albumen, with frequently a mixture of urée. The ingredients of calculi are often also diversified by intermixture in layers more or less distinct. These must of course be various, and as their production is in some measure accidental, irregularly arranged. Those which have been most frequently observed, are alternations of uric acid with phosphate of magnesia and ammonia, or phosphate of lime; or of oxalate of lime with the uric acid, or with either or both these phosphates.

An important subject of investigation, arising from our knowledge of the nature of these concretions, is that relating to the practicability of their solution, and the means by which this may be accomplished. The internal administration of alkalis, with this view, is a practice that has long been had recourse to; and it has been sufficiently ascertained that the urine may thus receive, to a certain extent, an alkaline impregnation, and that from this considerable relief is obtained. It has farther been supposed, that with regard to some calculi, at least those in which uric acid is predominant, and which are by far the most common, a real solvent power may be exerted; and from the continued use of alkalis, a solution of the calculus, if it is of a moderate size, may be obtained; the solution of the calculus of phosphate of ammonia and magnesia, and that of phosphate of lime, it has on the other hand been supposed, might be effected by the administration of an acid.

So far as relieving the pain and irritation which attend

stone in the bladder, the advantage derived from the moderate use of alkaline remedies is unquestionable. But there is every reason to doubt of the practicability of employing them so as to obtain the actual solution of a calculus; the degree of alkaline impregnation which the urine can receive is so inconsiderable, and the irritation produced, both in the stomach and bladder, by the alkali taken to this extent, so great, that its use cannot be continued for any length of time. Besides this, the recent observations of Mr Brande have placed in a still clearer light the impracticability of the attempt; for in rendering the urine alkaline, so as to enable it to act on the calculus, there is the risk of causing the deposition of phosphate of ammonia and magnesia, or phosphate of lime. On the other hand, the solution of a calculus of either of these could not be attempted, by rendering the urine acid, without the hazard of producing a precipitate of uric acid; nor is it probable that the alternate exhibition of these could be so adjusted as to produce any beneficial effect. All that is practicable probably is, the giving the alkali so far as to render the urine less irritating, and thus alleviate the pain.

Sect. IX.—*Of the Synovia.*

This name is given to the liquor found within the capsular ligaments of the joints, the motions of which it is evidently designed to facilitate. It is viscuous, of a green-

ish colour, and more or less transparent: when withdrawn from the capsule, it becomes gelatinous; after some time it loses this consistence, and deposites a fibrous elastic matter. It mixes easily with water, rendering it viscuous. Acids added to it throw down a flocculent precipitate, without diminishing the viscosity; but, when much diluted, they remove it; the liquor becomes thin and transparent, and a fibrous-like substance is precipitated.

This fibrous matter has properties analogous both to albumen and fibrin, yet still it differs from both. It is similar to the gluten of wheat in colour, taste, and odour, in tenacity and elasticity; it is soluble, however, by agitation in cold water.

There remains, after its precipitation, a portion of albumen, which may be separated by heat, or by alkohol; and when this is withdrawn, the residual liquor gives crystals of muriate of soda by evaporation. Its residual matter, when it is decomposed by heat, gives muriate and carbonate of soda; and its charcoal, by incineration, affords phosphate of lime.

Margueron, by whom it has been analysed, concludes that 100 parts of synovia contain 11.8 of fibrous matter, 4.5 of albumen, 1.75 of muriate of soda, 7 of carbonate of soda, and 7 of phosphate of lime.

Arthritic Concretions, or those concretions often deposited in the joints during a paroxysm of the gout, are probably formed by the medium of this fluid. Dr Wollaston found unexpectedly that they consist of urate of soda, as they had been supposed to be phosphate of lime.

Sect. X.—*Of the Amniotic Fluid.*

This fluid, with which the fœtus is surrounded in the amnios, is entitled to notice, as having afforded to Vauquelin what he has regarded as a new acid. The amniotic liquor of the cow is that which he examined; it is slightly viscid, has a reddish colour, an acid and bitter taste, and a faint odour. It reddens the more delicate vegetable colours. On evaporation, it forms brilliant crystals, coloured by a little animal matter, which may be removed by washing with a little water, and crystallizing again.

These crystals are the Amniotic Acid. It is white and brilliant, has a slightly sour taste, reddens infusion of litmus, is sparingly soluble in cold water, but dissolves more abundantly in hot water. It is also soluble in alkohol. It combines with the acids, forming peculiar salts, which are soluble. It does not decompose the alkaline carbonates, unless when aided by heat; nor does it precipitate the earthy salts, or the nitrates of silver or lead. It is decomposed by heat, exhales ammonia and prussic acid, and leaves a bulky charcoal.

It is singular, that the human amniotic fluid contains none of this acid, but consists of albumen and gelatin dissolved in water, with muriate and carbonate of soda, and phosphate of lime.

Sect. XI.—*Of the Humours of the Eye.*

The ball of the eye contains three fluids,—the Aqueous Humour, in the anterior chamber; the Crystalline Humour, or Lens, in the central space; and the Vitreous Humour, occupying the space behind the lens. They differ in their physical properties, but little in their chemical nature.

Aqueous Humour is a clear transparent liquid, having little smell or taste. It causes little change in the vegetable colours; exposed to the air at a moderate warmth, it evaporates, and a coagulum is formed, so small as hardly to be perceptible. Evaporated to dryness, it leaves a matter weighing not more than 8 *per cent.* of the original liquor. Tannin causes a precipitate in the fresh humour, both before and after it has been boiled, shewing the presence of gelatin. Nitrate of silver causes a precipitate, which is muriate of silver. It appears, therefore, that the aqueous humour is composed of water, albumen, gelatin, and a muriate, the basis of which is soda.

Crystalline Humour. This is solid, and composed of concentric lamellæ, which appear to become more dense towards the centre. The mean specific gravity is 1.100. When fresh, it is neither acid nor alkaline. It putrefies rapidly. It is nearly soluble in cold water, and is partly coagulated by heat. Tannin gives an abundant precipitate; but there are no traces of muriatic acid. It is composed, therefore, of less water than the others, but of a larger proportion of albumen and gelatin, and also a little phosphate of lime.

Vitreous Humour. This being pressed through linen, to free it from its capsules, Mr Chenevix could not, in that state, by all the experiments he made on it, perceive any difference between it and the aqueous humour, either in specific gravity, or in its chemical nature.

Sect. XII.—*Of the Skin, Cellular Fibre, and Membrane.*

The soft solids enumerated in the title of this section are closely connected, having the principle named Gelatin principally for their basis. The peculiar character which distinguishes this, is that of dissolving in warm water, and forming with it a solution which, when cold, is of a gelatinous consistence, more or less firm according to the proportion of water. It forms, too, an insoluble compound with tannin; and this affords a test of great delicacy, by which it is discovered. Corrosive muriate of mercury does not precipitate it, by which it is distinguished from albumen. The acids dissolve it, and partially decompose it; nitric acid disengaging nitrogen, though not in large quantity. The alkalis also dissolve it: the alkaline earths render its solution turbid. This principle, decomposed by heat, affords the usual products obtained from the decomposition of animal matter. It is the one most susceptible of spontaneous decomposition.

The Skin, which forms the external covering of the body, consists of the Cuticle, or Epidermis, and beneath this the Cutis, or true skin, with a cellular substance in-

terposed. The Cuticle is nearly inorganic; when detached from the parts beneath, it is extremely thin and transparent. It is insoluble in water, even by long boiling, and is equally insoluble in alkohol. Alkaline solutions dissolve it, forming a kind of soap. Lime also dissolves it. The acids decompose it, sulphuric acid forming with it a soapy pulp, nitric acid staining it yellow.

The true Skin is thicker than the epidermis, and has considerable firmness and elasticity. If boiled strongly in water it is dissolved, and the solution has all the characters of gelatin, being precipitated by tannin, and nitro-muriate of tin; and attaining, when evaporated, a gelatinous consistence. Even in its dense state, it combines with tannin slowly, and hence the change which it suffers in the operation of tanning, the combination taking place with more celerity, as the skin is more soft and flexible.

Acids decompose skin; nitric acid, which acts on it most readily, causing an evolution of nitrogen gas and prussic acid, and a formation of oxalic acid, the skin acquiring also a yellow colour. It is soluble in alkaline solutions. In its humid state it is liable to putrefaction, but suffers it more slowly, as the skin is more dense and firm. Decomposed by heat, it affords the usual products of animal matter.

The Cellular Fibre interposed between the cutis and cuticle, has been little examined. It is the seat of the colour of the surface of the body, and the colouring matter diffused through it can be acted on through the cuticle, the skin of the negro being whitened by oxy-muriatic acid.

The Membranes, which compose a large portion of the soft solids, forming the cellular texture, the coats of the

vessels, and the coverings of the viscera, appear to be of the same nature. They have similar flexibility, and dissolve in water, forming gelatinous solutions.

Glue is formed by boiling the skin and membranes in water strongly, and reducing the solution by evaporation so far, that on cooling it becomes concrete. It differs in the degree of consistence which it gives to water, as prepared from different substances; and although it is essentially gelatin in all these varieties, it differs somewhat in its chemical properties. The more firm and dense it is, its solution is less easily acted on by tannin, and it is also much less liable to putrefaction, than when obtained in that form in which it is soft and tremulous.

Sect. XIII.—*Of the Muscular Fibre.*

The Muscles, or Flesh of animals, have a distinctly fibrous texture. Their basis appears to be Fibrin not much changed, with which are intermingled small portions of albumen, gelatin, a peculiar extractive matter, and saline matter, these being derived, in part at least, from the blood diffused by the medium of the blood-vessels. To this, too, the colour is owing, as when washed with water, the muscular substance remains white, and similar in appearance to fibrin. The water employed in this operation holds dissolved the other principles. When heated, the albumen is separated from it by coagulation in flakes; if these are removed, and the liquor evaporated, it

becomes gelatinous, a little fatty matter separating and collecting on the surface; and by this simple experiment the albumen and gelatin are detected. Besides these, a portion of a peculiar extractive matter is obtained by evaporating the jelly to dryness, and treating it with alkohol, the alkohol dissolving the matter, and yielding it, by evaporation, in a solid form. It is of a brownish colour, has a pungent odour, and a taste somewhat aromatic. Lastly, the saline matter is procured by boiling water on the muscular fibre, previously washed; it consists of phosphates of soda and ammonia, and phosphate and carbonate of lime. As they remain in the muscle after washing, and are only extracted by boiling, they are probably essential to its composition; they differ, too, in their proportions, at different periods of life, being more abundant in the coarse and rigid muscular fibre of adult animals, than in the more delicate fibre of those who are young. In the latter, too, the proportion of gelatin is larger than in the former.

When the flesh, without any preparation, is boiled in water, the gelatin and albumen are more completely extracted and dissolved, and the fibrin is diffused in threads in the boiling liquor. The albumen coagulates, the gelatin is detected by the abundant precipitate formed with tannin, or if the liquor be sufficiently evaporated, it renders it gelatinous.

When the muscular substance is exposed to the air, it soon becomes tainted, and at length putrid, a change principally arising from the presence of gelatin, which is peculiarly liable to putrefaction when humid; and, accord-

ingly, if it has been removed by washing, the flesh remains much longer sound. If the air is excluded, and the flesh immersed in water, it is gradually converted into a fatty substance, a species of decomposition which is afterwards to be considered.

Muscular fibre, decomposed by heat, afford the usual products of animal matter. Its residual charcoal gives, by incineration, carbonate and phosphate of lime.

The acids decompose the muscular fibre, with results nearly similar to those afforded by their action on fibrin. Nitric acid disengages nitrogen gas, with a portion of carbonic acid gas, and the principal product is an unctuous substance of a yellow colour, rancid smell, bitter taste, and sensibly acid. The unctuous matter, according to Fourcroy and Vauquelin, may be separated by the action of alkohol from the acid. The latter is a substance altogether peculiar, to which these chemists have given the name of Yellow Acid, and which they suppose to have some relation to the yellow and bitter principle of bile. It is of a deep-yellow colour, has an intensely bitter taste; and its acidity, which is displayed in its power of reddening the vegetable colours, and combining with the alkalis, they conclude, belongs to it, and is not derived from any portion of the nitric acid employed in its formation adhering to it.

Sect. XIV.—*Of Tendon, Ligament, Cartilage, Horn, &c.*

These substances appear to have albumen for their basis; they pass insensibly into each other, and they form the transition into shell and bone.

The Tendons have a considerable degree of toughness and elasticity; their texture is fibrous. They are scarcely affected by water, unless by long boiling, when a gelatinous solution is said to be obtained.

The Ligaments are distinctly fibrous in their texture, and have much firmness and cohesion. When boiled in water, they afford a portion of gelatin, but the entire substance cannot be dissolved, and it probably, therefore, consists of indurated albumen.

Cartilage has a still greater degree of induration It is, however, sufficiently soft to be cut easily; it has also much cohesion and elasticity. It is softened by maceration in water, and the softer cartilages are, by boiling, nearly entirely dissolved. Acids do not exert much action on the matter of cartilage: when dilute or weak, they do not dissolve it; strong nitric acid decomposes it; alkalis dissolve it. The base of cartilage, and of many of the other animal solids, Mr Hatchet inferred from experiment to be indurated albumen, and to be analogous, in chemical properties, to pure coagulated albumen dried. In these solids, it is usually combined with portions of gelatin, and of earthy matter, principally phosphate of lime, but in cartilage it appears to be nearly pure.

Horn has a considerable similarity to cartilage, differing from it principally in a greater degree of induration. When boiled strongly in water, it affords a small quantity of gelatin, the most flexible horn yielding the largest quantity; the residual matter is indurated albumen, with a small quantity of phosphate of lime. It is singular, however, that the horn of the stag is of a very different nature, consisting principally of gelatin, with phosphate of lime, and being therefore analogous to bone. Hoof is, both in mechanical structure and chemical composition, similar to horn; as are also the matter of the Nail, the Scales of insects, Feather and Quill; all of these, when boiled in water, giving scarcely any gelatin, but consisting apparently of indurated albumen.

Hair, though apparently very different from these substances in mechanical structure, is similar in its chemical nature. When boiled with water, it affords a small portion of gelatin, and the residuum, Mr Hatchet found, had all the characters of indurated albumen. The hair also contains an oily matter, which may be extracted by alkohol macerated on it; in this the colouring matter appears to reside, as it is always obtained of the colour of the hair.

Wool is merely a finer hair. It has scarcely been chemically examined, but it has one of the characteristic properties of indurated albumen, that of forming a saponaceous compound with alkalis.

Silk is connected with these substances in physical properties and chemical constitution, though there are also some peculiarities with regard to it. It is in fine fibres, of different shades of colour, naturally covered with a kind

of varnish which communicates stiffness and elasticity; both the colouring matter and varnish are removed by the successive application of weak alkaline leys, alkohol, and diluted muriatic acid. The pure silk is insoluble in water, even at a boiling heat; it is also insoluble in alkohol. The fixed alkalis dissolve it, and decompose it, causing an exhalation of ammonia. The acids also dissolve and decompose it. Nitric acid disengages nitrogen gas, and forms prussic and oxalic acids, with a portion of a peculiar matter, named by Welter, who observed its production, Bitter Principle, from its intensely bitter taste, of a yellow colour, soluble in water and in alkohol, crystallizable and inflammable, and which appears to be the same product with the yellow bitter acid already noticed, as produced in the decomposition of the muscular fibre, by nitric acid.

The silk-worm forms along with the silk an acid liquor, which was supposed to be a peculiar acid, and received the name of Bombic acid. There is reason to believe that it is merely acetic acid, weak and impure.

Sect. XV.—*Of Bone and Shell.*

Bone and Shell differ from the preceding substances in their greater induration, derived from the larger quantity of earthy matter that enters into their composition. In bone the earthy matter is principally phosphate of lime,

in shell it is carbonate of lime, but these are intermixed in the different varieties; and there are intermediate substances, the crustaceous coverings of certain marine animals, and of zoophytes, in which the proportions of phosphate and carbonate are nearly equal.

Bone admits of a simple analysis, by which its immediate principles are discovered. By boiling in water, a liquor is formed, which becomes of the consistence of a jelly on cooling, proving the presence of a large proportion of gelatin. If the bone, without boiling in water, be digested in dilute muriatic or nitric acid, the gelatin and earthy matter are dissolved, and a transparent cartilaginous substance remains, retaining the figure of the bone. By calcination in the open fire, the animal matter is burnt out, and the earthy matter is obtained, which farther analysis discovers to be phosphate of lime; it is likewise separated during the decoction of bone under increased pressure, an experiment which proves that it pre-exists in the bone, and is not formed during the calcination. Lastly, during the boiling of bone in water, a portion of oily matter separates, and collects on the surface. By these experiments, then, bone is proved to be composed of gelatin, cartilage, phosphate of lime, and unctuous matter, the last being probably adventitious, and derived from the marrow diffused through the layers of bone. Some other principles appear to be present, too, in smaller proportion. A little carbonate of lime exists in recent bone; and a larger quantity, with a portion of sulphate of lime, are found in calcined bone, the greater part of which is probably formed during the calcination. Berzelius has discovered fluate of

lime; and in the bones of the lower orders of animals, there is a portion of phosphate of magnesia. The proportions of all these ingredients must be various in bones in different states; the earthy matter becomes more abundant as the animal advances in life. The quantity of gelatin extracted by boiling in water is from 25 to 50 in 100 parts, the remainder being principally phosphate of lime.

When bone is exposed to heat gradually raised, it is decomposed, a large quantity of carbonate of ammonia is volatilized, formed by new combinations of the elements of its animal matter. This is accompanied with a portion of a very fetid oil, and with quantities of prussic and sebacic acids, carburetted and sulphuretted hydrogen gases. The bone remains charred, but when urged with a strong heat in an open fire, it becomes white; this residual matter, which retains the figure of the lime, being composed of its earthy salts. It is analysed by the action of the acids. On the addition of any of the more powerful acids, an effervescence is excited from the disengagement of carbonic acid, and a pungent smell, arising probably from the evolution of prussic and carbonic acids. If sulphuric acid has been employed, sulphate of lime remains, and the liquor obtained by washing the materials is a solution of superphosphate of lime. If nitric acid has been used, the entire calcined bone is dissolved with effervescence; from the solution phosphate of lime is precipitated by the addition of ammonia; by adding to the residual liquor nitrate of barytes, sulphuric acid is detected; and from the quantity of it, the proportion of sulphate of lime may be inferred; and the proportion of carbonate of lime may likewise be

inferred from the quantity of carbonic acid disengaged during the solution.

Bone is not much liable to spontaneous decomposition, the re-action of the elements of its animal matter being in a great measure prevented by the inert earthy matter in which it is involved, and the solidity which this communicates to it. In fossil bones, or those which have been long buried in the earth, the animal matter is removed by slow decomposition, and its place supplied by carbonate of lime, conveyed probably by slow infiltration.

The Enamel of the teeth is evidently of the nature of bone. It has the peculiarity, however, of containing a very small proportion of animal matter. In dissolving in acids, it produces a slight effervescence, and contains therefore a portion of carbonate mixed with its phosphate of lime. Morichini announced the presence of fluoric acid in the enamel, vapours of it being disengaged by the action of sulphuric acid, and also the presence of the same acid in ivory, or the enamel or outer layer of the fossil-teeth of the elephant.

Shell, or the hard covering with which the bodies of many marine, and also of a number of land animals are covered, is in structure similar to bone. It was known, however, to contain a large proportion of carbonate of lime; and Mr Hatchet's experiments have shewn, that it is this which forms its principal earthy matter, mixed sometimes with small proportions of phosphate of lime. Marine shells are of two descriptions, either of a porcellaneous aspect, with an enamelled surface and fibrous texture, or composed of the substance called Nacre, or

Mother of Pearl. The former afford no trace of phosphate, but consist of carbonate of lime, with animal matter, which Mr Hatchet considers as indurated albumen, in small proportion. The latter also contain carbonate of lime, but the animal matter is in much larger proportion; it often constitutes even a large part of the shell, and is so highly indurated as not to be gelatinous. In shells of this kind it appears to be deposited in layers, alternating with corresponding thin layers of carbonate of lime. Mother of pearl, and pearl itself, are of this structure and composition; and their waved appearance, and iridescence, and nebulous semi-transparency, appear to arise from it.

The substance of zoophytes, comprising the varieties of madrepore, millipore, and tubipore, consists likewise of carbonate of lime, with animal membrane. The substance analogous to shell, which forms the covering of crustaceous marine animals, has the same cementing animal matter as other shells, but with this are united both carbonate and phosphate of lime. The shells of the eggs of birds are of similar composition. Both form therefore a substance intermediate between Bone and Shell.

Sect. XVI.—*Of Fat, Spermaceti, Sebacic Acid.*

Animal fat has nearly the same properties as vegetable oil. In the living animal body it is nearly fluid, and is contained in distinct cells; after death it in the greater

number of cases becomes concrete, and more or less firm, and is freed from the membranous matter by melting it out, a little water being usually added to prevent the heat from being applied too strong. As thus obtained, it is usually insipid and inodorous; when of a soft consistence it forms lard, when firmer, tallow. As obtained from a number of marine animals, it remains fluid, and has an offensive smell.

Fat is insoluble either in water or in alkohol. Exposed to the air it is liable to become rancid, a change which appears to be connected with the absorption of oxygen. It melts easily; by raising the heat it is rendered more acrid, a pungent vapour arises from it; and in close vessels it is decomposed, the oily fluid which distils over being changed in its properties, and this being accompanied with a production of acid, and a disengagement of carbonic acid, and carburetted hydrogen gases. Ammonia in small quantity is also produced in this process.

Fat is highly inflammable, and affords by its combustion water and carbonic acid. Carbon and hydrogen are therefore its chief elements. The production of an acid in its destructive distillation, indicates the presence of oxygen, and that of ammonia the presence of nitrogen in inconsiderable quantities.

The acids act chemically on fat. Sulphuric acid chars it. Nitric acid mixed with it in small quantity gives it a firmer consistence; distilled from it, it is decomposed, and acetic and oxalic acids are formed.

The alkalis combine with fat, and form with it perfect soaps. It forms also saponaceous compounds with some

of the earths; and it unites with a number of the metallic oxides, acquiring in the combination a firm consistence. It even facilitates the oxidation of some of the metals, as copper and quicksilver, by the atmospheric air.

The acid obtained in the distillation of fat was regarded as a peculiar one, and as such received the name of SEBACIC ACID. The common process for obtaining it consisted in exposing fat, in mixture with lime, to a strong heat in an iron pot: the acid formed from the decomposition of the fat is attracted by the lime; and the salt thus formed, being extracted by lixiviation, and freed from any adhering unctuous matter by calcination, is, by a second solution in water and crystallization, obtained pure and white. On adding to it sulphuric acid, the sebacic acid is separated, and may be procured by distillation. It has an acrid suffocating odour, is volatile, and reddens the vegetable colours.

From the researches of Gren and Thenard, it appears, however, that this acid is merely the acetic in an impure state. Still, according to Thenard, there is a proper sebacic acid. It is produced by distilling fat, and treating the product with hot water; to the filtered liquor acetate of lead is added; the precipitate which is formed is heated in a retort with sulphuric acid, a watery liquid distils over, and there floats on the liquor of the retort, an unctuous-like substance, soluble in water when boiled with it, and which, on the water cooling, is deposited in crystalline needles. This Thenard regards as the sebacic acid; its taste is slightly sour, it reddens litmus, is soluble in water and in alkohol, and melts at a

moderate heat, assuming an unctuous appearance. It combines with the alkalis and earths, and forms soluble salts.

Spermaceti, the substance deposited from the oil found in the head of several species of whale, particularly the Physeter Macrocephalus, though analogous to fat, differs from it in several of its properties. It is of a flaky texture, soft and brittle, white and brilliant; it melts at 113, and by raising the heat may be volatilized with little change, though by repeated distillation it is decomposed. It burns with a clear flame.

A property distinguishing it from fat, is that of solubility in alkohol and in ether. In alkohol it is very sparingly soluble. It dissolves more rapidly and abundantly in warm ether, but is precipitated on cooling. Oil of turpentine also dissolves it while warm, and allows it to separate when cold.

The alkalis form with spermaceti soaps less perfect than those with fat, and much less soluble. The acids have little effect on it.

This substance is similar in its properties to that which has been already noticed as forming the basis of biliary calculi, and also to that formed by the slow decomposition of muscular fibre; and the whole as a genus has been distinguished by Fourcroy by the name of Adipocire, denoting it as a substance intermediate between fat and wax.

Sect. XVII.—*Of the Cerebral Pulp.*

The soft pulpy matter which forms the substance of the brain, has been submitted to chemical examination, and the results prove it to be different from any other animal principle, though on the whole analogous to albumen. It speedily suffers decomposition when exposed to the air, but immersed under water, may be preserved long without much change. Heated moderately it coagulates, a portion of watery liquor separating from it. When diluted in water, it suffers a similar coagulation by heat; and alkohol and acids produce nearly the same change. Acids decompose it. Alkalis dissolve it, forming saponaceous compounds, and causing an ammoniacal exhalation. By the action of alkohol, aided by heat, there is produced not only the coagulation of the albuminous matter, but a substance is dissolved, and separated analogous to adipocire. Re-agents discover in it the presence of phosphates, principally phosphate of soda and of lime. It is decomposed by heat, and when dry, inflames if the air is admitted, and in its combustion produces a considerable quantity of sulphurous acid.

CHAP. III.

OF THE DECOMPOSITION OF ANIMAL SUBSTANCES FROM THE RE-ACTION OF THEIR ELEMENTS.

The elements of which animal matter is composed having all mutual affinities, and these being nicely adjusted in the combinations which constitute its several varieties, they are liable to be altered by very slight changes of circumstances; and hence the character eminently distinctive of the animal products,—their extreme susceptibility of decomposition. The results of the changes which they suffer from the new combinations into which their elements enter, are different according as these are established at a natural temperature, or by the application of heat; and these two species of decomposition require therefore to be considered apart.

Sect. I.—*Of the Decomposition of Animal Substances at a high temperature.*

The general result of the decomposition of animal substances by the application of heat, is the transition of their elements into binary combinations. From the union of

portions of their nitrogen and hydrogen, ammonia is formed; carbon combining with oxygen forms carbonic acid, and frequently carbonic oxide; and with the addition of hydrogen, empyreumatic acid; the combination of carbon with hydrogen gives rise to the formation of empyreumatic oil, and of different varieties of carburetted hydrogen; sulphur, and phosphorus, are disengaged partly in combination with hydrogen, and partly remain united with oxygen in the states of sulphuric and phosphoric acids, combined with the alkalis or earths of the animal matter. These products are much diversified with regard to their proportions, according to the proportions of the elements in different animal products, and are varied too by the circumstances of the decomposition, such as the state of humidity and the degree of heat.

A peculiar product is obtained in many of these cases of decomposition,—Prussic acid, the chemical history of which still remains to be delivered. Its existence as a product of vegetation has been already noticed; it is usually by the decomposition of animal matter that it is obtained.

It enters along with oxide of iron into the composition of the blue pigment known by the name of Prussian Blue. This substance is prepared by calcining dried blood with the potash of commerce, lixiviating the residual matter with successive portions of boiling water, and adding to the ley reduced by evaporation, a solution of sulphate of iron, and of common alum. A precipitate is thrown down of a greenish colour, which assumes a very rich blue, when washed with a little diluted muriatic acid.

Macquer discovered, that from this substance the Prus-

sian Blue of commerce, the principle which, united with oxide of iron, produces the blue colour, may be abstracted by the action of an alkali, the alkali combining with it, so that by adding it to a solution of a salt of iron, the blue precipitate is reproduced. Scheele completed the discovery with regard to the nature of this colouring principle, by obtaining it in an insulated state. This he did by subjecting the alkali which had been combined with it to distillation, with the addition of sulphuric acid. The liquor, which passed over with a gentle heat, had a peculiar smell and taste, and added to the salts of iron, produced a deep blue tint.

Scheele found it difficult to obtain this principle free from oxide of iron, to which it has so strong an affinity as to carry a portion of it into any combination into which it enters. The process which he found to succeed is complicated, but it is still the only one by which we procure it in a state of purity. Two ounces of prussian blue, and one ounce of red oxide of quicksilver prepared by nitric acid, are put into a flask with six ounces of water, and boiled for some minutes with constant agitation. It is then poured on a filtre, and the matter which remains on the paper, is lixiviated with two ounces of hot water. The liquid which has passed through, is a combination of the colouring matter with oxide of quicksilver, without any oxide of iron. This he found could not be decomposed by acids, alkalis, or lime; and the colouring matter could be separated only by reducing the mercurial oxide to the metallic state. To effect this, the filtered solution, from the above quantities of materials, is poured on an ounce and a half

of iron-filings, free from rust, to which are added three drachms of sulphuric acid. The oxide of quicksilver is reduced to the metallic state. The clear liquor, after the action has ceased, is poured off and distilled. When the fourth part has come over, the whole of the colouring matter is obtained, as it is more volatile than water, and rises first. There is a slight contamination of sulphuric acid, which may be removed by distilling from a little chalk.

The claims of this substance to be ranked as an acid are doubtful; its taste is not sour, and it does not redden the delicate vegetable colours. Its acidity is displayed only in its neutralizing the alkaline properties; and even this action is scarcely exerted by it, except when it is in combination at the same time with a portion of a metallic oxide. It then, however, forms neutral salts, very distinctly marked, these of course being ternary compounds.

Prussic acid has a peculiar odour, resembling that of peach blossom; it is a powerful narcotic; its watery solution has a sweetish pungent taste. Such is its volatility, that even at a common temperature it escapes rapidly from the water which holds it dissolved. In solution in water, it appears too to suffer spontaneous decomposition.

This acid combines with the alkalis and earths, forming compounds denominated Prussiates, and which scarcely admit of examination, as they are decomposed by the agency of water alone. According to Scheele's observation, it does not neutralize the properties of the fixed alkalis, even when added in excess; and ammonia retains its peculiar odour when there is a similar excess; its effects on the earths with which it combines are similar. It does not

act on the metals, but combines with several of the metallic oxides; with oxide of quicksilver it forms a crystallizable salt By complex affinity its combinations with the metallic oxides are more easily effected, precipitates being formed by adding prussiate of lime, or prussiate of potash, to the solutions of the different metals. These are probably ternary compounds of the prussic acid, with part of the potash or lime, and the metallic oxide. All these compounds are more permanent than the alkaline or earthy precipitates; the metallic oxide, by the affinity it exerts to the acid, resisting its decomposition.

Of these ternary compounds, those with oxide of iron are the most important; they differ according to the proportions, and also according to the oxidation of the metal.

The blue precipitate which forms the basis of prussian blue, appears to be a compound of this kind, for although it consists principally of prussic acid and oxide of iron, the acid appears to carry along with it a portion of the alkali into the combination. It may be obtained from any of the salts of iron by adding what is called the Prussian Ley, prepared from calcined blood and potash, to the solution of the metallic salt. The iron requires, however, to be at the maximum of oxidation, for when a salt at the minimum is employed, the precipitate is nearly of a white colour; from exposure to the air, it soon acquires a blue shade. According to Berthollet, the different results obtained in the action of the prussian ley on the salts of iron, at a high and at a low degree of oxidation, depend principally on the affinity exerted by the oxide to the acid with which it is combined being different in these states, so that when it is at the maximum it is more

easily abstracted, and enters into combination with the prussic acid; and hence, even from the salt at the minimum, the blue precipitate may be produced by circumstances which do not change the state of oxygenation, as by mere dilution with water. In its precipitation, as there is in the ley prepared from blood an excess of alkali, the colour of the precipitate is green from the intermixture of yellow oxide of iron, but this is removed by washing with dilute muriatic acid. The alum added in its preparation is designed to afford a portion of argillaceous earth, which mingling with the blue precipitate, gives it more consistence, and increases the quantity, while the colour still remains sufficiently deep. It is therefore always present in the prussian blue of commerce. The sulphate of iron is the salt employed, as being the most economical.

There is a different compound, a triple compound of prussic acid, alkali, and oxide of iron, which remains to be noticed. By boiling solution of potash on prussian blue, a portion of the prussic acid is attracted by the alkali, as has been already stated; and hence this liquid throws down a blue precipitate from the salts of iron. But it contains too a portion of oxide of iron, which the prussic acid has carried along with it into combination with the potash, as is rendered evident by the simple experiment of adding to it an acid, so as to saturate part of the alkali, a portion of prussian blue being precipitated.

The precipitate formed by this liquor, on adding it to a salt of iron, being extremely deep in its colour, it has been much used as a test to discover the presence of that metal. In its common state, however, as prepared by boiling solu-

tion of potash on prussian blue, it cannot form a test of any delicacy, for from the quantity of oxide of iron existing in its composition, a source of error is introduced, a blue precipitate being produced, either where any free acid is present, or when an acid is evolved by the action of the test itself. It has therefore been an object of much investigation, to avoid this by removing this oxide of iron. It now appears that the entire removal of the oxide is impracticable; its presence, to a certain extent at least, is necessary to maintain the constitution of the prussic acid, this acid, when combined with potash alone, being decomposed by the agency of water. Still the oxide of iron may be so far removed, that what remains is retained in combination with the prussic acid with such force as is not to be separated by the action of another acid; and from the compound in this state used as a test, no error can arise. Different processes have been given to obtain it. The liquor prepared from calcined blood and potash answers tolerably well, for although it contains a portion of iron derived from the blood, this is much less than is contained in that prepared by digesting an alkaline solution on prussian blue. And this affords the simplest method of preparing the test in a state fit for use. This test not only precipitates iron from its solution, but also the greater number of the metals; and as the precipitates it throws down are usually of a deep colour, it serves to discover them. The precipitate it forms from the salts of copper is of a delicate and permanent brown colour, and has been introduced as a pigment.

The ternary compound of prussic acid with potash and

oxide of iron, which forms the above test, may, by evaporation, be obtained in a crystallized state; its crystals are of a yellowish colour. The compounds of the acid and oxide, with other salifiable bases, scarcely require notice. That with barytes is obtained in rhomboidal crystals of a yellow colour, sparingly soluble in water; that with strontites is less disposed to crystallize, but is more soluble; that with lime is deposited in minute crystals of a yellowish tinge.

Prussic acid being formed from the decomposition of animal matter, may be inferred to be composed of its usual elements; it accordingly, when decomposed by heat, affords the usual products, and in particular a large quantity of ammonia. Scheele gave an instructive experiment with regard to its formation. It consisted in raising a mixture of charcoal powder, and sub-carbonate of potash, to a red heat, and introducing to it muriate of ammonia. The residual matter afforded, when washed with water, a ley, which threw down a blue precipitate from sulphate of iron. Prussic acid had therefore been formed, the ammonia affording hydrogen and nitrogen, the charcoal carbon, and any portion of oxygen required might be derived from the water contained in the salts. The acid has since been formed, by passing ammonia, in the gaseous form, over ignited charcoal in a tube,—an experiment in which the same elements are obviously present.

In these cases, though oxygen may be supplied to a certain extent, it can be only in sparing quantity; and these synthetic experiments prove, that no large quantity of this element enters into the composition of this acid. This

has been inferred, too, from its analysis, as when decomposed by heat, it affords scarcely any carbonic acid, the elastic fluid disengaged being carburetted hydrogen; and some chemists have even been disposed to conclude, that it contains no oxygen. All the species of carburetted hydrogen gases, however, probably contain oxygen; a portion of carbonic acid is also always produced in the decomposition of the prussiates. These facts warrant the conclusion, that oxygen enters into the composition of prussic acid; and, accordingly, Vauquelin found, that in its formation from ammonia and charcoal, at a high temperature, the quantity is much increased if a substance be added which can afford oxygen.

Prussic acid is partially decomposed by oxy-muriatic acid, which, in producing this change, yields its oxygen. The prussic acid thus acquires a stronger smell, becomes more volatile, and exerts less powerful affinities; it precipitates oxide of iron green from its salts, the precipitate becoming blue from exposure to light, or the action of substances which abstract oxygen. The acid, in this state, has been named Oxy-Prussic Acid. If still farther impregnated with oxy-muriatic acid, and exposed to light, it is converted into an oily-like substance, having an aromatic odour, not soluble in water, and having no acidity.

Sect. II.—*Of the Spontaneous Decomposition of Animal Substances at low temperatures.*

The spontaneous changes which animal matter undergoes from the re-action of its elements, are various, according to the circumstances under which it is placed.

If it be completely excluded from air and moisture, it decays with extreme slowness; it is finally changed, however, so that nothing remains but an earthy-like substance.

If those animal substances which are not soluble in water, those, for example, which consist principally of fibrin, as the muscular fibre or flesh, be kept immersed in water, the soluble parts are removed, and the fibrin is gradually changed into a fatty matter, similar to spermaceti. A similar change is produced by the agency of very diluted nitric acid on the muscular fibre. In either case the nitrogen and phosphorus seem to be disengaged, probably in combination with hydrogen; while another portion of the hydrogen, with perhaps a quantity of oxygen, combined with the carbon, form the residual matter.

When atmospheric air is not entirely excluded, and when moisture with a certain degree of heat is present, the process named Putrefaction commences. The elements of the animal matter enter into new combinations, which generally pass off in the gaseous form; and an inconsiderable quantity of earthy matter remains when the process is finished. The precise nature of these combinations has not, from the offensiveness of the process, been accurately ob-

served; and they probably vary according to the nature of the animal matter, and the circumstances under which it is decomposed. Ammonia formed by the union of the nitrogen and hydrogen of the animal matter, is always disengaged in considerable quantity. Phosphuretted hydrogen appears to be produced, as this gas, even when obtained pure, has the odour exclusively termed Putrid. Sulphuretted hydrogen forms another part of the vapours disengaged from putrefying substances, as these vapours have in some degree its smell, and blacken the metals,—a peculiar property of this gas. Carburetted hydrogen and carbonic acid are likewise separated. And, lastly, it is probable that not only these binary combinations, but compound gases consisting of three or more of these elements with oxygen, are formed and discharged.

As this process must necessarily be carried on at the surface of the earth, its products are diffused through the atmosphere, dissolved by water, and absorbed by the soil. They furnish the principal nutritious matter for the support of vegetables, and are again prepared for the nourishment of animals.

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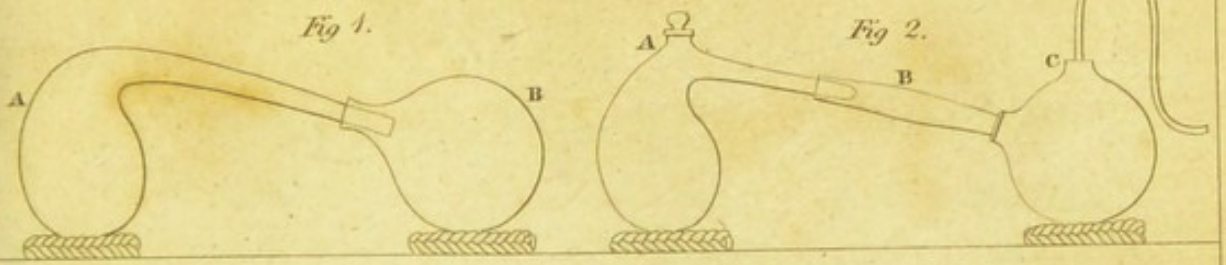
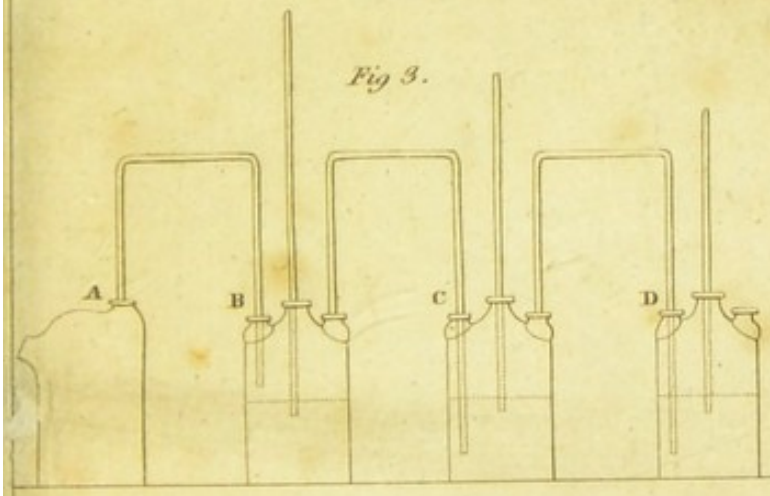
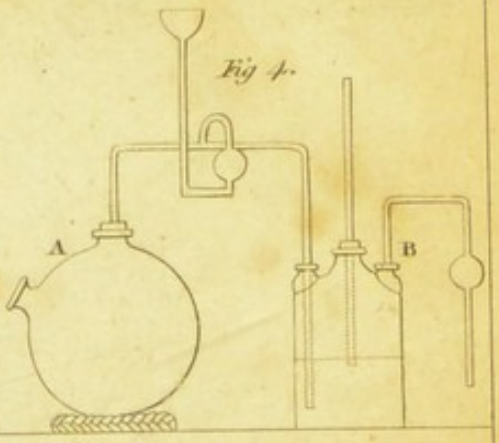
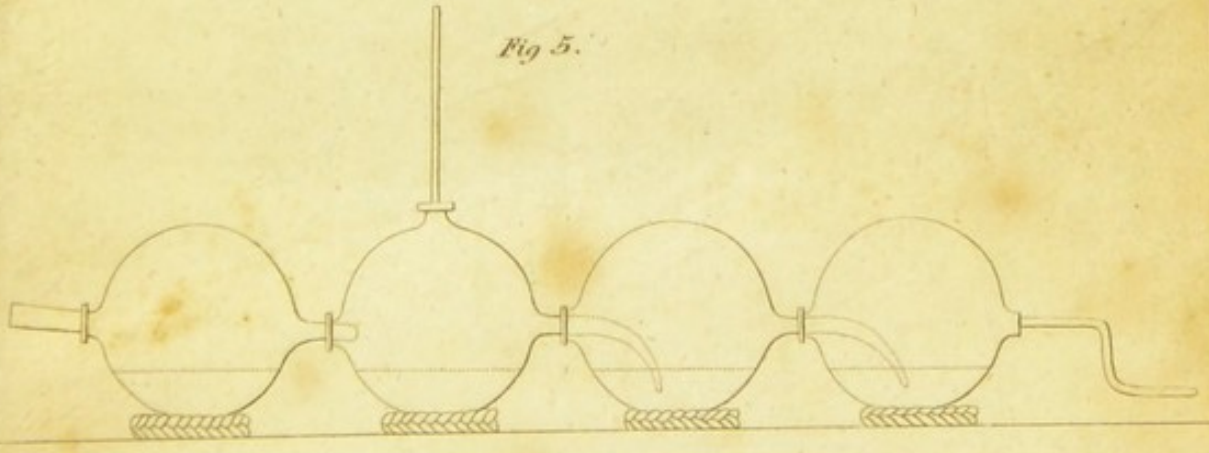
THE END.

PLATE I.









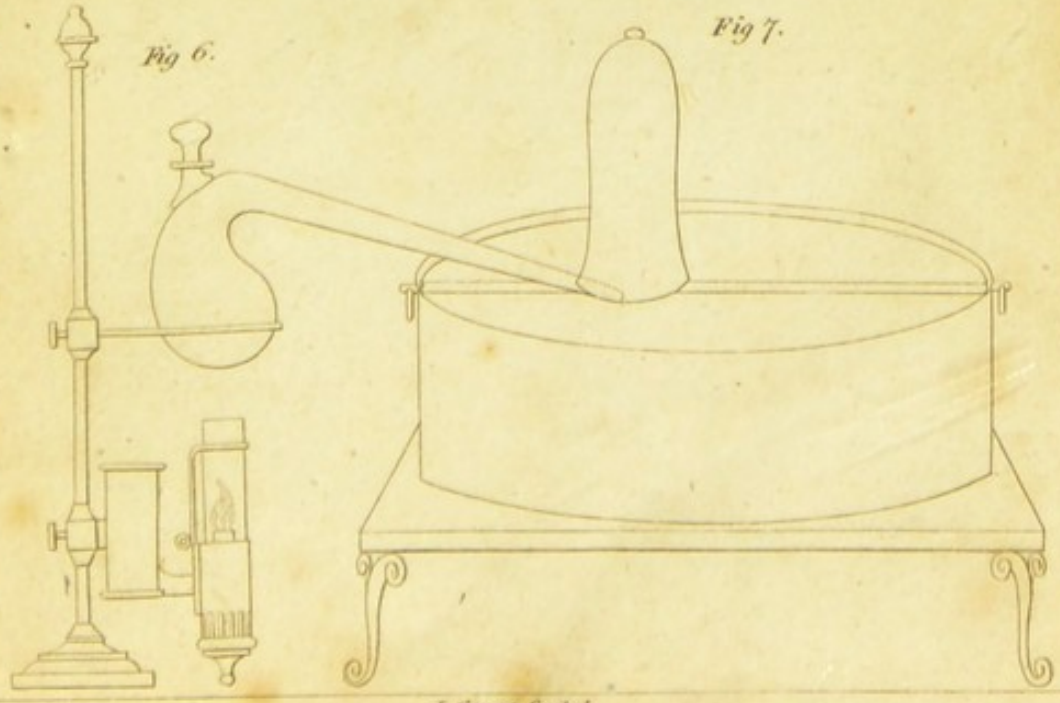


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PLATE II.

Fig 8.

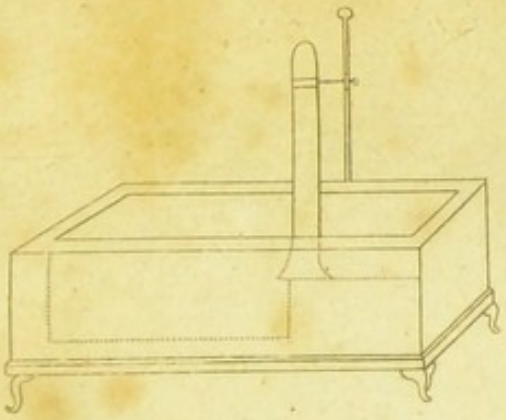


Fig 9.

Fig 10.

Fig 11.

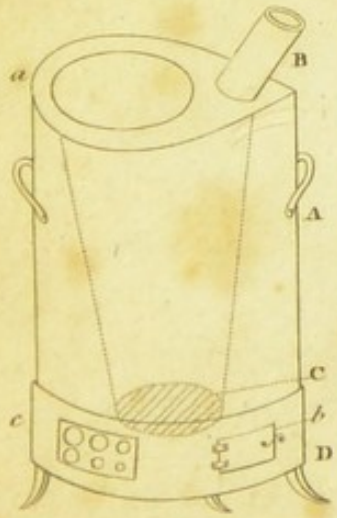
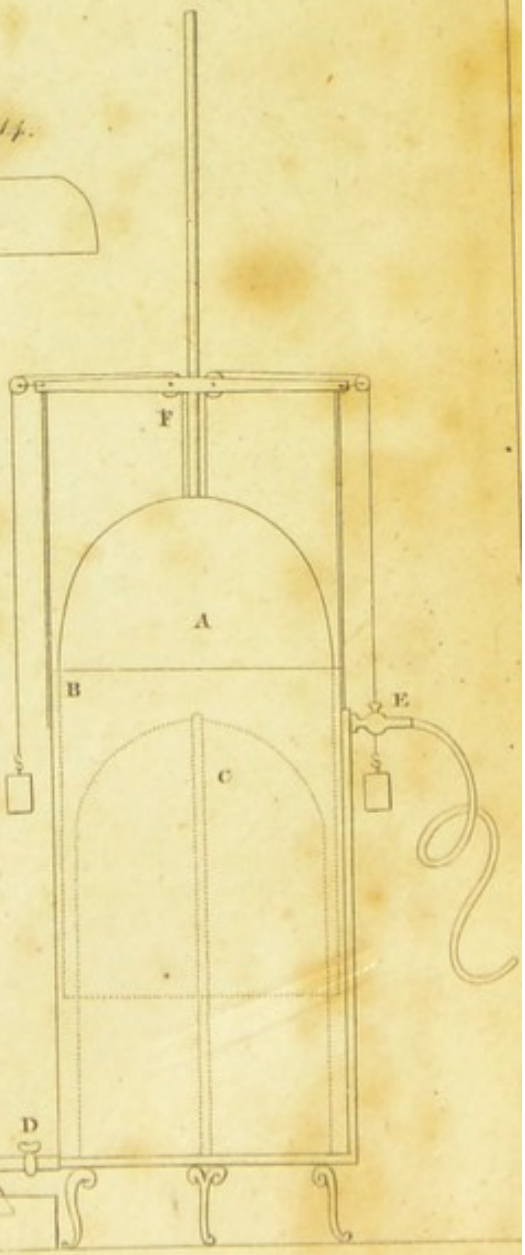


Fig 12.

Fig 13.

Fig 14.

Fig 15.



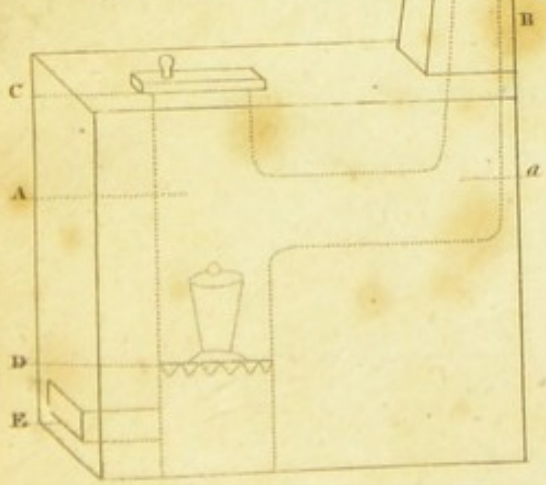


Fig 16.

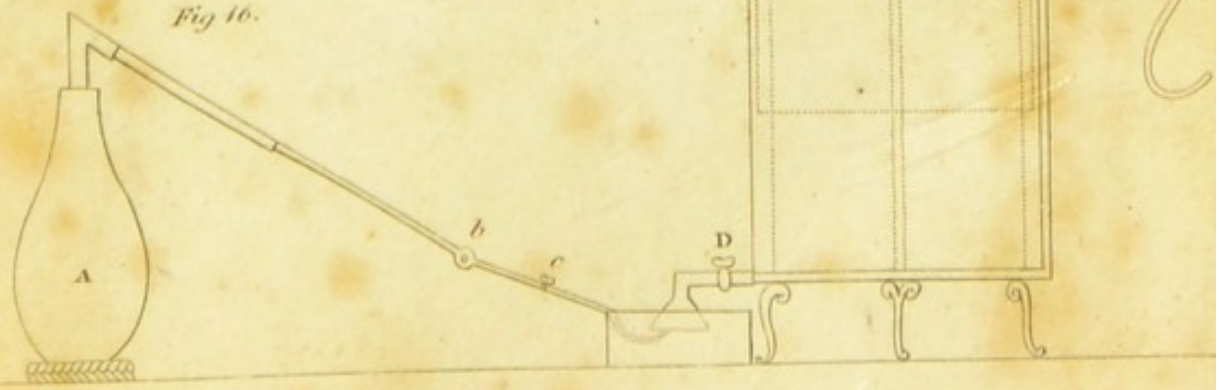


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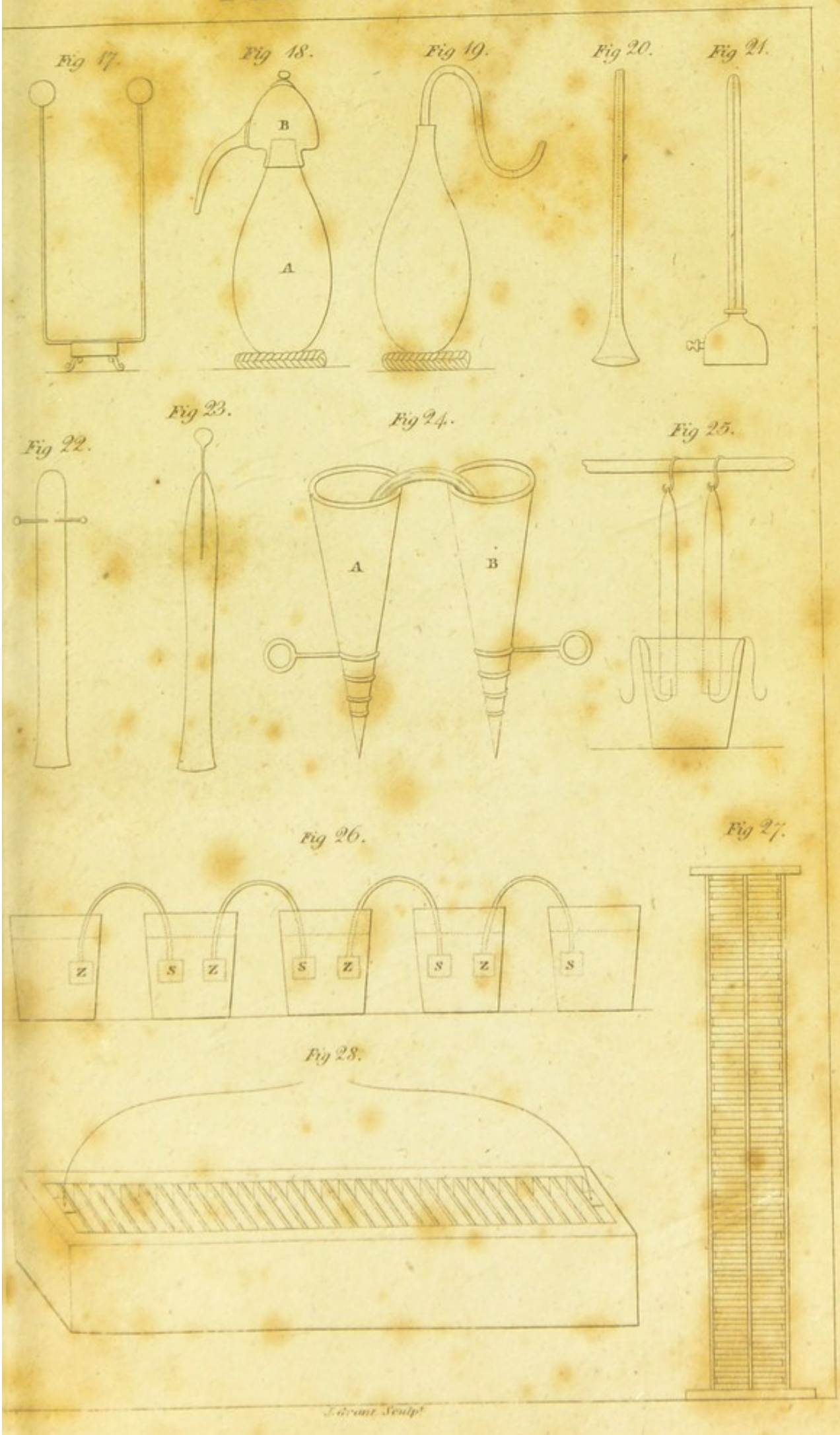
PLATE III.



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Effects of the carbon surrounding the m
articles having an excess of zinc, and placed
into the reverberating furnace.

the atmospheric air in passing through
the combustible of the furnace in a state
of combustion loses the propriety of
oxidising, (if the small articles were becom
uncovered with zinc) the metal; since the
air decomposes its oxigen in the fire.
and as in the same time that oxigen,
on account of its affinity, combines rapidly
with the combustible body (the carbon in
this case) and forms ~~an~~ acid carbonic ~~p~~
and an oxide of carbon which have
both the propriety of preventing the
oxidation of metals. (see page 262)

crawford specif.° 452
453

carbon is infusible to any heat
than a furnace can raise (451)