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ELEMENTS

OF

CHEMICAL PHILOSOPHY.

BY

SIR HUMPHRY DAVY, LL. D.

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PART I. VOL. I.

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TO LADY DAVY.

THERE is no individual to whom I can with so much propriety or so much pleasure dedicate this work as to you. The interest you have taken in the progress of it, has been a constant motive for my exertions; and it was begun and finished in a period of my life which, owing to you, has been the happiest. Regard it as a pledge that I shall continue to pursue Science with unabated ardour. Receive it as a proof of my ardent affection, which must be unalterable, for it is founded upon the admiration of your moral and intellectual qualities.

H. DAVY.

ADVERTISEMENT.

IN this work I have endeavoured, as far as it was in my power, to employ the nomenclature most in use amongst the chemists of the present day in Britain. In consequence of the progress of discovery, some of the names adopted from the French school of chemistry now imply erroneous ideas. In such cases I have recurred as often as was possible to the familiar names, or the old names.

In adopting new names, I have been guided by the necessity of the case; and have applied them only to new substances, or to substances the nature of which had been misunderstood, and which were confounded with other bodies differing from them in their nature.

I may perhaps be censured for having proposed to signify the combinations of chlorine or oxymuriatic gas by simple terminations, connected with the name of the basis, such as ane and ana; but these terminations will serve at least as symbols of the class, and in this way may assist the memory.

In the last Bakerian lecture, published in the Philosophical Transactions, I have proposed to denominate the combinations of chlorine supposed to contain one proportion, by the termination *anè*, those supposed to contain two by *ana*, and those containing three by *anèe*. As, however, amongst the metallic combinations of chlorine, there are never more than two distinct combinations belonging to the same metal, I have given the termination ane to the first, and that of ana to the second, without reference to proportions; or where there has been only one, I have used simply ane. If my original proposal should be adopted, it will however be easy to make the corrections, and the cases are very few that will require it. Common salt, which contains two proportions of chlorine, and which in this work is called sodane, will be called sodana; ferrane will be called ferranea; ferranea, ferranèe; and arsenicane must be changed to arsenicana.

Some persons may chuse rather to use the word chloride, following the analogy of oxide; but as I have expressed in the introduction, our nomenclature would have been more simple and useful without any attempt at theoretical expressions of the composition of bodies; and as the fixed alkalies, earths, and oxides, are similar bodies, and the termination *a* has been applied to the two first, it might be properly extended to the last.

The word oxide is however now current, I have therefore used it, and have employed Dr. Thomson's method of distinguishing the different oxides of the same metal, by prefixing to them syllables derived from the Greek numerals; deutoxide, tritoxide, tetroxide, signify that the bodies contain two, three, or four proportions of oxygene. When the word oxide alone is used, one proportion only of oxygene is supposed to exist in it.

Whatever pains be taken, it will not be possible to make the existing nomenclature conformable to the idiom of our language; and till some general principles for its improvement are agreed to by the enlightened in different parts of Europe, it cannot be expected to be even a philosophical language; and till a more simple system is adopted, innovation will be censured sometimes perhaps even when it is necessary, and neology generally brought forward as a reproach.

I have in a few instances only given an account of the experiments, from the results of which the numbers representing the undecomposed bodies were calculated.

To have given accurate histories of those experiments, would have deen incompatible with the object of an elementary book devoted to the general truths and methods of the science; I shall however shortly present them to the public, in a work containing the details of labours that I have carried on during the last twelve years in analytical chemistry.

I have usually given whole numbers, taking away or adding fractional parts, that they may be more easily retained in the memory. When the number was gained from experiments in which a loss might be supposed, I have added fractional parts, so as to make a whole number. Thus the number representing barium, is nearer 129 than 130; but it is given as 130, because it was deduced from an indirect experiment in which a loss of weight was more probable than an increase from any foreign source.

In a future edition of this work, should my imperfect labours be favourably received, I may hope to be able to complete the series of numbers, and to fix some that are doubtful.

I cannot conclude without acknowledging my obligations to my brother Mr. John Davy, for the able assistance he afforded me in the progress of the researches which form the foundation of this treatise.

I have likewise received much useful experimental aid from Mr. E. Davy, and Mr. W. Moore.

The greater number of the experiments were made in the laboratory of the Royal Institution; and all that were fitted for demonstration have been exhibited in the theatre of that useful public establishment in my annual courses of lectures; and have been received by the members in a manner which I shall always remember with gratitude.

Berkeley Square,
June 1, 1812.

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INTRODUCTION.

MOST of the substances belonging to our globe are constantly undergoing alterations in sensible qualities, and one variety of matter becomes as it were transmuted into another.

Such changes, whether natural or artificial, whether slowly or rapidly performed, are called chemical; thus the gradual and almost imperceptible decay of the leaves and branches of a fallen tree exposed to the atmosphere, and the rapid combustion of wood in our fires, are both chemical operations.

The object of Chemical Philosophy is to ascertain the causes of all phænomena of this kind, and to discover the laws by which they are governed.

The ends of this branch of knowledge are the applications of natural substances to new uses, for increasing the comforts and enjoyments of man, and the demonstration of the order, harmony, and intelligent design of the system of the earth.

The foundations of chemical philosophy, are observation, experiment, and analogy. By observation, facts are distinctly and minutely impressed on the mind. By analogy, similar facts are connected. By experiment, new facts are discovered; and, in the progression of knowledge, observation, guided by analogy, leads to experiment, and analogy, confirmed by experiment, becomes scientific truth.

To give an instance.—Whoever will consider with attention the slender green vegetable filaments *(Conferva rivularis)* which in the summer exist in almost all streams, lakes, or pools, under the different circumstances of shade and sunshine, will discover globules of air upon the filaments exposed under water to the sun, but no air on the filaments that are shaded. He will find that the effect is owing to the presence of light. This is an *observation;* but it gives no information respecting the nature of the air. Let a wine glass filled with water be inverted over the conferva, the air will collect in the upper part of the glass, and when the glass is filled with air, it may be closed by the hand, placed in its usual position, and an inflamed taper introduced into it; the taper will burn with more brilliancy than in the atmosphere. This is an *experiment.* If the phænomena are reasoned upon, and the question is put, whether all vegetables of this kind, in fresh or in salt water, do not produce such air under like circumstances, the enquirer is guided by *analogy:* and when this is determined to be the case by new trials, a *general scientific truth* is established—That all confervæ in the sunshine produce a species of air that supports flame in a superior degree; which has been shewn to be the case by various minute investigations.

These principles of research, and combinations of methods, have been little applied, except in late times. A transient view of the progress of chemical philosophy will prove that the most brilliant discoveries, and the happiest theoretical arrangements belonging to it are of very recent origin; and a few historical details and general observations upon the progress and effects of the science will form, perhaps, no improper introduction to the elements of this branch of knowledge.

The only processes which can be called chemical, known to the civilized nations of antiquity, belonged to certain arts, such as metallurgy, dyeing, and the manufacture of glass or porcelain; but these processes appear to have been independent of each other, pursued in the workshop alone, and unconnected with general knowledge.

In the early mythological systems of the Egyptian priests, and the Bramins of Hindostan, some views respecting the chemical changes of the elements seem to have been developed, which passed, under new modifications, into the theories of the Greeks; but as the most refined doctrines of this enlightened people, concerning natural causes, in their best times, were little more than a collection of vague speculations, rather poetical than philosophical, it cannot well be supposed that in earlier ages, and amongst nations less advanced in cultivation, there were any traces of genuine science.

The inhabitants of Lower Egypt, where the overflowing of the Nile covered a sandy desert with vegetation and life, might easily adopt the notion, that water, in different modifications, produced all the varieties of inanimate and organized matter; and this dogma characterized the earliest school of Greece.

To generalize upon the great forms or powers of nature, as elements, requires only very superficial observation; and hence the theories seem to have originated, which have been attributed to Anaximander, and others of the early Greek philosophers, concerning air, earth, water, and fire.

As geometry and the mathematical sciences became improved, mechanical solutions of the changes of bodies were natural consequences, such as the atomic philosophy of the Ionian sect, and the five regular solids assumed by the Pythagoreans as the materials of the universe.

In the beginning of the Macedonian dynasty, the school of Aristotle gave a transient attention to the objects of natural science, but the great founder attempted too many subjects to be able to offer correct views of any one series.—And his erroneous practice, that of advancing general principles, and applying them to particular instances, so fatal to truth in all sciences, more particularly opposed itself to the progress of one founded upon a minute examination of obscure and hidden properties of natural bodies.

Theophrastus, the successor of Aristotle, did not, it appears, adopt the sublime, though purely speculative doctrine of his master, the identity of matter, and its diversity of form*;—for he says, in the beginning of his book concerning fossils, 'stones are produced from earth, metals from water†.'—How such a notion as the last could have been formed, it is difficult to discover; yet, Theophrastus is perhaps the best observer amongst the ancients, whose works are in our possession, and the theories of this distinguished teacher, who is said to have had a class of 2000 pupils, cannot be considered as an unfavourable specimen of the theoretical physics of the age.

* Επειδὴ δὲ ἡ φυσις διχῶς, τὸ τε εἶδος καὶ ἡ ὕλη. Aristotelis Natural. Auscult. Lib. ii. 495, fol. Par. 1654.

† ῾Υδατος μὲν τὰ μελλευὸμενα καθάπερ ἄργυρος καὶ χρυσος, καὶ ταλλα. μῆς δὲ λιθος τε καὶ ὅσα λίθων περιττοτερα. Theophrasti de Lapidibus. Lug. Bat. 1613.

In all pursuits which required only the native powers of the intellect, or the refinements of taste, the Greeks were pre-eminent;—their literature, their works of art, offer models which have never been excelled. They possessed, as if instinctively, the perception of every thing beautiful, grand, and decorous. As philosophers, they failed not from a want of genius, or even of application, but merely because they pursued a false path,—because they reasoned more upon an imaginary system of nature, than upon the visible and tangible universe.

It will be in vain to look in the annals of Rome for science, that did not exist in Greece. The conquerors became the pupils of the conquered; and the Romans did little more than clothe the systems of their masters in a new dress, and adapt them to a new people.

The grand, but unequal poem of Lucretius, contains the abstract of the opinions of Epicurus, compared with those of other celebrated teachers. The Natural History of Pliny, is a collection from all sources, but principally from Theophrastus and Aristotle. The details from his own observation are more interesting when they relate to artificial, than when they refer to natural operations; the speculative notions are of the rudest kind. The earlier philosophical work of the Romans, as if indicative of the youth of the people, is marked by power and genius, by boldness and incorrectness; the latter, as if it belonged to their old age, by garrulity, copious and amusing anecdote, superstitious notions, and vulgar prejudices.

Some of the historians of this science*, in their zeal for the honour of its antiquity, have indeed endeavoured to find instances of an ac-

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* Many of the alchemical writers derive alchemy from Tubal Cain; others from Hermes Trismegistus, the Mercury of the Greeks. The first writing specifically on a chemical subject, is a manuscript supposed to be of the fifth century, by Zosimus, on the art of making gold and silver; which was in the king's library at Paris. Suidas, who wrote in the ninth or tenth century, mentions Diocletian as having burnt the books of the Egyptians concerning the chemistry of silver and gold: "περι χυμείας αργυρȣ καὶ χρυσȣ." Lexicon, Tom. i. pag. 595.

For a minute investigation of the claims of the ancients to chemical knowledge, the reader may consult Borrichius de Ortu et Progress. Chæm. Bergman. Opuscula, vol. IV. de primordiis Chæm. and Lenglet Dufrenoy, Histoire de la Philosophie hermetique.

quaintance with some doctrines of practical chemistry, at least, amongst the ancients.—Thus Democritus is quoted by Laertius as having employed himself in processes for imitating gems, and for softening and working ivory. Caligula is said to have made experiments with the view of extracting gold from orpiment.—Dioscorides, who is supposed to have been physician to the celebrated Cleopatra, has described the process of subliming mercury from its ores. —Even Cleopatra herself, on the evidence of such circumstances, might be considered as an experimenter, because, in the madness of profusion, she dissolved a pearl in vinegar, and made a nauseous draught of a costly and beautiful substance; but it is idle to relate such circumstances as indications of *science*. If chemical operations had been known to any extent, beyond their mere relations to the arts, some mention of them might have been expected in the medical writings of those times; but not even distillation is noticed in the works of Hippocrates or Galen; and the same Dioscorides who has been just alluded to, and who probably possessed whatever knowledge was at that time extant in Egypt, recommends the use of a fleece of wool or a sponge, for collecting the products from boiling or burning substances*.

The origin of chemistry, as a science of experiment, cannot be dated farther back than the seventh or eighth century of the christian era, and it seems to have been coeval with the short period in which cultivation and improvement were promoted by the Arabians.

The early Mahometans endeavoured to destroy all the records of the former progress of the human mind; and, as if to make compensation for this barbarian spirit, the same people were destined, in a more advanced period, to rekindle the light of letters, and to become the inventors and cultivators of a new science.

The early nomenclature of chemistry demonstrates how much it owes to the Arabians.—The words alcohol, alkahest, aludel, alembic, alkali, require no comment.

The first Arabian systematic works on chemistry are said to have been composed by Geber in the reigns of the caliphs Almainon and Almanzor. The preparation of medicines seems to have been the

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* Dioscoridis liber 1. de picino oleo, pag. 52.

primary object in this study; and Rhases, Avicenna, and Avenzoar, who have described various chemical operations in their works, were the celebrated physicians of the age.

Amongst a people of conquerors, disposed to sensuality and luxury even from the spirit of their religion, and romantic and magnificent in their views of power, it was not to be expected that any new knowledge should be followed in a rational and philosophical manner; and the early chemical discoveries led to the pursuit of alchemy, the objects of which were to produce a substance capable of converting all other metals into gold; and an universal remedy calculated indefinitely to prolong the period of human life.

Reasonings upon the nature of the metals, and the composition of the philosopher's stone, form a principal part of the treatises ascribed to Geber*; and the disciples of the school of Bagdat seem to have been the first professed alchemists.

It required strong motives to induce men to pursue the tedious and disgusting processes of the furnace; but labourers could hardly be wanting, when prospects so brilliant and magnificent were offered to them; the means of procuring unbounded wealth; of forming a paradise on earth; and of enjoying an immortality depending on their own powers.

The processes supposed to relate to the transmutation of metals, and the elixir of life, were probably first made known to the Europeans during the time of the crusades; and many of the warriors who, animated with visionary plans of conquest, fought the battles of their religion in the plains of Palestine, seemed to have returned to their native countries under the influence of a new delusion.

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* The library of the British Museum contains several works bearing the name of Geber: amongst them are, De Alchemia argentea, Speculum Alchemiæ, et de Inventione perfectionis: but they appear to be compilations formed by alchemists of the 15th and 16th centuries. Arsenic, mercury, and sulphur, are considered in them as elements of the metals; distillation is distinctly described. Alcohol, corrosive sublimate, and different saline combinations of iron, tin, copper, and lead, are mentioned in them; but they abound in obscure descriptions of mysterious processes, and contain an account of some impracticable experiments.—The Liber Fornacum is the most intelligible part of the works ascribed to Geber; it contains a description of several metallurgical operations, and of the common apparatus of the assayer.

The public spirit in the west was calculated to assist the progress of all pursuits that carried with them an air of mysticism. Warm with the ardor of an extending and exalted religion, men were much more disposed to believe than to reason;—the love of knowledge and power is instinctive in the human mind; in darkness it desires light, and follows it with enthusiasm even when appearing merely in delusive glimmerings.

The records of the middle ages contain a great variety of anecdotes relating to the transmutation of metals, and the views or pretensions of persons considered as adepts in alchemy: these early periods constitute what may be regarded as the heroic or fabulous ages of chemistry. Some of the alchemists were low impostors, whose object was to delude the credulous and the ignorant; others seemed to have deceived themselves with vain hopes; but all followed the pursuit as a secret and mysterious study. The processes were communicated only to chosen disciples, and being veiled in the most enigmatic and obscure language, their importance was enhanced by the concealment. In all times men are governed more by what they desire or fear, than by what they know; and in this age it was peculiarly easy to deceive, but difficult to enlighten, the public mind; truths were discovered, but they were blended with the false and the marvellous; and another era was required to separate them from absurdities, and to demonstrate their importance and uses.

Arnald of Villa Nova, who is said to have died in 1250, was one of the earliest European enquirers who attended to chemical operations. In the edition of the works ascribed to him, published at Leyden in 1509*, there are several treatises on alchemical subjects, which shew that he firmly believed in the transmutation of metals; the same opinions are attributed to him and to Geber; and he seems to have followed the study with no other views than those of preparing medicines, and attempting the composition of the philosopher's stone.

Raymund Lully of Majorca is said to have been a disciple of Arnald, and applied himself much more than his instructor to philosophy; but the works on general science, ascribed to him, are more

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* Opera Arnaldi de Villa Nova, fol. 1509.

abundant in abstract metaphysical propositions, than in facts; he followed, in his physical views, the plan of Aristotle, and our opinion of his chemical talents cannot be very exalted, if the alchemical treatises bearing his name be regarded as genuine documents.

Arnald and Lully are both celebrated by the vindicators of alchemy, as having been certainly possessed of the secret of transmutation. Arnald is said to have converted iron into gold at Rome; and it is pretended that Lully performed a similar operation before Edward I. in London, of which gold nobles were said to have been made*.

That the delusions of alchemy were ardently pursued at this time may be learnt from a reference to the public acts of these periods. Pope John the 22d, who was raised to the pontificate in the year 1316, openly condemned the alchemists as impostors, and the bull begins by stating, that "they promise what they do not perform;" and in England an act of Parliament was passed in the fifth year of the reign of Henry IV, prohibiting the attempts at transmutation, and making them felonious†.

Even in these times, however, there were some few efforts to form scientific views. In the beginning of the thirteenth century, Roger Bacon of Oxford applied himself to experiment, and his works offer proofs of talents, industry, and sagacity. He was a man of a truly philosophical turn, desirous of investigating nature, and of extending the resources of art, and his enquiries offered some very extraordinary combinations; but neither his labours, nor those of Albert of Cologne, his contemporary, who appears to have been a genius of a kindred character, had any considerable influence on the improvement of their age. The wonders performed by the experimental art were attributed by the vulgar to magic; and at a time when knowledge belonged only to the cloister, any new philosophy was of course regarded even by the learned with a jealous eye.

It would be a labour of little profit to dwell upon the works of the professed alchemists of the fourteenth and fifteenth centuries, of

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* Bergman. Opuscula, Tom. IV. pag. 126.

† Lord Coke calls this act the shortest he ever met with. 5 H. IV. Statutes at large, Vol. I. page 457. "None from henceforth shall use to multiply gold or silver, or use the craft of multiplication, and if any the same do, he shall incur the pain of felony."

Richard and Ripley in England, Isac in Holland, Pico of Mirandula and Koffsky in Poland. The works attributed to these persons are of a similar stamp[*], and contain nothing which can either instruct or amuse an intelligent reader. Basil Valentine of Erfurt deserves to be separated from the rest of the enquirers of this age, on account of the novelty and variety of his experiments on metallic preparations, particularly antimony: in his *Currus triumphalis Antimonii* he has described a number of the combinations of this metal. He used the mineral acids for solutions, and seems to have been one of the first persons who observed the production of ether from alcohol. He flourished about the year 1413.

Cornelius Agrippa, who was born at Cologne in 1486, openly professed magic, and endeavoured to connect together judicial astrology, the hermetic art, and metaphysical philosophy; and he was followed by Paracelsus, in Switzerland, and Digby, Kelly, and Dee, in England.

The first Arabian alchemists seem to have adopted the idea, that the elements were under the dominion of spiritual beings, who might be submitted to human power; and the notions of fairies and of genii, which have been depicted with so much vividness of fancy and liveliness of description in the Thousand and One Nights, seem to have been connected with the pursuit of the science of transmutation, and the production of the elixir of life. The speculative ideas of the Arabians were more or less adopted by their European disciples. The Rosicrucian philosophy, in which gnomes, sylphs, salamanders, and nymphs were the spiritual agents, supposed capable of being governed or enslaved by man, seems to have originated with the alchemists of this period; and Agrippa, Paracelsus, and their followers, above mentioned, all professed to believe in supernatural powers, in an art above experiment, in a system of knowledge not derived from the senses. It would be a tedious and useless task, to describe all the absurdities in the opinions and practices of this school. Paracelsus alone deserves particular notice, from the circumstance of his being the first public lecturer on chemistry in

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[*] Amongst them are Ricardi Angli Libellus, περι χημειας, Opus Saturni Johan. Isac. Compounde of Alchemy by George Ripley.

Europe, and from the more important circumstance of his application of mercurial preparations to the cure of diseases. The magistrates of Basle established a professor's chair for their countryman, but he soon quitted an occupation in which regularity was necessary, and spent his days in wandering from place to place, searching for, and revealing secrets. He pretended to confer immortality by his medicines, and yet died at the age of 49, at Saltsburg, in the year 1541*.

The enthusiasm of this man almost supplied his want of genius. He formed a number of new preparations of the metals, which were studied and applied by his disciples; his exaggerated censure of the methods of the ancients, and of the systems of his day, had an effect in diminishing their popularity; one error was expelled by another; and it is a great step towards improvement, that men should know they have been in delusion.

Van Helmont, of Brussels, born in 1588†, was formed in the school of alchemy, and his mind was tinctured with its prejudices: but his views concerning nature and the elements were distinguished by much more philosophical acuteness, and more sagacity, than those of any former writer. He is the first person who seems to have had any idea respecting elastic fluids, different from the air of the atmosphere; and he has distinctly mentioned three of these substances, to which he applied the term gases: namely, aqueous gas or steam, unctuous or inflammable gas, and gas from wood or carbonic acid gas. Van Helmont developed some accurate views respecting the permanent elasticity of air, and the operation of heat upon it; and a sketch of a curious instrument very similar to the differential thermometer, is to be found in his works‡.

Van Helmont has used a term not so applicable or intelligible as gas, namely, blas; which he supposed to be an influence derived from the heavenly bodies, of a most subtile and etherial nature; and on the idea of its operations in our terrestial system, he has endeavoured to found the vindication of astrology||.

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* Dictionnaire Historique, par Moreri, tome viii. pag. 64.

† Ibid, tom. v. pag. 570.

‡ Johan Baptist. Van Helmont, Opera Omnia, 4to. pag. 61. article Aer.

|| Ibid. pag. 114.

At this period there was no taste in the public mind to restrain vague imaginations. There were no severe critics to correct the wanderings of genius. The systems of logic, adopted in the schools, were founded rather upon the analogies of words, than upon the relations of things; and they were more calculated to conceal error, than to discover truth.—Till the revival of literature in Europe, there was no attempt at philosophical discussion in any of the sciences; the diffusion of letters gradually brought the opinions of men to the standard of nature and truth; failures in the experimental arts produced caution, and the detection of imposture created rational scepticism.

The delusions of alchemy were exposed by Guibert, Gassendi, and Kepler. Libavius answered Guibert in a tone which demonstrated the weakness of his cause. This person, who died in 1616, was the last active experimentalist who believed that transmutation had actually been performed; and in the beginning of the 17th century the processes of rational chemistry were pursued by a number of enlightened persons in different parts of Europe.

A metallurgical school had before this time been founded in Germany. George Agricola published, in 1542, his twelve books, *de Re Metallica*, or, on the methods of extracting and purifying the useful metals; and he was followed by Lazarus Erckern, assay-master general of the empire of Germany, whose works, brought forward in 1574, contain a number of useful practices detailed in a simple and perspicuous manner.

Lord Bacon happily described the alchemists as similar to those husbandmen who, in searching for a treasure supposed to be hidden in their land, by turning up and pulverising the soil, rendered it fertile; in seeking for brilliant impossibilities, they sometimes discovered useful realities; and in speaking of the chemistry of his time, he says, a new philosophy has arisen from the furnaces, which has confounded all the reasonings of the ancients. This illustrious man himself pointed out many important objects of chemical enquiry; but he was a still greater benefactor to the science, by his developement of the general system for improving natural knowledge. Till his time there had been no distinct views concerning the art of experiment and observation. Lord Bacon demonstrated how little could be effected by the unassisted human powers, and the weakness of the strongest intellect even without artificial resources. He directed the attention of enquirers to instruments for assisting the senses, and for examining bodies under new relations. He taught that Man was but the servant and interpreter of Nature; capable of discovering truth in no other way but by observing and imitating her operations: that facts were to be collected and not speculations formed: and that the materials for the foundations of true systems of knowledge were to be discovered, not in the books of the ancients, not in metaphysical theories, not in the fancies of men, but in the visible and tangible external world.

Though Van Helmont had formed some just notions respecting the properties of air, yet his views were blended with obscure and vague speculations, and it is to the disciples of Gallilæo, that the true knowledge of the mechanical qualities and agencies of elastic fluids is owing. After Torricelli and Pascal had shewn the pressure and weight of the atmosphere, the investigation of its effects in chemical operations became an obvious problem.

John Rey is generally quoted as the first person who shewed by experiments that air is fixed in bodies during calcination: but it appears from the work of this acute and learned man, that he reasoned upon the processes of others, rather than upon his own observations.

He quotes Fachsius, Libavius, Cesalpin, and Cardan, as having ascertained the increase of weight of lead during its conversion into a calx*, and he mentions an experiment of Hammerus Poppius, who found that antimony calcined by a burning-glass, notwithstanding the loss of vapours, yet was heavier after the process.

Rey ridicules the various notions of the alchemists on the cause of this phænomenon; and ascribes it to the union of air with the metal; he supposes that air is miscible with other bodies besides metals, and states distinctly that it may be expelled from water.

The observations of John Rey seem to have excited no attention amongst his cotemporaries. The philosophical spirit was only be-

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* Sur la Recherche de la cause par laquelle Estain et le Plomb augmentent de poids quand on les calcine. A Bazas, 1630.

ginning to animate chemistry, and the labourers in this science, occupied by their own peculiar processes, were little disposed to listen to the reasonings of an enquirer in general science; yet, though the most active of the forms of matter were neglected in the processes of the operative chemists of this day, and consequently no just views formed by them, still they discovered a number of important facts respecting the combinations and agencies of solid and fluid bodies. Glauber, at Amsterdam, about 1640, made known several neutral salts, and several compounds of metallic and vegetable substances. Kunckel, in Saxony and Sweden, pursued technical chemistry with very great success, and was the first person who made any philosophical experiments upon phosphorus, which was accidentally discovered by Brandt in 1669*. Barner in Poland, and Glaser in France, published elementary books on the science, and Borichius in Denmark, Bohn at Leipzic, and Hoffman at Halle pursued specific scientific investigations with much zeal and success; and Hoffman was the first person who attempted the philosophical analysis of mineral waters.

About the middle of this century likewise mathematical and physical investigations were pursued in every part of the civilized world with an enthusiasm before unknown. The new mode of improving knowledge by collecting facts, associated together a number of labourers in the same pursuit. It was felt that the whole of nature was yet to be investigated, that there were distinct subjects connected with utility and glory, sufficient to employ all enquirers, yet tending to the common end of promoting the progress of the human mind. Learned bodies were formed in Italy, England, and France, for the purpose of the interchange of opinions, the combination of labour and division of expense in performing new experiments, and the accumulation and diffusion of knowledge.

The Academy del Cimento was established in 1651, under the patronage of the Duke of Tuscany; the Royal Society of London, in 1660; the Royal Academy of Sciences of Paris, in 1666. And a number of celebrated men, who have been the great luminaries of the different departments of science, were brought together or

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* Homberg, Mem. Acad. Paris, tom. x. pag. 58.

formed in these noble establishments. The ardour of scientific investigation was excited and kept alive by sympathy: taste was improved by discussion, and by a comparison of opinions. The conviction that useful discoveries would be appreciated and rewarded, was a constant stimulus to industry, and every field of enquiry was open for the free and unbiassed exercise of the powers of genius.

Boyle, Hooke, and Slare, were the principal early chemical investigators attached to the Royal Society of London. Homberg, Geoffroy, and the two Lemerys, a few years later, distinguished themselves in France.

Otto de Guericke of Magdeburgh invented the air pump; and this instrument, improved by Boyle and Hooke, was made an important apparatus for investigating the properties of air. Boyle[*] and Hooke[†], from their experiments, concluded that air was absolutely necessary to combustion and respiration, and that one part of it only was employed in these processes. And Hooke formed the sagacious conclusion, that this principle is the same as the substance fixed in nitre, and that combustion is a chemical process, the solution of the burning body in elastic fluid, or its union with this matter.

Mayow of Oxford, in 1674, published his treatises on the nitroærial spirit, in which he advanced opinions similar to those of Boyle and Hooke, and supported them by a number of original and curious experiments[‡]; but his work, though marked by strong ingenuity, abounds in vague hypotheses. He attempted to apply the imperfect chemistry of his day to physiology; his failure was complete, but it was the failure of a man of genius.

Boyle was one of the most active experimenters, and certainly the greatest chemist of his age. He introduced the use of tests or reagents, active substances for detecting the presence of other bodies; he overturned the ideas which at that time were prevalent, that the

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[*] Boyle's Works, vol. iv. page 90.

[†] Hooke's Micographia, page 45, 104, 105.

[‡] Tract. p. 28. He has particularly assigned the cause of the calcination of metals, " Quippe vix concipi potest unde augmentum illud antimonii nisi a particulis nitro aereis igneisque inter calcinandum fixis procedat."

results of operations by fire were the real elements of things, and he ascertained a number of important facts respecting inflammable bodies, acids, alkalies, and the phænomena of combination; but neither he nor any of his contemporaries endeavoured to account for the changes of bodies by any fixed principles. The solutions of the phænomena were attempted either on rude mechanical notions, or by occult qualities, or peculiar subtile spirits or ethers supposed to exist in the different bodies. And it is to the same great genius, who developed the laws that regulate the motions of the heavenly bodies, that chemistry owes the first distinct philosophical elucidations of the powers which produce the changes and apparent transmutations of the substances belonging to the earth.

Sugar dissolves in water, alkalies unite with acids, metals dissolve in acids. Is not this, says Newton, on account of an attraction between their particles? Copper dissolved in aquafortis is thrown down by iron. Is not this because the particles of the iron have a stronger attraction for the particles of the acid than those of copper; and do not different bodies attract each other with different degrees of force*?

A few years after Newton had brought forward these sagacious views, the elder Geoffroy endeavoured to ascertain the relative attractive powers of bodies for each other, and to arrange them in an order in which these forces, which he named affinities, were expressed†.

Chemistry had scarcely begun to assume the form of a science, when the attention of the most powerful minds were directed to other objects of research; the same great man who bestowed on it its first accurate principles, in some measure impeded its immediate progress by his more important discoveries in optics, mechanics, and astronomy.

These objects of the Newtonian philosophy were calculated by their grandeur, their simplicity, and their importance, to become the study of the men of most distinguished talents; the effect that they occasioned on the scientific mind may be compared to that which the new sensations of vision produce on the blind receiving sight;

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* Newton's Works, quarto, tom. iv. page 242.

† Mémoires de l'Academie, 1718, page 256.

they awakened the highest interest, the most enthusiastic admiration, and, for nearly half a century, absorbed the attention of the most eminent philosophers of Britain and France.

Germany still continued the great school of practical chemistry, and at this period it gained an ascendancy of no mean character over the rest of Europe in the philosophy of the science. Beecher, who was born at Spires in 1645, after having studied with minute attention the operations of metallurgy, and the phænomena of the mineral kingdom, formed the bold idea of explaining the whole system of the earth by the mutual agency and changes of a few elements. And by supposing the existence of a vitrifiable, a metallic, and an inflammable earth, he attempted to account for the various productions of rocks, crystalline bodies, and metallic veins, assuming a continued interchange of principles between the atmosphere, the ocean, and the solid surface of the globe, and considering the operations of nature as all capable of being imitated by art.

The *Physica subterranea*, and the *Oedipus chemicus* of this author are very extraordinary productions. They display the efforts of a vigorous mind, the conceptions of a most fertile imagination, but the conclusions are too rapidly formed; there is a want of logical precision in his reasonings; the objects he attempted were grand, but his means of execution comparatively feeble. He endeavoured to raise a perfect and lasting edifice upon foundations too weak, from materials too scanty, and not sufficiently solid; and the work, though magnificent in design, was rude, unfinished, and feeble, and rapidly fell into decay.

Beecher added very little to the collection of chemical experiments, but he improved the instruments of research, simplified the manipulations, and, by the novelty and boldness of his speculations, excited inquiry among his disciples.

His most distinguished follower was George Ernest Stahl, born in 1660, who soon attained a reputation superior to that of his master, and developed doctrines which for nearly a century constituted the theory of chemistry of the whole of Europe.

Albertus Magnus had advanced the idea that the metals were earthy substances impregnated with a certain inflammable principle. Beecher supported the idea of this principle, not only as the cause of metallization, but likewise of combustibility; and Stahl endeavoured, by a number of ingenious and elaborate experiments, to prove the existence of phlogiston, as it was called, and to explain its agencies in the phænomena of nature and art.

Glauber, about fifty years before Stahl began his labours, had discovered the combination of fossil alkali and sulphuric acid, which still bears his name. And Stahl, in operating upon this body, thought he had discovered the proof, that the inflammability not only of metals, but likewise of all other substances, was owing to the same principle. Charcoal is entirely dissipated or consumed in combustion; therefore, says this philosopher, it must be phlogiston nearly pure: by heating charcoal with metallic earths, they become metals; therefore they are compounds of metallic earths and phlogiston: by heating Glauber's salt, which consists of sulphuric acid and fossil alkali, with charcoal, a compound of sulphur and alkali is obtained; therefore sulphur is an acid combined with phlogiston. Stahl entirely neglected the chemical influence of air on these phænomena; and though Boyle had proved that phosphorus and sulphur would not burn without air, and had stated that sulphur was contained in sulphuric acid, and not the acid in sulphur, yet the ideas of the Prussian school were received without controversy. Similar opinions were adopted in France by Homberg and Geoffroy, who assumed them without reference to the views of the Prussian philosopher, and opposed them to the more correct and sagacious views of the English school of chemistry.

Though misled in his general notions, few men have done more than Stahl for the progress of chemical science. His processes were, many of them, of the most beautiful and satisfactory kind; he discovered a number of properties of the caustic alkalies and metallic calces, and the nature of sulphureous acid; he reasoned upon all the operations of chemistry in which gaseous bodies were not concerned, with admirable precision. He gave an axiomatic form to the science, banishing from it vague details, circumlocutions, and enigmatic descriptions, in which even Beccher had too much indulged; he laboured in the spirit of the Baconian school, multiplying instances, and cautiously making inductions, and appealing in all cases to experiments which, though not of the most refined kind, were more perfect than any which preceded them.

Dr. Hales, about 1724, resumed the investigations commenced with so much success by Boyle, Hooke, and Mayow; and endeavoured to ascertain the chemical relations of air to other substances, and to ascertain by statical experiments the cases in nature, in which it is absorbed or emitted. He obtained a number of important and curious results; but, misled by the notion of one elementary principle constituting elastic matter, and modified in its properties by the effluvia of solid or fluid bodies, he formed few inferences connected with the refined philosophy of the subject: he disengaged, however, elastic fluids from a number of substances, and drew the conclusion that air was a chemical element in many compound bodies, and that flame resulted from the action and re-action of ærial and sulphurous particles*.

In 1756 Dr. Black published his admirable researches on calcareous, magnesian, and alkaline substances, by which he proved the existence of a gaseous body, perfectly distinct from the air of the atmosphere. He shewed that quicklime differed from marble and chalk by containing this substance, and that it was a weak acid, capable of being expelled from alkaline and earthy substances by strong acids†.

Ideas so new and important as those of the British philosopher, were not received without opposition; several German enquirers endeavoured to controvert them. Meyer attempted to shew that limestones became caustic, not by the emission of elastic matter, but by combining with a peculiar substance in the fire; but the loss of weight was perfectly inconsistent with this view: and Bergman at Upsal, Macbride in Ireland, Keir at Birmingham, and Cavendish in London, demonstrated the correctness of the opinions of Black; and a few years were sufficient to establish his theory upon immutable foundations.

The knowledge of one elastic fluid different from air, immediately led to the enquiry whether there might not be others. The pro-

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* Hales' Statical Essays, 2d ed. 8vo. vol. i. pag. 315.

† Essays and Observations Physical and Literary, vol. ii. page 159.

cesses of fermentation which had been observed by the ancient chemists, and those by which Hales had disengaged and collected elastic substances, were now regarded under a novel point of view; and the consequence was, that a number of new bodies, possessed of very extraordinary properties, were discovered.

Mr. Cavendish, about 1765, invented an apparatus for examining elastic fluids confined by water, which has been since called the hydro-pneumatic apparatus. He discovered inflammable air, and described its properties; he ascertained the relative weights of fixed air, inflammable air, and common air, and made a number of beautiful and accurate experiments on the properties of these elastic substances.

Dr. Priestley, in 1771, entered the same interesting path of enquiry; and, principally by repeating the processes of Hales, added a number of most important facts to this department of chemical philosophy. He discovered nitrous air, nitrous oxide, and dephlogisticated air; and by substituting mercury for water in the pneumatic apparatus, ascertained the existence of several æriform substances, which are rapidly absorbable by water, muriatic acid air, sulphurous acid air, and ammonia.

Whilst a new branch of the science was making this rapid progress in Britain, the chemistry of solid and fluid substances was pursued with considerable zeal and success in France and Germany; and Macquer, Rouelle, Margraff, and Pott, added considerably to the knowledge of fossile bodies, and the properties of the metals. Bergman, in Sweden, developed refined ideas on the powers of chemical attraction, and reasoned in a happy spirit of generalization on many of the new phænomena of the science; and in the same country Scheele, independently of Priestley, discovered several of the same æriform substances: he ascertained the composition of the atmosphere; he brought to light fluoric acid, prussic acid, and the substance which has been improperly called oxymuriatic gas.

Black, Cavendish, Priestley, and Scheele, were undoubtedly the greatest chemical discoverers of the eighteenth century; and their merits are distinct, peculiar, and of the most exalted kind. Black made a smaller number of original experiments than either of the other philosophers; but being the first labourer in this new department of the science, he had greater difficulties to overcome. His methods are distinguished for their simplicity, his reasonings are admirable for their precision; and his modest, clear, and unaffected manner, is well calculated to impress upon the mind a conviction of the accuracy of his processes, and the truth and candour of his narrations.

Cavendish was possessed of a minute knowledge of most of the departments of natural philosophy: he carried into his chemical researches a delicacy and precision, which have never been exceeded: possessing depth and extent of mathematical knowledge, he reasoned with the caution of a geometer upon the results of his experiments: and it may be said of him, what, perhaps, can scarcely be said of any other person, that whatever he accomplished, was perfect at the moment of its production. His processes were all of a finished nature; executed by the hand of a master, they required no correction; the accuracy and beauty of his earliest labours even, have remained unimpaired amidst the progress of discovery, and their merits have been illustrated by discussion, and exalted by time.

Dr. Priestley began his career of discovery without any general knowledge of chemistry, and with a very imperfect apparatus. His characteristics were ardent zeal and the most unwearied industry. He exposed all the substances he could procure to chemical agencies, and brought forward his results as they occurred, without attempting logical method or scientific arrangement. His hypotheses were usually founded upon a few loose analogies; but he changed them with facility; and being framed without much effort, they were relinquished with little regret. He possessed in the highest degree ingenuousness and the love of truth. His manipulations, though never very refined, were always simple, and often ingenious. Chemistry owes to him some of her most important instruments of research, and many of her most useful combinations; and no single person ever discovered so many new and curious substances.

Scheele possessed in the highest degree the faculty of invention; all his labours were instituted with an object in view, and after happy or bold analogies. He owed little to fortune or to accidental circumstances: born in an obscure situation, occupied in the duties of an irksome employment, nothing could damp the ardour of his mind or chill the fire of his genius: with very small means he accomplished very great things. No difficulties deterred him from submitting his ideas to the test of experiment. Occasionally misled in his views, in consequence of the imperfection of his apparatus, or the infant state of the enquiry, he never hesitated to give up his opinions the moment they were contradicted by facts. He was eminently endowed with that candour which is characteristic of great minds, and which induces them to rejoice as well in the detection of their own errors, as in the discovery of truth. His papers are admirable models of the manner in which experimental research ought to be pursued; and they contain details on some of the most important and brilliant phænomena of chemical philosophy.

The discovery of the gases, of a new class of bodies, more active than any others in most of the phænomena of nature and art, could not fail to modify the whole theory of chemistry. The ancient doctrines were revised; new modifications of them were formed by some philosophers; whilst others discarded entirely all the former hypotheses, and endeavoured to establish new generalizations.

The idea of a peculiar principle of inflammability was so firmly established in the chemical schools, that even the knowledge of the composition of the atmosphere for a long while was not supposed to interfere with it; and the part of the atmosphere which is absorbed by bodies in burning, was conceived to owe its powers to its attraction for phlogiston.

All the modern chemists who made experiments upon combustion, found that bodies increased in weight by burning, and that there was no loss of ponderable matter. It was necessary therefore to suppose, contrary to the ideas of Stahl, that phlogiston was not emitted in combustion, but that it remained in the inflammable body after absorbing gaseous matter from the air. But what is phlogiston? was a question constantly agitated. Inflammable air had been obtained during the dissolution of certain metals, and during the distillation of a number of combustible bodies. This light and subtile matter, therefore, was fixed upon as the principle of inflammability; and Cavendish, Kirwan, Priestley, and Fontana, were the illustrious advocates of this very ingenious hypothesis.

In 1774, Bayen* shewed that mercury converted into a calx or earth, by the absorption of air, could be revived without the addition of any inflammable substance; and hence he concluded, that there was no necessity for supposing the existence of any peculiar principle of inflammability, in accounting for the calcination of metals. The subject, nearly about the same time, was taken up by Lavoisier, who had been for some time engaged in repeating the experiments of the British philosophers. Bayen formed no opinion respecting the nature of the air produced from the calx of mercury. Lavoisier, in 1775, shewed that it was an air which supported flame and respiration better than common air, which he afterwards named oxygene; the same substance that Priestley and Scheele had procured from other metallic substances the year before, and had particularly described†.

Lavoisier discovered that the same air is produced during the revivification of metallic calces by charcoal, as that which is emitted during the calcination of limestone; hence he concluded, that this elastic fluid is composed of oxygene and charcoal; and from his experiments on nitrous acid and oil of vitriol, he concluded that this gas entered into the composition of these substances.

Dr. Black had demonstrated by a series of beautiful experiments, that when gases are condensed, or when fluids are converted into solids, heat is produced. In combustion, gaseous matter usually assumes the solid or the fluid form. Oxygene gas, said Lavoisier, seems to be compound of the matter of heat, and a basis. In the act of burning, this basis is united to the combustible body, and the heat is evolved. There is no necessity, said this acute philosopher, to suppose any phlogiston, any peculiar principle of inflammability; for all the phænomena may be accounted for without this imaginary existence.

Lavoisier must be regarded as one of the most sagacious of the chemical philosophers of the last century; indeed, except Cavendish, there is no other inquirer who can be compared to him for precision of

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* Journal de Physique, 1774, page 288.

† In the Journal de Physique for 1789, Preliminary Discourse, De la Metherie has given an admirable view of the progress of the investigations concerning the gases. See p. 24, &c.

logic, extent of view, and sagacity of induction. His discoveries were few, but he reasoned with extraordinary correctness upon the labours of others. He introduced weight and measure, and strict accuracy of manipulation into all chemical processes. His mind was unbiassed by prejudice; his combinations were of the most philosophical nature; and in his investigations upon ponderable substances, he has entered the true path of experiment with cautious steps, following just analogies, and measuring hypotheses by their simple relations to facts.

The doctrine of Lavoisier, soon after it was framed, received some important confirmations from the two grand discoveries of Mr. Cavendish, respecting the composition of water, and nitric acid; and the elaborate and beautiful investigations of Berthollet respecting the nature of ammonia; in which phænomena, before anomalous, were shewn to depend upon combinations of æriform matter.

The notion of phlogiston was, however, defended for nearly 20 years, by some philosophers in Germany, Sweden, Britain, and Ireland. Mr. Cavendish, in 1784, drew a parallel between the hypothesis, that all inflammable bodies contain inflammable air, and the doctrine in which they are considered as simple substances, in a paper equally remarkable for the precision of the views displayed in it, and for the accuracy and minuteness of the experiments it contains. To this great man, the assumption of M. Lavoisier, of the matter of heat, appeared more hypothetical than that of a principle of inflammability. He states, that the phænomena may be explained on either doctrine; but he prefers the earlier view, as accounting, in a happier manner, for some of the operations of nature.

De Morveau, Berthollet, and Fourcroy, in France, and William Higgins and Dr. Hope, in Britain, were the first advocates for the antiphlogistic chemistry. Sooner or later, that doctrine which is an expression of facts must prevail over that which is an expression of opinion. The most important part of the theory of Lavoisier was merely an arrangement of the facts relating to the combinations of oxygene: the principle of reasoning which the French school professed to adopt was, that every body which was not yet decompounded, should be considered as simple; and though mistakes were made with respect to the results of experiments on the nature of bodies, yet this logical and truly philosophical principle was not violated; and the systematic manner in which it was enforced, was of the greatest use in promoting the progress of the science.

Till 1786, there had been no attempt to reform the nomenclature of chemistry; the names applied by discoverers to the substances which they made known were still employed. Some of these names, which originated amongst the alchemists, were of the most barbarous kind; few of them were sufficiently definite or precise, and most of them were founded upon loose analogies, or upon false theoretical views.

It was felt by many philosophers, particularly by the illustrious Bergman, that an improvement in chemical nomenclature was necessary, and in 1787, Messrs. Lavoisier, Morveau, Berthollet, and Fourcroy presented to the world a plan for an almost entire change in the denomination of chemical substances, founded upon the idea of calling simple bodies by some names characteristic of their most striking qualities, and of naming compound bodies from the elements which composed them.

The new nomenclature was speedily adopted in France; under some modifications it was received in Germany; and after much discussion and opposition, it became the language of a new and rising generation of chemists in England. It materially assisted the diffusion of the antiphlogistic doctrine, and even facilitated the general acquisition of the science; and many of its details were contrived with much address, and were worthy of its celebrated authors; but a very slight reference to the philosophical principles of language will evince that its foundations were imperfect, and that the plan adopted was not calculated for a progressive branch of knowledge.

Simplicity and precision ought to be the characteristics of a scientific nomenclature; words should signify things, or the analogies of things, and not opinions. If all the elements were certainly known, the principle adopted by Lavoisier would have possessed an admirable application; but a substance, in one age supposed to be simple, in another is proved to be compound; and *vice versa*. A theoretical nomenclature is liable to continued alterations; *oxygenated muriatic acid* is as improper a name as *dephlogisticated marine acid*. Every school believes itself in the right; and if every school assumes to itself the liberty of altering the names of chemical substances, in consequence of new ideas of their composition, or decomposition, there can be no permanency in the language of the science, it must always be confused and uncertain. Bodies which are similar to each other should always be classed together; and there is a presumption that their composition is analogous. Metals, earths, alkalies, are appropriate names for the bodies they represent, and independent of all speculative views; whereas oxides, sulphurets, and muriates are terms founded upon opinions of the composition of bodies, some of which have been already found erroneous. The least dangerous mode of giving a systematic form to a language seems to be, to signify the analogies of substances by some common sign affixed to the beginning or the termination of the word. Thus, as the metals have been distinguished by a termination in *um*, as *aurum*, so their calciform or oxidated state might have been denoted by a termination in *a*, as *aura;* and no progress, however great, in the science, could render it necessary that such a mode of appellation should be changed. Moreover, the principle of a composite nomenclature must always be very limited. It is scarcely possible to represent bodies consisting of five or six elements in this way, and yet it is in such difficult cases that a name implying a chemical truth would be most useful.

The new doctrines of chemistry, before 1795, were embraced by almost all the active experimental enquirers in Europe; and the adoption of a precise mode of reasoning, and more refined forms of experiment, led not only to the discovery of new substances, but likewise to a more accurate acquaintance with the properties and composition of bodies that had long been known.

New investigations were instituted with respect to all the productions of nature, and the immense variety of substances in the mineral, vegetable, and animal kingdom, submitted to chemical experiments.

The analysis of mineral bodies, first attempted by Pott in experiments principally on their igneous fusion, and afterwards refined by the application of acid and alkaline menstrua, by Margraaf, Bergman, Bayen, and Achard, received still greater improvements from the labours of Klaproth, Vauquelin, and Hatchett. Hoffman, in the beginning of the 18th century, pointed out magnesia as a peculiar substance*. Margraaf, about fifty years later†, distinguished accurately between the silicious, calcareous, and aluminous earths. Scheele, in 1774, discovered barytes. Klaproth‡, in 1788, made known zircone. Dr. Hope‖, strontites in 1791. Gadolin, ittria¶ in 1794; and Vauquelin, glucine in 1798.

Seven metals only had been accurately known to the ancients, gold, silver, mercury, copper, lead, tin, and iron. Zinc, bismuth, arsenic, and antimony, though mentioned by the Greek and Roman authors, yet were employed only in certain combinations, and the production of them in the form of reguli or pure metals, was owing to the alchemists.

Cobalt had been used to tinge glass in Saxony in the sixteenth century; but the metal was unknown till the time of Brandt, and this celebrated Swedish chemist discovered it in 1733. Nickel** was procured by Cronstedt in 1751. The properties of manganese, which was announced as a peculiar metal by Kaim†† in 1770, were minutely investigated by Scheele and Bergman a few years after. Molybdic acid was discovered by Scheele in 1778, and a metal procured from it by Hielm in 1782, the same year that tellurium was made known by Muller. Scheele discovered tungstic acid in 1781; and soon after a metal was extracted from it by Messrs. D'Elhuyars. Klaproth discovered uranium in 1789‡‡. The first description of the properties of the oxide of titanium was given by Gregor in 1791‖‖. Vauquelin made known chromium in 1797¶¶; Hatchett columbium in 1801***; and shortly after, the same substance was noticed by Eke-

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* Hoffman, Opera, Tom. iv. pag. 479.

† Opuscules, Tom. ii. pag. 137.

‡ Annales de Chimie, Tom. i. pag. 183.

‖ Edinburgh Trans. Vol. iv. p. 44.

¶ Crell's Annals, 1796.

** Bergman, Opuscula, Tom. ii. page 22.

†† De Metallis dubiis, p 48.

‡‡ Journal de Physique, 1789, pag. 39.

‖‖ Annales de Chimie, xii. pag. 147.

¶¶ Ibid. xxv. 21.

*** Phil. Trans. 1802.

berg, and named by him tantalium. Cerium was discovered in 1804, by Hissinger and Berzelius. Platina had been brought into Europe and examined by Lewis in 1749: and in 1803, Descotils, Fourcroy, and Vauquelin announced a new metallic substance in it; but the complete investigation of the properties of this extraordinary body was reserved for Messrs. Tennant and Wollaston, who in 1803 and 1804 discovered in it no less than four new metallic substances, besides the body which exists in it in the largest proportion, namely, iridium, osmium, palladium, and rhodium.

The attempts made to analyse vegetable substances previous to 1720, merely produced their resolution into the supposed elements of the chemists of those days, namely, salts, earths, phlegm, and sulphur. Boerhaave and Newmann attempted an examination by fluid menstrua, which was pursued with some success by Rouelle, Macquer, and Lewis. Scheele, between 1770 and 1780, pointed out several new vegetable acids. Fourcroy, Vauquelin, Deyeux, Seguin, Proust, Jacquin, and Hermbstadt, between 1780 and 1790, in various interesting series of experiments, distinguished between different secondary elements of vegetable matter, particularly extract, tannin, gums, and resinous substances; and investigations of this kind have been pursued with great success by Hatchett, Pearson, Shræder, Chenevix, Gehlen, Thomson, Thenard, Chevreul, Kind, Brande, Bostock, and Duncan. The chemistry of animal substances has received great elucidations from several of the same enquirers; and Berzelius has examined most of their results, and has added several new ones, in a comprehensive work expressly devoted to the subject, published in 1808.

That solid masses fell from above, connected with the appearance of meteors, had been advanced as early as 500 years before the Christian æra, by Anaxagoras; and the same idea had been brought forward in a vague manner by other enquirers among the Greeks and Romans, and was revived in modern times; but till 1802 it was regarded by the greater number of philosophers as a mere vulgar error, when Mr. Howard, by an accurate examination of the testimonies connected with events of this kind, and by a minute analysis of the substances said to have fallen in different parts of the globe, proved the authenticity of the circumstance, and shewed that these meteoric productions differed from any substances belonging to our earth ; and since that period a number of these phænomena have occurred, and have been minutely recorded.

The philosophy of heat, the foundations of which were laid between 1757 and 1785, by Black, Wilcke, Crawford, Irvine, and Lavoisier, since that period has received some new and very important additions, from the enquiries of Pictet, Rumford, Herschel, Leslie, Dalton, and Gay Lussac. The circumstances under which bodies absorb and communicate heat, have been minutely investigated ; and the important discoveries of the different physical and chemical powers of the different solar rays, and of a property analogous to polarity in light, bear immediate relation to the most refined doctrines of corpuscular science, and promise to connect, by close analogies, the chemical and mechanical laws of matter.

A general view of the philosophy of chemistry was published under the name of Chemical Statics, in 1803, by the celebrated Berthollet. It is a work remarkable for the new views that it contains on the doctrines of attraction ; views which are still objects of discussion, and which bear an immediate relation to some of the conclusions depending upon very recent discoveries.

At the time when the antiphlogistic theory was established, electricity had little or no relation to chemistry. The grand results of Franklin, respecting the cause of lightning, had led many philosophers to conjecture, that certain chemical changes in the atmosphere, might be connected with electrical phænomena ;—and electrical discharges had been employed by Cavendish, Priestley, and Vanmarum, for decomposing and igniting bodies ; but it was not till the era of the wonderful discovery of Volta, in 1800, of a new electrical apparatus, that any great progress was made in chemical investigation by means of electrical combinations.

Nothing tends so much to the advancement of knowledge as the application of a new instrument. The native intellectual powers of men in different times, are not so much the causes of the different success of their labours, as the peculiar nature of the means and artificial resources in their possession. Independent of vessels of glass, there could have been no accurate manipulations in common chemistry : the air pump was necessary for the investigation of the properties of gaseous matter; and without the Voltaic apparatus, there was no possibility of examining the relations of electrical polarities to chemical attractions.

By researches, the commencement of which is owing to Messrs. Nicholson and Carlisle, in 1800, which were continued by Cruickshank, Henry, Wollaston, Children, Pepys, Pfaff, Desormes, Biot, Thenard, Hissinger, and Berzelius, it appeared that various compound bodies were capable of decomposition by electricity; and experiments, which it was my good fortune to institute, proved that several substances which had never been separated into any other forms of matter in the common processes of experiment, were susceptible of analysis by electrical powers: in consequence of these circumstances, the fixed alkalies and several of the earths have been shewn to be metals combined with oxygene; various new agents have been furnished to chemistry, and many novel results obtained by their application, which at the same time that they have strengthened some of the doctrines of the school of Lavoisier, have overturned others, and have proved that the generalizations of the antiphlogistic philosophers were far from having anticipated the whole progress of discovery.

Certain bodies which attract each other chemically, and combine when their particles have freedom of motion, when brought into contact, still preserving their aggregation, exhibit what may be called electrical polarities; and by certain combinations these polarities may be highly exalted; and in this case they become subservient to chemical decompositions; and by means of electrical arrangements the constituent parts of bodies are separated in a uniform order, and in definite proportions.

Bodies combine with a force, which in many cases is correspondent to their power of exhibiting electrical polarity by contact; and heat, or heat and light, are produced in proportion to the energy of their combination. Vivid inflammation occurs in a number of cases in which gaseous matter is not fixed; and this phænomenon happens in various instances without the interference of free or combined oxygene.

Experiments made by Richter and Morveau had shewn that, when there is an interchange of elements between two neutrals salts, there is never an excess of acid or basis; and the same law seems to apply generally to double decompositions. When one body combines with another in more than one proportion, the second proportion appears to be some multiple or divisor of the first; and this circumstance, observed and ingeniously illustrated by Mr. Dalton, led him to adopt the atomic hypothesis of chemical changes, which had been ably defended by Mr. Higgins in 1789, namely, that the chemical elements consist of certain indestructible particles which unite one and one, or one and two, or in some definite numbers.

Whether matter consists of indivisible corpuscles, or physical points endowed with attraction and repulsion, still the same conclusions may be formed concerning the powers by which they act, and the quantities in which they combine; and the powers seem capable of being measured by their electrical relations, and the quantities on which they act of being expressed by numbers.

In combination certain bodies form regular solids; and all the varieties of crystalline aggregates have been resolved by the genius of Haüy into a few primary forms. The laws of crystallization, of definite proportions, and of the electrical polarities of bodies, seem to be intimately related; and the complete illustration of their connection, probably will constitute the mature age of chemistry.

To dwell more minutely upon the particular merits of the chemical philosophers of the present age, will be a grateful labour for some future historian of chemistry; but for a contemporary writer, it would be indelicate to assume the right of arbitrator, even where praise only can be bestowed. The just fame of those who have enlightened the science by new and accurate experiments, cannot fail to be universally acknowledged; and concerning the publication of novel facts there can be but one judgment; for facts are independent of fashion, taste, and caprice, and are subject to no code of criticism; they are more useful perhaps even when they contradict, that when they support received doctrines, for our theories are only imperfect approximations to the real knowledge of things; and, in physical research, doubt is usually of excellent effect, for it is a principal motive for new labours, and tends continually to the developement of truth.

The slight sketch that has been given of the progress of chemistry, has necessarily been limited to the philosophical details of discovery. To point out in historical order the manner in which the truths of the science have been applied to the arts of life, or the benefits derived by society from them, would occupy many volumes. From the first discovery of the production of metals from rude ores, to the knowledge of the bleaching liquor, chemistry has been continually subservient to cultivation and improvement. In the manufacture of porcelain and glass, in the arts of dyeing and tanning, it has added to the elegancies, refinement, and comforts of life; in its application to medicine it has removed the most formidable of diseases; and in leading to the discovery of gunpowder, it has changed the institutions of society, and rendered war more independent of brutal strength, less personal, and less barbarous.

It is indeed a double source of interest in this science, that whilst it is connected with the grand operations of nature, it is likewise subservient to the common processes as well as the most refined arts of life. New laws cannot be discovered in it, without increasing our admiration of the beauty and order of the system of the universe; and no new substances can be made known which are not sooner or later subservient to some purpose of utility.

When the great progress made in chemistry within the few last years is considered, and the number of able labourers who are at present actively employed in cultivating the science, it is impossible not to augur well concerning its rapid advancement and future applications. The most important truths belonging to it are capable of extremely simple numerical expressions, which may be acquired with facility by students; and the apparatus for pursuing original researches is daily improved, the use of it rendered more easy, and the acquisition less expensive.

Complexity almost always belongs to the early epochs of every science; and the grandest results are usually obtained by the most simple means. A great part of the phænomena of chemistry may be already submitted to calculation; and there is great reason to believe, that at no very distant period the whole science will be capable of elucidation by mathematical principles. The relations of the common metals to the bases of the alkalies and earths, and the gradations of resemblance between the bases of the earths and acids, point out as probable a similarity in the constitution of all inflammable bodies; and there are not wanting experiments, which render their possible decomposition far from a chimerical idea. It is contrary to the usual order of things, that events so harmonious as those of the system of the earth, should depend on such diversified agents, as are supposed to exist in our artificial arrangements; and there is reason to anticipate a great reduction in the number of the undecompounded bodies, and to expect that the analogies of nature will be found conformable to the refined operations of art. The more the phænomena of the universe are studied, the more distinct their connection appears, the more simple their causes, the more magnificent their design, and the more wonderful the wisdom and power of their Author.

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ELEMENTS
OF
CHEMICAL PHILOSOPHY.

PART I.

ON THE LAWS OF CHEMICAL CHANGES:
ON
UNDECOMPOUNDED BODIES
AND
THEIR PRIMARY COMBINATIONS.

ELEMENTS, &c.

DIVISION I.

ON THE POWERS AND PROPERTIES OF MATTER, AND THE GENERAL LAWS OF CHEMICAL CHANGES.

I. *Preliminary Observations.*

1. THE forms and appearances of the beings and substances of the external world are almost infinitely various, and they are in a state of continued alteration: the whole surface of the earth even undergoes modifications: acted on by moisture and air, it affords the food of plants; an immense number of vegetable productions arise from apparently the same materials; these become the substance of animals; one species of animal matter is converted into another; the most perfect and beautiful of the forms of organised life ultimately decay, and are resolved into inorganic aggregates; and the same elementary substances, differently arranged, are contained in the inert soil, or bloom and emit fragrance in the flower, or become in animals the active organs of mind and intelligence. In artificial operations, changes of the same order occur: substances having the characters of earths are converted into metals; clays and sands are united so as to become porcelain; earths and alkalies are combined into glass; acrid and corrosive matters are formed from tasteless substances;—colours are fixed upon stuffs, or changed, or made to disappear; and the productions of the mineral, vegetable, and animal kingdoms are converted into new forms, and made subservient to the purposes of civilized life.

2. To trace in detail these diversified and complicated phænomena, to arrange them and deduce general laws from their analogies, would be a labour to which even the longest life of the most industrious and sagacious individual might be devoted in vain. The student who has the advantage of referring to the knowledge accumulated by many individuals in different times, may adopt much more simple methods of acquiring the science. Those of recurring to its general principles, so as to ascertain the powers and properties of matter, which are the causes of the phænomena of chemistry; and of applying these principles to the actions taking place between the various substances existing in nature, or produced by art; proceeding gradually, referring to observations, experiments, and distinct analogies, from the more simple to the more complicated changes, so as to understand the laws by which they are governed.

II. *Of the Forms of Matter.*

1. In the general views that may be taken of the properties of natural substances, certain relations appear, which afford the means of arranging them in four distinct classes, each of which is distinguished by certain sensible and obvious qualities.

2. The first class consists of *solids*, which compose the great known part of the globe. Solid bodies, when in small masses, retain whatever mechanical form is given to them: their parts are separated with difficulty, and cannot readily be made to unite after separation; some solid bodies yield to pressure, and do not recover their former figure, when the compressing force is removed, and they are called non-elastic solids; others that regain this form, are called elastic bodies. Solids differ in degrees of hardness, in colour, in degrees of opacity or transparency, in density or in the weight afforded by equal volumes; and when their forms are regular or crystallised, in the nature of these forms.

3. The second class consists of *fluids*, of which there are much fewer varieties. Fluids when in small masses assume the spherical form; their parts possess freedom of motion; they differ in degrees of density and tenacity, in colour and degrees of opacity or transparency. They are usually regarded as incompressible, at least a very

great mechanical force is required to make them occupy a space perceptibly smaller.

4. *Elastic fluids* or *gasses*, the third class, exist free in the atmosphere; but they may be confined by solids, or by solids and fluids, and their properties examined. Their parts are highly moveable; they are compressible and expansible, and their volumes are inversely as the weights compressing them. All known elastic fluids are transparent, and present only two or three varieties of colour; they differ materially in density.

5. Besides these forms of matter which are easily submitted to experiment, and the parts of which may be considered as in a state of apparent rest, there are other forms of matter which are known to us only in their states of motion when acting upon our organs of sense, or upon other matter, and which are not susceptible of being confined. They have been sometimes called *etherial substances*, which appears a more unexceptionable name than *imponderable substances*. It cannot be doubted that there is matter in motion in space, between the sun and the stars and our globe, though it is a subject of discussion whether successions of particles be emitted from these heavenly bodies, or motions communicated by them to particles in their vicinity, and transmitted by successive impulses to other particles. *Etherial* matter differs either in its nature or in its affections by motion; for it produces different effects; for instance, as radiant heat, and as different kinds of light.

6. The various forms of matter, and the changes of these forms, depend upon active powers, such as gravitation, cohesion, calorific repulsion or heat, chemical attraction, and electrical attraction, the laws of which it is necessary to study with attention.

III. *Gravitation.*

1. When a stone is thrown into the atmosphere, it rapidly descends towards the surface of the earth. This is owing to *gravitation*. All the great bodies in the universe are urged towards each other by a similar force. A cannon ball sent from a piece of artillery describes a curve, and at last falls to the ground; were the impulse given to it by the gunpowder increased to a certain extent, and

exerted in free space, it would continuously revolve round the earth, in consequence of the equilibrium between the two forces. The moon and the planets, as Newton has demonstrated, are retained in their orbits by similar laws, and their harmonious and constant revolutions produced.

2. Bodies mutually gravitate towards each other; but the smaller body proportionally more than the larger one: hence the power of gravity is said to be directly as the mass; it is, in fact, the measure of the mass or quantity of matter.

3. Gravitation acts inversely, as the square of the distance.

IV. *Cohesion.*

1. When two particles of quicksilver are brought into apparent contact, they may be made to unite, and form one globule: when a glass tube, having a very fine bore, is introduced into a vessel containing water, the water rises in the tube to a higher level than it occupied in the vessel: both these effects are said to be owing to *cohesion* or *cohesive attraction*. It is the same force which preserves the forms of solids, and gives globularity to fluids, and is thus a prime cause of the permanency of the arrangements which compose the surface of the globe. It is usually said to act only at the surfaces of bodies, or by their immediate contact; but this does not seem to be the case. It certainly acts with much greater energy at small distances; but the spherical form of minute portions of fluid matter can only be produced by the attractions of all the parts of which they are composed for each other; and most of these attractions must be exerted at sensible distances; so that, for any thing we know to the contrary, gravitation and cohesion may be mere modifications of the same general power of attraction, in the one case acting at distances that can be easily measured, and in the other case operating at distances which it is difficult to estimate.

2. Some philosophers have attempted to account for *attraction in general*, by supposing that there is a certain unknown matter always moving through the universe in right lines, by which bodies are impelled towards each other; but, though the phænomena may be explained by such a supposition, it is without proof; and there is no

ground for supposing that matter cannot act at a distance, and it is absolutely necessary for the explanation of the planetary motions, to suppose space in the universe void of matter.

V. *Of Heat, or calorific Repulsion.*

1. When a body which occasions the sensation of heat on our organs, is brought into contact with another body which has no such effect, the result of their mutual action is that the hot body contracts, and loses to a certain extent its power of communicating heat, and the other body expands, and in a degree acquires this power.

This law may be exemplified with respect to every form of ponderable matter. If a polished cylinder of tin, which accurately fits a ring, be heated so as to make water boil, it will no longer pass through the ring, and will be found enlarged in all its dimensions. If spirits of wine be heated in a glass vessel having a narrow tubulated neck, as it becomes capable of communicating the sensation of heat, it will be found to expand and to rise in the narrow neck; and if the body of the same vessel be filled with air, and it be inverted in water, its neck containing water, the air will rapidly expand, on the application of a heated body, and will cause the water to descend in the neck of the vessel*.

2. Different solids and fluids expand very differently when heated by the same means.

Glass is less expansible than any of the metals; 100,000 parts raised from the degree of freezing to that of boiling water, expand so as to become 100,083 parts; 100,000 of platinum under similar circumstances expand so as to become 100,087; and equal parts of gold, antimony, cast-iron, steel, iron, bismuth, copper, cast-brass, silver and tin, lead, zinc, and hammered zinc expand in the following order: 100094, 100108, 100111, 100112, 100126, 100139, 100170, 100189, 100238, 100287, 100296, 100308. The expansive power of liquids in general is greater than that of solids; alcohol appears to be more expansible than oils, and oils in general more expansible than water. 100,000 parts of mercury of the same degree of heat

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* Plate I. fig. 1.

as ice become at the degree of heat at which water boils 101,835. All the elastic fluids, or the different species of air that have been examined, as has been demonstrated by Messrs. Dalton and Gay Lussac, expand alike when heated to the same degree; 100 parts of each at the freezing point of water becoming about 137,5 at the boiling point.

It is evident that the density of bodies must be diminished by expansion; and in the case of fluids and gasses, the parts of which are mobile, many important phænomena depend upon this circumstance. If heat be applied to fluids or to gasses, the heated parts change their places and rise; and the colder parts descend and occupy their places. Currents are constantly produced in the ocean and in great bodies of water, in consequence of this effect. The heated water rises to the surface in the tropical climates, and flows towards colder ones: thus the warmth of the gulf stream is felt a thousand miles from its source; and deep currents pass from the colder to the warmer parts of the sea: and the general tendency of these changes is to equalize the temperature of the globe.

In the atmosphere heated air is constantly rising, and colder air rushes in to supply its place; and this event is the principal cause of winds: the air that flows from the poles towards the equator, in consequence of the rotation of the earth, has less motion than the atmosphere into which it passes, and occasions an easterly current; the air passing from the equator towards the poles having more motion, occasions a westerly current; and by these changes, the different parts of the atmosphere are mixed together: cold is subdued by heat, moist air from the sea is mixed with dry air from the land, and the great mass of elastic fluid surrounding the globe preserved in a state fitted for the purposes of vegetable and animal life.

3. There are very few exceptions to the law of the *expansion* of bodies, at the time they became capable of communicating the sensation of heat; and these exceptions seem entirely to depend upon some chemical change in the constitution of bodies, or on their crystalline arrangements. Thus clay contracts considerably in dimensions by a very intense heat, and on the measure of its contractions the pyrometer of Wedgwood is founded: but in this case

the clay first gives off water, which was united to its parts, and afterwards these parts cohere together with more force, and from being in a state of loose aggregation become strongly united. Water expands a little before it congeals, and expands considerably during its conversion into ice; but in this case it assumes the crystalline form; and its parts whilst they are arranging themselves to form regular solids, probably leave greater interstices than they occupied when at uniform distances in the fluid. Thus the same weight of matter will occupy much more space when arranged in a certain number of octahedrons, than when arranged in a similar number of cubes, or hexagonal prisms. Certain saline solutions likewise, that shoot into prismatic crystals, expand at the moment they become solid; and the case is the same with cast-iron, bismuth, and antimony.

The expansion of water during its conversion into ice, is shewn by the circumstance of ice swimming upon water; and if water in a deep vessel be examined at the time ice is forming, it will be found a little warmer at the bottom than at the top; and these circumstances are of great importance in the œconomy of nature. Water congeals only at the surface, where it is liable to be acted upon by the sun, and by warm currents of air which tend to restore it to the fluid state; and when water approaches near the point of freezing it begins to descend, so that no ice can form till the whole of the water has been cooled to the point where it possesses the great density; and in the deep parts of the sea and lakes, even in some of the northern latitudes, the duration of the long winter is insufficient to cool the water to the degree at which ice forms.

4. When equal quantities of the same matter differently heated are mixed together, as much as the one contracts, so much the other seems to expand. It is easy to prove this by shaking together 100 parts of mercury so hot as not to be touched without pain, and 100 parts in its common state, having previously measured the space they occupy; if the mixture is made in the tube that contained the hot mercury, there will be no sensible change of volume.

It is on the idea, that when heat or the power of repulsion is communicated from body to body, as much is gained by one body as is lost by the other, that thermometers have been framed, and the doctrines of temperature, and capacity for heat founded.

5. The most common thermometer is a glass bulb, containing mercury, terminated by a glass tube, having a very narrow bore. The mercury is boiled to expel any air or moisture that might be attached to it; and at the moment it is in ebullition, the extremity of the tube being drawn to a fine point, is hermetically sealed by a spirit lamp. For the purpose of acquiring a scale, the bulb is first plunged into melting ice, and the place where the mercury stands is marked; the bulb is afterwards plunged into boiling water, and the same operation repeated. On Fahrenheit's scale this space is divided into 180 equal parts, and similar parts are taken above and below for extending the scale, and the freezing point of water is placed at 32°, and the boiling point at 212°. 1.8 degrees of Fahrenheit are equal to one degree of the centigrade thermometer, and 2.25 to one degree of Reaumur.

Other fluids besides mercury, such as alcohol, are sometimes used in thermometers, particularly for measuring low degrees when mercury freezes.

Air is employed in the differential thermometer, which consists of two bulbs filled with air, and connected by a capillary tube containing oil of vitriol: the heated body is brought in contact with one bulb, the air of which expands and drives the fluid towards the other bulb*.

6. *Temperature* is the power bodies possess of communicating or receiving heat, or the energy of repulsion; and the temperature of a body is said to be high or low with respect to another, in proportion as it occasions an expansion or contraction of its parts; and the thermometer is the common measure of temperature.

7. When equal volumes of different bodies of different temperatures are suffered to remain in contact till they are possessed of the same temperature, it is found that this temperature is not a mean one, as it would be in the case of equal volumes of the same body.

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* Plate I. fig. 2, represents Mr. Leslie's differential thermometer. Fig. 3 is copied from Van Helmont. This instrument appears to have been the first in which the expansive power of heated air, was exhibited by its action upon cold air.

Thus, if a pint of quicksilver at 100°, be mixed with a pint of water at 50°, the resulting temperature is not 75°, but about 70°: the mercury has lost 30°, whereas the water has gained only 20°. In the common language of chemical philosophers this difference is said to depend upon the different *capacities* of bodies for heat, and the *capacity* of a body is said to be greater or less, in proportion as its temperature is less or more raised by the addition, or diminished by the subtraction of equal quantities of the power of repulsion, or heat. Thus mercury is said to have a much less capacity for heat than water; and taking the facts above stated as data, and comparing the weights of the two bodies, which are as 13.3 to 1, their capacities will be to each other as about 19 to 1.

Tables of the relative capacities of bodies are given in the works of different authors. In referring to the various bodies which are the subjects of chemistry, this property will be described amongst other properties. In general it appears that the substances most expansible by heat are those which have the greatest capacities: thus gasses in general have greater capacities than fluids, and fluids than solids; but the exact ratio has not been yet determined.

8. Different bodies, it appears, have their temperatures differently raised by the addition, or diminished by the subtraction of equal quantities of heat, or the power of repulsion, and they are likewise affected by heat, or expanded, with very different degrees of celerity. If slender cylinders of silver, of glass, and of charcoal, of equal length and size, be held in the central part of the flame of a candle, the silver rapidly becomes heated throughout, and cannot be held in the hand; the heat is more slowly communicated through the glass, but the charcoal becomes red-hot at the one extremity long before any heat is felt at the other extremity. These differences are said to depend upon the different powers of these bodies *for conducting* heat; thus the silver is said to be a better conductor than the glass, and the glass than the charcoal. In general those bodies that are the densest, and that have the least capacity for heat, are the best conductors: thus the metals conduct better than any other solids; gasses are worse conductors than fluids, and fluids than solids: but there are exceptions with respect to this correspondence between conducting power and density, and a remarkable one, in the densest

known body in nature, platina, which is perhaps the worst conductor amongst the metals.

Animal and vegetable substances in general, are very bad conductors: thus the hair and wool of animals, and the feathers of birds, are admirably fitted to protect them from the cold, and they inclose and retain air, which being a still worse conductor, enhances the effect. It was supposed by Count Rumford, that fluids and gasses are perfect *nonconductors* of heat, and that their particles can be heated in no other way, except by coming in succession to the source of heat; but some very conclusive experiments seem to render this opinion untenable. In general, however, fluids and gasses alter their places from a change of specific gravity, much more rapidly than they communicate or receive heat. This is illustrated by a very simple experiment: let an air thermometer be inverted in a vessel of water, so that the extremity of the bulb is barely beneath the surface, let a little ether be poured upon the water so as to form a stratum about one-eighth of an inch above the thermometer, and let the ether be inflamed*; however delicate the thermometer, the air in it will not soon expand; the ether boils violently, but a very long process of this kind is required to communicate any sensible heat to the water. Unless the particles of gasses and fluids had been capable of communicating heat to a certain extent, the upper strata of liquids would be almost the only permanently heated parts; and heat would be constantly accumulating on the surface of extensive seas. Our lower atmosphere likewise would be intensely cold during the absence of the sun; but by the relations between the conducting power and the mobility of fluids and gasses, the changes of temperature of air and water are made progressive and equable, and adapted to a habitable globe. As heat is propagated very slowly through gaseous bodies, so they communicate it very slowly to other bodies, a circumstance that might be expected from the small quantity of matter they contain, when compared to other substances. The heat of metals at the temperature of 120° is scarcely supportable; water scalds at 150°; but air may be heated to 240° without being painful to our organs of sensation, and a tem-

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* See Plate I. fig. 4.

perature near this was experienced for some minutes, by Sir Joseph Banks, Sir Charles Blagden, and Dr. Fordyce, in a room artificially heated.

The power of abstracting heat in air is likewise comparatively very small; in the high northern latitudes a cold has been experienced without injury, in which mercury froze; and if, in this state of the atmosphere, metallic substances, of the same temperature, were touched, a sensation like that of burning was experienced, and the part blistered.

9. Heat, or the power of repulsion, may be considered as the *antagonist* power to the attraction of cohesion, the one tending to separate, the other to unite the parts of bodies; and the forms of bodies depend upon their respective agencies. In solids the attractive force predominates over the repulsive; in fluids, and in elastic fluids, they may be regarded as in different states of equilibrium; and in ethereal substances the repulsive must be considered as predominating over, and destroying the attractive force.

All the different substances in nature, under certain circumstances, are probably capable of assuming all these forms: thus solids, by a certain increase of temperature, become fluids, and fluids gasses; and *vice versa*, by a diminution of temperature, gasses become fluids, and fluids solids.

Instances of the fusion of solids by heat are too familiar to require any particular notice; when water becomes steam by boiling, it is merely the conversion of a fluid into an elastic fluid; and a simple instance of this circumstance may be given in the ebullition of ether. Let a little ether be introduced into a small glass retort filled with water, and inverted in water: the ether will swim above the water, in the upper part of the retort; let a heated bar of metal* be held near the part of the retort containing the ether, as the heat is communicated, globules will be seen to rise, and in a very short time elastic fluid will be formed, in such quantities, as to expel the water from the vessel: on suffering the glass to cool, the elastic matter will be condensed, and will become again fluid.

If a globule of mercury be held in a spoon of platina, over the flame of a lamp, it will be vividly agitated, and will rapidly diminish.

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* Plate I. fig. 5.

This is owing to its becoming elastic, and flying off in gas: and by a very low temperature, which may be artificially produced by mixing together very cold snow and a salt called muriate of lime, mercury may be congealed into the solid form.

Different bodies change their states at very different temperatures. Thus mercury, which is a solid at about 40° below Fahrenheit, boils at about 660°; sulphur, which becomes fluid at 218°, boils at 575°; ether boils at 98°. The temperatures at which the common metals become gaseous, are generally very high, and most of them incapable of being produced by common means. Iron, maganese, platina, and some other metals, which can scarcely be fused in the best furnaces, are readily melted by electricity; and by the Voltaic apparatus a degree of heat is attained, in which platina not only fuses with readiness, but seems even to evaporate.

With respect to the conversion of solids, fluids, or gasses, into ethereal substances, the proofs are not of the same distinct nature as those belonging to their conversion into each other. When the temperature of a body is raised to a certain extent, it becomes luminous; and heated bodies not only affect other bodies by direct contact, but likewise exert an influence on them at a distance, which is ascribed to what is usually called radiant heat. One solution of this phænomenon is, that particles are thrown off from heated bodies with great velocity, which by acting on our organs produce the sensations of heat or light, and that their motion, communicated to the particles of other bodies, has the power of expanding them: thus if heat, or the force of repulsion, be so increased in an elastic fluid, as to overcome the force of cohesion and gravitation, these particles would move in right lines through free space; and we know of no other effects they could produce, than those of heat and light. It is perhaps in favour of this opinion, that all the different elastic fluids expand equally, when their temperatures are equally raised; and from observations made on the eclipses of Jupiter's satellites, and from other phænomena presented by the heavenly bodies, it appears that the motions of light are equable.

It may, however, be said, that the radiant matters emitted by bodies in ignition, are specific substances, and that common matter is not susceptible of assuming this form; or it may be contended, that the phænomena of radiation do, in fact, depend upon motions communicated to subtile matter every where existing in space.

9. The temperatures at which bodies change their states from fluids to solids, though in general definite, are influenced by a few circumstances, such as motion and pressure. Water, kept perfectly at rest, may sometimes be cooled to 22°, without congelation; but if at a temperature below 32° it be agitated, ice instantly forms. A saturated solution of Glauber's salt, introduced whilst warm into a bottle, from which the pressure of the atmosphere is excluded, remains liquid after cooling, but if the atmosphere be suffered to act upon it, it instantly crystallizes. The boiling point of fluids is still less fixed, than the point of fusion of solids, and is immediately dependent upon pressure. Thus ether will boil readily at the freezing point of water, in the exhausted receiver of an air-pump; and it appears from the researches of Professor Robison, that in a vacuum, all liquids boil about 145° lower, than in the open air. Under pressure, liquids may be heated to a high degree; water in a Papin's digester, may have its temperature raised to 300°, but at the moment the pressure is removed, elastic matter is disengaged with great violence.

10. A peculiar distinction has been made by some authors between permanent elastic fluids, and elastic fluids which are condensable by pressure or cold; but these subtances differ only in the degree of the point of vaporization; and steam at 500 degrees of Fahrenheit, there is every reason to believe, would be equally incondensible with air at a range of temperature such as we can command below our common temperatures; and some gasses that are permanent under all common circumstances, as ammonia, are condensible by intense cold aided by pressure.

All bodies that boil at moderate temperatures, seem to evaporate, so as to produce a certain quantity of elastic matter in the common state of the atmosphere; and this quantity is greater in proportion as the temperature is high. According to Mr. Dalton, the force of vapour increases in geometrical progression to the temperature, but the ratio differs in different fluids. It is certain that as the temperature approaches near the point of ebullition, in liquids, the strength of the vapour, i. e. the quantity that would rise in free space, rapidly increases.

In hot, dry weather, it is obvious that there must be much more vapour in the atmosphere, than in cold, wet weather; and the largest quantity exists in summer and in the tropical climates, when moisture is most needed for the purposes of life; and it appears to be the aqueous vapour in the atmosphere, which, when condensed by the mixture of cold with hot air, or by other agencies occasioning a change of its temperature, is the cause of dew, mists, rain, and ultimately of springs, and rivers.

11. When solids are converted into fluids, or fluids into gasses, there is always a loss of heat of temperature, and vice versa, when gasses are converted into fluids, or fluids into solids, there is an increase of heat of temperature, and in this case it is said that *latent heat* is absorbed or given out. Thus if equal weights of snow at 32° and of water at 172° be mixed together, the whole of the snow is melted, but the temperature of the mixture is found to be 32°, so that 140° of heat are lost. Again, if water be heated in a Papin's digester to 300 degrees, and the valve be raised, a quantity of steam instantly rises, which has the temperature of 212°, and the temperature of the water in the digester is found to be the same, so that a great quantity of heat of temperature is lost in converting the water into steam.

If when the air is at 20°, a quantity of water be exposed to it in a tall glass, the water gradually cools down to 22°, without freezing; but if it be shaken, so as to be converted into ice, the temperature of the ice is found to be at 32°, so that the degree of heat is raised during the act of freezing.

If one part of steam or aqueous gas, at 212°, be mixed with 6 parts by weight of water, at 62°, the whole of the steam will be condensed, and the temperature of the fluid will be about 212°, so that there is an immense increase of the heat of temperature, and 900° may be considered as taken from the steam, and as added to the water.

All the phænomena of these changes may be referred to a simple general law, of which Dr. Black was the discoverer, and which has been most ably illustrated by the researches of Wilke, Watt, Irvine, and Crawford, namely, "that whenever a body changes its form, its relations to temperature are likewise changed, either increased or diminished;" and many important operations, both artificial and natural, depend upon this law. The knowledge of it, for instance, led Mr. Watt to make his great improvement of the steam engine, by which the steam is condensed out of the cylinder in which its force is efficient, and fresh gaseous matter introduced without any chance of a loss of its elasticity.

One of the most perfect modes of heating large rooms, and of procuring a uniform temperature for the purposes of manufacture, is by the condensation of steam. By the cold produced in consequence of the evaporation of water in hot climates, congelation is effected; and in the nights in Bengal, when the temperature is not below fifty, by the exposure of water in earthenware pans upon moistened bamboos, thin cakes of ice are formed, which are heaped together and preserved under ground by being kept in contact with bad conductors of heat. The cold produced by evaporation is likewise the cause of the formation of ice in Mr. Leslie's elegant experiment, in which sulphuric acid is placed in a vessel upon the plate of an air-pump, and water in another vessel raised above it; the surfaces both of the acid and the water being considerable. When an exhaustion is made, the sulphuric acid rapidly absorbs the vapour rising from the water; fresh vapour is immediately formed, and in a few minutes, if the circumstances are favourable, spiculæ of ice are seen to form on the surface of the water.

When aqueous vapour is condensed into fluid in the atmosphere, heat is produced; and the formation of rain, hail, and snow, tends to mitigate the severity of the winter. In the summer, evaporation is constantly tending to cool the surface. The melting of the polar ice moderates the heat that would arise in the northern regions from the constant presence of the sun during the polar summer. And the evolution of heat during the congelation of water, prevents too great a degree of cold, and renders the transitions of temperature more slow and gradual.

12. When the forms of bodies are changed by mechanical means, or when mechanical forces are made to act upon them, there is usually a change of temperature. A piece of caotchouc extended

and suffered to contract rapidly by mechanical means, becomes hot; a nail is easily made red hot by a few well-directed blows of the hammer; and by the friction of solids, considerable increase of temperature is produced: thus the axle-trees of carriages sometimes inflame.

By strong pressure, fluids even are made luminous, as has been lately shewn by M. Dessaignes.

When an elastic fluid is compressed by mechanical means, its temperature is raised, and when the compressing forces are great and rapidly applied, the effect is such as to cause the ignition of bodies. A machine for setting fire to tinder of the agaric, by the compression of air, has been for some time in use.

When air is made to expand by removing compressing forces, a diminution of temperature is occasioned. Thus the mercury in the thermometer sinks at the time of the rarefaction of air, by exhausting the receiver of an air pump.

In the common language of chemistry, it may be said that the capacity of elastic fluids for heat is diminished by compression, and encreased by rarefaction; and it is probable that when the volumes of elastic fluids are changed by change of temperature, there is likewise a change of capacity; and on these ideas it is easy to account for the correspondence between the diminution of the temperature of the atmosphere and its height; for if it be conceived that the capacity of air rarefied by heat, increases as it ascends, the heat of temperature which was the cause of its ascent, must, at a certain elevation, become heat of capacity: and the higher and more rarefied the air, the more it is removed from the source of heat, and the greater its power of diminishing temperature.

A very curious phænomenon is produced during the action of the fountain of Hiero at Schemnitz in Hungary; the air in the machine is compressed by a column of water, 260 feet high, and when a stop-cock is opened so as to suffer air to escape, its sudden rarefaction produces a degree of cold which not only precipitates aqueous vapour, but causes it to congeal in a shower of snow, and the pipe from which the air issues becomes covered with icicles. Dr. Darwin has ingeniously explained the production of snow on the tops of the highest mountains by the precipitation of vapour from the rarefied air which ascends from plains and valleys. The Andes, placed almost under the line, rises in the midst of burning sands; about the middle height is a pleasant and mild climate; the summits are covered with unchanging snows: and these ranges of temperature are always distinct; the hot winds from below, if they ascend, become cooled in consequence of expansion, and the cold air, if by any force of the blast it is driven downwards, is condensed, and rendered warmer as it descends.

It seems probable that the capacity of solids and fluids is increased by expansion, and diminished by condensation, and if this is the case, the additions of equal quantities of heat will give smaller increments of temperature at high than at low degrees, which must to a certain extent render the thermometer inaccurate in the higher degrees, though probably only to a very small extent, of little importance as to all practical purposes; and this cause of inaccuracy appears to be counteracted by another, that fluids seem to be more expansible by heat in proportion as their temperature is higher.

13. In all chemical changes there is an alteration of temperature; and in most instances when gasses become fluids, or fluids solids, there is an increase of temperature; and *vice versa*, there is usually a diminution of temperature when solids become fluids, or fluids solids. For instance, when the highly inflammable substance called phosphorus, the properties of which will be hereafter described, is burnt in the air, it is found to condense a particular part of the air, and a high temperature is produced during the process. When a a solid amalgam of bismuth, and a solid amalgam of lead, substances which will be noticed in that part of this work relating to the metallic compounds, are mixed together, they become fluid, and the thermometer sinks during the time of their action.

There are, however, a number of cases in which, though gaseous bodies or fluids are formed from solids, an increase of temperature occurs: thus, in the explosion of gunpowder a large quantity of æriform matter is disengaged, yet a violent heat is produced.

And there is an instance in which at the time of the separation of two species of gaseous matter from each other, which is connected with expansion, there is an increase of temperature; thus, when a little of the gas which I have named euchlorine, and which consists of the substance called by the French chemists oxymuriatic gas, and oxygene gas, is gently heated in a small glass tube over mercury, an explosion takes place, fire appears, and yet the two gasses occupy a greater volume than before the explosion.

14. As attempts have been made to account for attraction, by the supposition of the existence of a peculiar matter, so *calorific repulsion* has been accounted for by supposing a subtile fluid, capable of combining with bodies, and of separating their parts from each other, which has been named the *matter of heat*, or *caloric*.

Many of the phænomena admit of a happy explanation on this idea, such as the cold produced during the conversion of solids into fluids or gasses, and the increase of temperature connected with the condensation of gasses and fluids: but there are other facts which are not so easily reconciled to the opinion: such are the production of heat by friction and percussion; and some of the chemical changes which have been just referred to. When the temperature of bodies are raised by friction, there seems to be no diminution of their capacities, using the word in its common sense; and in many chemical changes connected with an increase of temperature, there appears to be likewise an increase of capacity. A piece of iron made red hot by hammering cannot be strongly heated a second time by the same means, unless it has been previously introduced into a fire. This fact has been explained by supposing that the fluid of heat has been pressed out of it, by the percussion, which is recovered in the fire; but this is a very rude mechanical idea: the arrangements of its parts are altered by hammering in this way, and it is rendered brittle. By a moderate degree of friction, as it would appear from Rumford's experiments, the same piece of metal may be kept hot for any length of time; so that if heat be pressed out, the quantity must be inexhaustible. When any body is cooled, it occoccupies a smaller volume than before: it is evident, therefore, that its parts must have approached towards each other: when the body is expanded by heat, it is equally evident that its parts must have separated from each other. The immediate cause of the phænomena of heat then is motion, and the laws of its communication are precisely the same as the laws of the communication of motion.

Since all matter may be made to fill a smaller volume by cooling, it is evident that the particles of matter must have space between them; and since every body can communicate the power of expansion to a body of a lower temperature, that is, can give an expansive motion to its particles, it is a probable inference that its own particles are possessed of motion; but as there is no change in the position of its parts as long as its temperature is uniform, the motion, if it exist, must be a vibratory or undulatory motion, or a motion of the particles round their axes, or a motion of particles round each other.

It seems possible to account for all the phænomena of heat, if it be supposed that in solids the particles are in a constant state of vibratory motion, the particles of the hottest bodies moving with the greatest velocity, and through the greatest space; that in fluids and elastic fluids, besides the vibratory motion, which must be conceived greatest in the last, the particles have a motion round their own axes, with different velocities, the particles of elastic fluids moving with the greatest quickness; and that in etherial substances the particles move round their own axes, and separate from each other, penetrating in right lines through space. Temperature may be conceived to depend upon the velocities of the vibrations; increase of capacity on the motion being performed in greater space; and the diminution of temperature during the conversion of solids into fluids or gasses, may be explained on the idea of the loss of vibratory motion, in consequence of the revolution of particles round their axes, at the moment when the body becomes fluid or æriform, or from the loss of rapidity of vibration, in consequence of the motion of the particles through greater space.

If a specific fluid of heat be admitted, it must be supposed liable to most of the affections which the particles of common matter are assumed to possess, to account for the phænomena; such as losing its motion when combining with bodies, producing motion when transmitted from one body to another, and gaining projectile motion, when passing into free space: so that many hypotheses must be adopted to account for its mode of agency, which renders this view of the subject less simple than the other. Very delicate experiments have been made which shew that bodies when heated do not increase in weight. This, as far as it goes, is an evidence against a specific subtile elastic fluid producing the calorific expansion; but it cannot be considered as decisive, on account of the imperfection of our instruments; a cubical inch of inflammable air requires a good balance to ascertain that it has any sensible weight, and a substance bearing the same relation to this, that this bears to platinum, could not perhaps be weighed by any methods in our possession.

Some arguments have been raised in favour of the existence of a specific fluid of heat, from the circumstances of the communication of heat to bodies in exhausted receivers, and from the manner in which they are affected by this heat; but there are no means known in experimental science of producing a perfect vacuum; even the best Torricellian vacuum must contain elastic matter. The great capacity of such highly rarefied matter, is an obstacle to the indication of temperature; but supposing a communication of heat, the laws must be analogous to those of heat communicated to common air. If a long *cylinder* of metal, placed perpendicularly, be heated in the middle, the warmest part will be above, from the ascent of heated particles of the elastic medium; but if a *sphere* be heated in the middle, the hottest portion will be below, as the heated elastic matter must remain longer in contact with the inferior than with the superior portion.

The laws of the communication of heat, and the philosophy of its effects, are independent of this speculative question, which will again be considered, under new relations, in the part of this work relating to the properties of *etherial* or *radiant matter*.

VI. *On chemical Attraction, and the laws of Combination and Decomposition.*

1. When olive oil and water are agitated together, they refuse to act upon each other, and separate according to the order of their densities, the oil swimming above the water. Oil and water will not mix intimately; they will not *combine;* and they are said to have no chemical *attraction* or *affinity* for each other. But if oil and soap lees, or solution of potassa in water, be mixed, the oil and the solution blend together, and a species of soap will be formed,

which may be procured as a soft solid substance by evaporating a part of the water. This is an instance of *combination;* and solution of potassa and oil are said to *attract* each other chemically, or to have an *affinity* for each other.

2. Oil is almost insipid, but the solution of potassa is a caustic substance, which corrodes the skin, and has a strong taste.—The body resulting from their union differs both from the oil and the alkali in taste, smell, colour, and in all its sensible qualities; and it is a general character of *chemical combination*, that it changes the sensible qualities of bodies.

Corrosive and pungent substances often become mild and tasteless by their union, as is the case with sulphuric acid and quicklime, which form gypsum, or sulphate of lime.

Bodies possessed of little taste or smell often gain these qualities in a high degree by combination. Thus sulphur, when inflamed in oxygene or in common air, dissolves and forms an elastic fluid of a most penetrating and disagreeable odour and peculiar flavour. The forms of bodies, or their densities, likewise usually alter; solids become fluids, and solids and fluids gasses, and gasses are often converted into fluids or solids. Thus sugar, or salt, or isinglass, dissolves in water. The consumption of charcoal in our fires depends upon its uniting with a part of the air, with which it forms an invisible elastic fluid: mercury is rendered solid by being heated with half its weight of tin, and a substance of this kind is used for silvering mirrors. The gas produced by the combustion of charcoal is condensed by another gas procured from quicklime and sal ammoniac, when they are mixed over mercury; and the two invisible elastic fluids form a white saline solid.

3. Many substances may be made to unite by chemical affinity or attraction: thus common salt, sugar, and pearl-ashes, will all dissolve together in water. And the fossil alkali, sand, and the glass of lead, when melted together, unite to form flint glass. And, in like manner, porcelain is formed by heating together mixtures of different earths. In a number of the productions of nature likewise many substances are combined into one mass or compound. Thus many stones and gems are capable of being resolved into several elements; and in the vegetable and animal kingdom there are scarcely any com-

pounds which do not contain more than two principles, and complexity of constitution seems uniformly connected with organization.

4. That chemical attraction may be exerted between bodies, it is necessary that they should be brought into apparent contact. Thus no body will act chemically upon another at any sensible distance.

5. A freedom of motion in the parts of bodies, or a want of cohesion, greatly assists combination; and this circumstance is so marked, that it was formerly considered as a chemical axiom, which is still retained in some elementary books, that bodies cannot act chemically on each other unless one of them be fluid or æriform. Such an extensive generalization is, however, incorrect; thus crystalline muriate of lime and snow, both cooled to 0° Fahrenheit, act upon each other and liquify; and crystals of oxalic acid and dry lime treated in the same manner readily combine. The hardest and the densest bodies, however, undergo chemical changes with the greatest difficulty. Thus the sapphire, in its crystallized state, is not affected by boiling sulphuric acid; but when in a fine powder, as alumine, it is easily dissolved. Minute division, or solution, or fusion, is necessary in almost all chemical processes. In the chemical arts these circumstances are always attended to; and in the phænomena of external nature, the commencement of chemical operations may in almost all cases be traced to the agencies of fluids or æriform substances. Thus in the bosom of our rocks and mountains, where air and water are incapable of penetrating, all is permanent and still, without change or motion; wherever water and air are capable of acting, decomposition slowly goes on; and these agents gradually change the nature of the surface, render the soil fertile, and decompose and degrade the exterior of strata.

6. If equal weights of magnesia and of quicklime, in fine powder, and diluted aquafortis or nitric acid, be mixed together, and suffered to remain for some hours, it will be found, by a minute examination, that a considerable part of the lime has been dissolved, but all the magnesia will remain untouched. Hence, it is said, that lime has a stronger *attraction* for nitric acid, than magnesia has.

This is proved, likewise, by another experiment of a different kind: it is easy to make a solusion of magnesia, in nitric acid, by heating them together; and to make a solution of lime in water, by agitating some powdered quicklime in distilled water. Let the solution of lime be poured into the solution of magnesia, a white powder or precipitate will separate, and gradually fall to the bottom of the vessel in which the mixture is made. This powder, when examined, is found to be magnesia, and it is said that magnesia is precipitated from nitric acid, in consequence of the stronger *attraction* of lime for that acid.

All bodies, that differ in their nature, combine with different degrees of force; and some very important chemical phænomena in the arts depend upon this circumstance. Thus the astringent or tanning substance, in the bark of trees, which is soluble in water, is attracted from water, by the prepared skins of animals, in consequence of their stronger affinity for it, and the skin, from being destructible by boiling water, and decomposable, becomes indestructible and permanent. In like manner, indigo, and other dyeing materials, are separated from their solutions, by vegetable or animal fibres, and new combinations of them effected; and a number of instances of the same kind might be brought forward.

7. Different bodies unite with different degrees of force; and hence, one body is capable of separating others, from certain of their combinations; and in consequence of the same circumstance, mutual decompositions of different compounds take place. This has been called *double affinity*, or *complex chemical attraction.* Thus, if an aqueous neutral solution of lime and nitric acid, and a like solution of magnesia and sulphuric acid, be mixed together, the lime will quit the nitric acid, to unite to the sulphuric acid, and the magnesia will leave the sulphuric acid, to combine with the nitric acid. The combination of nitric acid and magnesia, will remain in solution; but the compound of lime and sulphuric acid, being only slightly soluble in water, will for the most part be precipitated, in the form of a white powder.

In many cases decompositions, that cannot be produced by single attractions, may be produced by double affinities. Thus the elements of sulphate of baryta, or the combination of sulphuric acid and the earth called baryta, are so firmly united, that no alkali, nor earth, will separate the acid from the baryta. Potassa, which has a very strong attraction for the acid, will not decompose it alone; but if potassa, combined with carbonic acid, be digested for some time, with powdered sulphate of baryta, there is a double decomposition ; and combinations of sulphuric acid and potassa, and carbonic acid and baryta, are formed.

8. If one part of pure oxygene gas, and two parts of pure hydrogene gas, in volume, be mixed together, in a glass tube, over mercury, furnished with wires for passing the electrical spark through it, and they be inflamed by the electrical spark*; the gaseous matter will disappear, and water will result. If two parts of oxygene be employed, and two of hydrogene, one part of oxygene will remain ; in whatever proportions they are mixed together, it is found, that one of oxygene always condenses two of hydrogene. It is evident, then, that oxygene and hydrogene combine only in definite proportions, and that the water resulting is always the same in its constitution.

If a piece of well-burnt charcoal be introduced into a vessel, two-thirds filled with oxygene gas, over mercury ; and the mercury be brought to the same level on the inside and on the outside of the jar, and the charcoal be inflamed by a burning-glass† ; there will be at first an expansion, but after the experiment is over, it will be found, that the volume of the gas has not perceptibly altered ; and if the charcoal has been in sufficient quantity, the whole of the oxygene will be found converted into carbonic acid ; now the densities of oxygene gas and carbonic acid gas, in whatever way they are formed, are always the same, and to each other as 34 to 47 nearly. It is evident, then, that carbonic acid must always contain the same weight of oxygene and charcoal. If there is twice as much oxygene in the vessel as is necessary for the consumption of the charcoal, half of it remains untouched ; and if the charcoal is partly unconsumed, still the gas is the same in quality ; it always contains by weight 5.7 of charcoal and 15 of oxygene.

There is an inflammable gas, called carbonic oxide, which burns with a blue flame, and which is obtained by igniting together zinc filings and chalk. When two in volume of this gas, and one in volume of oxygene, are acted upon by an electric spark, over mercury, they

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[*] See Plate I, fig. 6.

[†] Plate II, fig. 7.

inflame, and there result exactly two volumes of carbonic acid gas; there is no other product, and the weight of the carbonic acid gas exactly equals the weight of the carbonic oxide and the oxygene gas; so it is evident, that the carbonic oxide contains exactly half as much oxygene as carbonic acid, that is, 5.7 of charcoal require 7.5 of oxygene to become carbonic oxide. Again this is proved by decomposition: if electrical sparks be passed through carbonic acid gas, over mercury, it expands, and part of it is decomposed, two volumes becoming two volumes of carbonic oxide, and one volume of oxygene.

When the salt, called nitrate of ammonia, is decomposed by heat, an elastic fluid is disengaged, called nitrous oxide; when one volume of this gas is mixed with one volume of hydrogene, and an electric spark is passed through the mixture, inflammation takes place, water is formed, and one volume of elastic matter remains, which is azote. Now, as one volume of hydrogene takes half a volume of oxygene, for its conversion into water, it is evident, that this gas, nitrous oxide, must be composed of two in volume of azote, and one in volume of oxygene, condensed into a space equal to two.

There is a gas produced by the solution of copper in diluted nitric acid. If a little of this gas be passed into a curved glass tube* over mercury, and metallic arsenic be sublimed in the gas, it is gradually decomposed. A solid combination of arsenic and oxygene is formed, which is found (if the weight of the azote remaining be compared with that of the nitrous gas) to contain half a volume of oxygene, and half a volume of gas remains, which is azote. So it is evident, that as azote combined with one proportion of oxygene gas, forms nitrous oxide, so combined with two proportions, it forms nitrous gas; and one volume of nitrous gas mixed over water with half a volume of oxygene, is condensed, and forms a solution of nitrous acid gas in water. So that this body must consist of azote with four proportions of oxygene, nitrous oxide being considered as azote with one proportion of oxygene; and the quantities in these bodies are always the same.

It would be easy to bring forward a great collection of evidences to shew, that in all compound gaseous bodies, the quantities of the

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* Plate II, fig. 8

elements are uniform for each species*, and that when two gaseous elements combine in more than one proportion, that the second or third proportion is always a multiple, or a divisor of the first; and the case seems to be analogous with respect to all true chemical compounds, whether solids or fluids, in which no mechanical mixtures can be suspected, and where no partial decompositions can have taken place.

Thus, if sulphuric acid be poured into any solution of baryta, the solid precipitate of sulphate of baryta which falls down is uniform in its nature, and always contains about 34 of acid, and 66 of baryta; and the case is the same with other similar compounds, and with neutral salts in general.

And if two neutral salts mutually decompose each other, in the interchange of principles, there is never an excess of acid or of

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* That the proportions in compound gasses are definite has long been generally acknowledged; but Mr. Higgins is, I believe, the first person who conceived that when gasses combined in more than one proportion, all the proportions of the same element were equal; and he founded this idea, which was made public in 1789, on the corpuscular hypothesis, that bodies combine particle with particle, or one with two, or three, or a greater number of particles. Mr. Dalton, about 1802, adopting a similar hypothesis, apparently without the knowledge of what Mr. Higgins had written, extended his views to compounds in general. Mr. Richter seems to have been the first person to shew that in the decomposition of neutral salts by double affinity, the neutral state is preserved; and likewise that, when a metallic salt is decomposed by a metal, all the oxygene and acid is transferred, and the metal only changed, and that the new solution is as neutral as the former one. It had been ascertained, by different experiments, that in certain cases when solids dissolved in gasses, the volume is unchanged, and some instances of the combination of gasses were known, in which the volumes bore simple ratios to each other, as in nitrous oxide, and water; but M. Gay Lussac is the first philosopher who attempted to generalize on the phænomena, and shew that, in all cases where gasses unite, it is always in simple ratios of volume, 1 to 1, or 1 to 2, or 1 to 3, and that the condensation, if any, is in a simple ratio. His very ingenious ideas on this subject were made known towards the close of 1808. Berzelius, in a work published in 1810, has determined very correctly some of the definite proportions of several important compounds. See *Higgins's Comparative View. Dalton's New Chemical Philosophy. Richter Ueber die neuren gegenstande der Chemie. Memoires d'Arcueil*, T. ii. *Berzelius Annales de Chemie*, T. lxvii. *Thomson's System of Chemistry*, vol. iii.

basis*, and the resulting compounds are likewise perfectly neutral. Thus, if 100 parts of nitrate of baryta, which contain 41 nitric acid, and 59 baryta, be mixed with 67 of sulphat of potassa, which consist of 30 of sulphuric acid, and 37 potassa, there will be found 89 of sulphate of baryta, and 78 of nitrate of potassa; so that 41 of nitric acid will combine with the 37 of potassa, and 30 of sulphuric acid with the 59 of baryta.

It is evident from these circumstances, that when one body has the power of detaching another from its combinations, it will always detach the same proportion. Thus, from whatever basis baryta attracts sulphuric acid, it will always detach the same quantity; and the same quantity of potassa, from whatever acid it precipitates magnesia, will always throw down the same proportion.

9. In cases when an alkaline substance combines with more than one proportion of acid, the same circumstances seem to occur as in the combinations of gaseous bodies. The proportion is either a multiple or a divisor of the first; this is shewn by a very simple experiment, first made by Dr. Wollaston: let a given weight of the salt called carbonate of potassa be thrown into a tube over mercury, and diluted sulphuric acid sufficient to cover it be introduced into the tube, a certain volume of carbonic acid gas will be disengaged; let an equal weight of the salt be heated to redness, when it becomes a subcarbonate, and let this subcarbonate be treated in the same way, it will be found to give off exactly half as much carbonic acid gas.

10. In the combination of solid and fluid substances which have not yet been decompounded, with gasses, and in the union of compound inflammable bodies with each other, and in all mutual decompositions between bodies of this class, similar circumstances appear to occur: thus there are two combinations of mercury with oxygene, the black and the red; and one appears to contain twice as much oxygene as the other. There are two known combinations of iron with oxygene, the black and the red oxide of iron; and the oxygene in the first being considered as 2, that in the second must be consi-

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* M. M. Gay Lussac and Thenard have lately stated, "that, in some mutual decompositions of fluates and muriates, slightly acid solutions become alkaline." *Recherches*, T. ii. page 28; but such changes must be complicated; and perhaps a minute investigation may shew that they are not anomalous.

dered as 3, that is, 100 parts of iron take 29 parts of oxygene to become the black oxide, and 43.5* to become the red.

The decompositions of compounds containing oxymuriatic gas, or chlorine gas, by water, afford the best and most intelligible instances of double decomposition. If equal volumes of light inflammable air, or hydrogene, and chlorine be mixed together, and exposed to daylight, they slowly act upon each other, no condensation takes place, and they form an equal volume of muriatic acid gas; so that muriatic acid gas consists of hydrogene and chlorine in equal volumes; and water, as has been before stated, consists of two parts in volume of hydrogene, and one part in volume of oxygene. Now phosphorus and sulphur, and most of the metals, combine with chlorine, and form peculiar compounds, many of which are decomposed by water, and the results are phosphorus, sulphur, or the metals combined with oxygene, and muriatic acid; and the oxidated compounds formed are the same as those produced in other ways; and it is evident, that the quantity of hydrogene given to the chlorine to form the acid must be exactly in the ratio of the oxygene added to the inflammable substance or the metal: thus phosphorus, burnt in chlorine in excess, forms a white volatile substance, which I have named phosphorana. When water is added to this, phosphoric and muriatic acids are formed, and there are no other products.

11. As in all well-known compounds, the proportions of the elements are in certain definite ratios to each other; it is evident, that these ratios may be expressed by numbers; and if one number be employed to denote the smallest quantity in which a body combines, all other quantities of the same body will be multiples of this number; and the smallest proportions in which the undecomposed bodies enter into union being known, the constitution of the compounds they form may be learnt, and the element which unites chemically in the smallest quantity being expressed by unity, all the other elements may be represented by the relations of their quantities to unity.

Hydrogene gas, or inflammable air, is the substance of which the smallest weights seem to enter into combination; and it appears to

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* These results I have obtained very nearly, namely, 28 and 43; and they differ very little from those of Mr. Hassenfratz, Dr. Thomson, and Mr. Berzelius.

exist in no definite compound in less proportion than water. The specific gravity of hydrogene is to that of oxygene as 1 to 15; and as 2 volumes of hydrogene to 1 of oxygene enter into the composition of water, the ratio of the hydrogene in water will be to the oxygene as 2 to 15; and it may be regarded as composed of two proportions of hydrogene and one of oxygene: and the number representing hydrogene will be 1, and that representing oxygene 15.

The weights of equal volumes of azote and oxygene are to each other nearly as 13 to 15; therefore supposing the number representing the proportion, in which azote combines, gained from the composition of nitrous oxide, which contains two volumes of azote to one of oxygene, it will be represented by 26; and nitrous oxide will consist of two proportions of azote equal to 26, and one proportion of oxygene, equal to 15. Nitrous gas will consist of 1 of azote and 2 of oxygene, 26 and 30. Nitrous acid gas of 1 of azote and 4 of oxygene, 26 and 60.

Ammonia, which is decomposed by electricity into 3 volumes of hydrogene and 1 volume of azote, will consist of 6 proportions of hydrogene and 1 proportion of azote, or 6 and 26.

The weight of chlorine or oxymuriatic gas, is to that of hydrogene nearly as 33.5 to 1; and muriatic acid gas consists of equal volumes of these gasses, and therefore is composed of 33.5 of chlorine, and 1 of hydrogene;—but 2 of chlorine may be made to combine with one of oxygene in volume; and double proportions of this gas combine to form compounds, which when decomposed by water, afford compounds containing single proportions of oxygen, so that the ratio of chlorine to oxygene, is that of 67 to 15, and the number representing chlorine is correctly stated 67.

In like manner it is easy to deduce the number representing the other undecompounded bodies; and they will be found to correspond as nearly as can be expected, in whatever way they are obtained. Thus, whether the number representing the proportion in which potassium the basis of potassa combines, be gained from its combination with oxygene or with chlorine, the result will scarcely differ; for 8 grains of potassium converted into the compound of chlorine and potassium I have found gain about 7.1 grains, and when converted into potassa, they gain a grain and $\frac{6}{10}$; and as 7.1 : 8 : : 67 : 75.4; and as

1.6 : 8 : : 15 : 75, giving the number representing potassium as about 75.

It is easy to form a series of proportional numbers by taking $\frac{1}{4}$ of these numbers, on the supposition that water is composed of one proportion of hydrogene and one of oxygene; but in this case the number representing the proportion in which oxygene combines must contain a fraction; and the calculations are much expedited, and the formula rendered more simple, by considering the smallest proportion an integer.

Mr. Higgins has supposed that water is composed of one particle of oxygene and one of hydrogene, and Mr. Dalton, of an atom of each; but in the doctrine of proportions derived from facts, it is not necessary to consider the combining bodies, either as composed of indivisible particles, or even as always united, one and one, or one and two, or one and three proportions. Cases will hereafter be pointed out, in which the ratios are very different; and at present, as we have no means whatever of judging either of the relative numbers, figures, or weights, of those particles of bodies which are not in contact, our numerical expressions ought to relate only to the results of experiments.

If it should hereafter be discovered, that any of those substances now considered as undecompounded, consist of other elements, these elements must be represented by some division of their numbers; and should even hydrogene be found a compounded body, it would merely be necessary to multiply all the numbers representing the other elements, by some common number which would admit of a division into proportions, representing the elements of hydrogene; so that no discovery concerning the composition of bodies, can interfere with the general law of the definite nature of their combinations.

12. If the black oxide of manganese be exposed to a strong heat, it gives off oxygene gas, and becomes brown; but no heat as yet applied is capable of depriving it of the whole of its oxygene. Hence it is evident that when one proportion of one substance is combined with more than one proportion of another, the first proportions may be separated with much more facility than the last. There are numbers of other instances: thus the carbonate of soda,

which contains two proportions of carbonic acid to one of soda, gives off half its carbonic acid with great facility, by heat, but obstinately retains the other half. Nitric acid is easily brought to the state of nitrous gas by the abstraction of oxygene: nitrous gas with more difficulty is converted into nitrous oxide, but nitrous oxide is still less decomposable than nitrous gas.

When one proportion of a body is combined with two or more proportions of another, it seems to enter with more difficulty into new combinations, than when it is combined with one proportion. Thus iron combined with two proportions of sulphur in golden pyrites is not acted upon by diluted sulphuric acid: but when combined only with one proportion of sulphur, as in the common artificial sulphuret, it is readily acted upon.

It seems from these facts, that two or more proportions of one body attract a single proportion of another body with more energy than one proportion, and that two proportions or more adhere to a single proportion with less energy than one proportion; or at least that a second or a third proportion adheres with less energy than the first.

It may possibly be said, that the effect of two or three proportions, in defending one proportion from the action of a new substance, may depend upon mechanical causes, from their more completely enveloping its parts; but the other solution of the effect seems to be the most probable.

13. M. Berthollet, to whom the first distinct views of the relations of the force of attraction to quantity are owing, has endeavoured to prove that these relations are universal, and that elective affinities cannot strictly be said to exist. He considers the powers of bodies to combine as depending in all cases upon their relative attractions, and upon their acting masses, whatever these may be: and he conceives that in all cases of decomposition, in which two bodies act upon a third, that third is divided between them in proportion to their relative affinities, and their quantities of matter. Were this proposition strictly correct, it is evident that there could be scarcely any definite proportions: a salt crystallizing in a strong alkaline solution, would be strongly alkaline; in a weak one less alkaline; and in an acid solution, it would be acid; which does not seem to

be the case. In combinations, in which gaseous bodies are concerned, the particles of which have perfect freedom of motion, the proportions are unchangeable; and in all solid compounds, which have been accurately examined, and in which there is no chance of mechanical mixture, the same law seems to hold good. It is certainly possible to dissolve different bodies in fluid menstrua, in very various proportions, but the result may be a mixture of different solutions, rather than a combination. M. Berthollet brings forward glasses and alloys of metals, as compounds, containing indefinite proportions; but it is not easy to prove, that in these, all the elements are chemically combined; and the points of fusion of alkali, glass, and certain metallic oxides, are so near each other, that transparent mixtures of them *may* be formed.—It cannot but be supposed, that the attractive power of matter is general, but in the formation of aggregates, certain arrangements seem to be always uniform.

14. M. Berthollet conceives, that he has proved that a large quantity of a body having a weak affinity, may separate a part of a second body, from a small quantity of a third, for which it has a strong affinity; but even granting this, it does not destroy the idea of definite proportions. Thus in the fact, noticed by Bergman, the decomposition of sulphate of potassa by nitric acid, one proportion of potassa may be separated from the acid; and the other proportion may combine with two proportions of acid; phænomena analogous to those of common double affinity.

M. Berthollet states, that a large quantity of potassa will separate a small quantity of sulphuric acid from sulphate of baryta; but he made his experiments in contact with the atmosphere, in which carbonic acid constantly floats; and carbonate of potassa and sulphate of baryta mutually decomposed each other (7). Even allowing the correctness of his views, still he has not given a complete statement of facts. If potassa separates sulphuric acid from baryta, either there must exist an insoluble sulphate of baryta, containing more baryta than the common sulphate, and which of course may contain two proportions of baryta; or baryta, sulphuric acid, and potassa, must all be dissolved, in the same fluid, which seems highly improbable. M. Berthollet regards baryta as separable from sulphuric acid, by potassa; but has not endeavoured to shew in what form it appears after the process.

15. M. Berthollet states, that soda is capable of separating a certain quantity of potassa from sulphuric acid; but, in his experiment, water was present, as the soda must have been a hydrate; and he likewise used alcohol: and the phænomenon may be a phænomenon of double attraction. Potassa has a much stronger attraction for water than soda; and the soda may quit its water, and the potassa its sulphuric acid; and the effect may be assisted by the stronger attraction of hydrate of potassa for alcohol.

In general, when large quantities of fluid or fusible bodies are used in experiments, the attraction of the substances which are capable of acting upon each other, is more rapidly brought into play. In many solutions all the elements are in chemical combination; and their separations depend not merely upon the relative attractions of their parts, but likewise on the manner in which they are acted on by water; and earths, and oxides, are usually thrown down from their solutions in union with water.

16. When an alkali precipitates an earth from its solution in an acid, the earth, according to M. Berthollet's ideas, ought to fall down in combination with a portion of acid. But if a solution of potassa be poured into a sulphuric solution of magnesia, the precipitate produced, after being well washed, affords no indication of the presence of acid; and M. Pfaff has shewn by some very decisive experiments, that magnesia has no action upon neutral combinations of the alkalies and sulphuric acid; and likewise, that the tartarous acid is entirely separated from lime, and the oxalic acid from oxide of lead, by quantities of sulphuric acid, merely sufficient to saturate the two bases; and these are distinct and simple instances of elective attraction. Again, when one metal precipitates another from an acid solution, the body that falls down is usually free both from acid and oxygene: thus zinc precipitates lead and tin, and iron, copper; and the whole of the oxygene and the acid, is transferred from one metal to the other.

17. M. Berthollet, in crystallizing sulphate of potassa, from acid solutions, states that he obtained salts, of which the first portion contained 55.83 of acid in 100 parts, and another portion only 49.5; but

it is far from improbable, that these salts were both mixtures of the acidulous sulphate, and the neutral sulphate of potash; and the idea is strengthened by the circumstance, that he obtained neutral sulphate from the same solution, towards the end of the process; but even allowing the substances to have been principally simple binary combinations, and not mixtures, still the potassa and the acid may be regarded in them as in definite proportions. The number representing potassa being considered as 90, and that representing sulphuric acid as 75, the first may be conceived to contain four of alkali and seven of acid, and the second, three of alkali and four of acid.

In cases in which solutions of salts are formed in acid or alkaline menstrua, which are supposed incapable of decomposing them, the results must be considered as depending upon a new combination; and in the evaporation of the water or of the menstruum, and the crystallization of the remaining constituents, the proportions, that have acted, will determine the nature of the solids which are formed. There appears no difficulty in reconciling the doctrine of definite proportions, with the influence of quantity; none of the experiments of M. Berthollet can be considered as strictly contradictory to the doctrine, and some of the most important results of this sagacious chemist afford it confirmation.

18. M. Berthollet supposes that the attractions of bodies for each other, are inversely, as the quantities that saturate. Thus, magnesia and ammonia take up more sulphuric acid than equal quantities of potassa; and therefore he concludes, that magnesia and ammonia have a stronger attraction for acids than potassa: yet potassa instantly separates magnesia and ammonia from acids; and though the facility with which ammonia is expelled from a compound, may be hypothetically accounted for, by assuming that the ease, with which it takes the gaseous state, assists its escape; yet magnesia is in an opposite case; and to account for chemical changes, by supposing the effects of forms of matter, which are about to appear, or powers not in actual existence, such as elasticity or cohesion, is merely the solution of one difficulty, by the creation of another; and ammonia, when solid or fluid, should require a new force to render it elastic: and the cohesion, in a compound, can only be regarded as

the exertion of the chemical attractions of its elements. The action between the constituents of a compound must be mutual; sulphuric acid, there is every reason to believe, has as much attraction for baryta, as baryta for sulphuric acid: and baryta is the alkaline substance, of which the largest quantity is required to saturate sulphuric acid; therefore, on M. Berthollet's view, it has the weakest affinity for that acid; but less sulphuric acid saturates this substance, than any other earthy or alkaline body; therefore, according to M. Berthollet, sulphuric acid has a stronger affinity for baryta, than for any other substance; which is contradictory.

19. It cannot be laid down as a general law, that the attractions of bodies are connected with the weights of the proportions in which they combine; yet in some cases the proportions, which unite in the greatest quantity, or the bodies represented by the highest numbers, are separated by proportions combining in smaller quantity, or by bodies represented by lower numbers. Thus gold, platina, mercury, and silver, are separated in their metallic states by the common metals, which are represented by much lower numbers, and the metallic oxides by the alkalies; but there are many exceptions; and the intensity of attraction seems to be dependent upon other causes, which are intimately related to the electrical phænomena, to be discussed in the next section.

20. The uniformity of the law of condensation, when gasses combine and form denser gaseous compounds, in which the volume is unaltered, or in which one of the elements is condensed to $\frac{1}{2}$, or in which both are condensed to $\frac{1}{2}$, and the regularity of the forms of solid bodies, seem to depend entirely upon the constancy of the nature of the combination, and probably upon the corpuscular aggregates being all of the same kind. If the particles of matter be supposed to be globular, or to act in spheres of attraction and repulsion, it would be easy to account for their forms, by supposing a few independent primary arrangements. Thus, four particles may compose a tetrahedron, five a tetraedral pyramid, six an octaedron, or a triedral prism, and eight, a cube or a rhomboid.

21. It would be premature in this part of the work, to enter upon any more minute views of the laws of attraction, and the more refined

details will properly follow the history of the agencies of different bodies on each other.

With respect to a power so constantly in action, it is necessary, however, even at an early period of the study, to possess some definite ideas. If it be regarded as capricious in its effects, and tending constantly to produce different arrangements, chemistry would be without a guide, without certain combinations, and no results of analysis could be perfectly alike; but fortunately for the progress of science, this is not the case: the changes of the terrestrial cycle of events, like the arrangements of the heavens, and the system of the planetary motions, are characterized by uniformity and simplicity; weight and measure can be applied to them, their order perceived, and their laws discovered.

VII. *Of Electrical Attraction and Repulsion, and their Relations to Chemical Changes.*

1. If a piece of dry silk be briskly rubbed against a warm plate of polished flint glass, it will be found to have acquired the property of adhering to it, which it will retain for some seconds; if at the time this adhesive power exists, the silk and glass be separated from each other, they will both be found to have gained the property of attracting very light substances, such as the ashes of paper or fragments of gold leaf; and the long filaments of the silk, if there be any, will be seen to repel each other.

2. These bodies are said to be *electrically excited*, and the phænomena are called *electrical* phænomena; the peculiar circumstances under which they occur, are best observed by the use of an instrument called the electrical machine; it consists of a cylinder of glass* supported upon glass pillars, and which can be made to revolve, so as to press against a cushion of silk rubbed over with a little amalgam of zinc and mercury; and of two cylinders of metal, one in contact with the cushion, and the other opposite to the glass cylinder, both supported upon glass.

3. If two gilt pith balls, suspended upon strings of silk covered with tinsel, be hung upon a wire, placed in contact with either of

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* Plate II. fig. 9.

the metallic cylinders, and the machine be put in action, the balls will repel each other; but if one ball be attached to a wire, connected with one metallic cylinder, and the other ball be attached to a wire connected with the other, the two balls, when the machine is put into action, will attract each other; and at the moment that they come in contact, sparks of light will be perceived, if the experiment be made under favourable circumstances.

As the two balls, when in contact with the same cylinder, may be considered as receiving the same impulse or impression, they are said to be *similarly electrified;* but when in contact with different cylinders, they are said to be *differently electrified;* and electrified bodies that repel each other, are considered as in the same electrical states; those that attract each other as in different electrical states.

4. There are probably no two bodies differing in nature, which are not capable of exhibiting electrical phænomena, either by contact, pressure, or friction; but the first substances in which the property was observed, were *vitreous* and *resinous* bodies; and hence the different states were called states of *resinous* and *vitreous* electricity; and resinous bodies bear the same relation to flint glass, as silk. The terms, *negative* and *positive* electricity, have been likewise adopted, on the idea, that the phænomena depend upon a peculiar subtile fluid, which becomes in excess in the vitreous, and deficient in the resinous bodies; and which is conceived by its motion and transfer, to produce the electrical phænomena.

5. Flint glass and silk, silk and sulphur, sulphur and metals, resin and metals, all by friction or contact, become strongly electrical, and of course attractive, and communicate their attractive powers to small masses of matter brought in contact with them; a pith ball, or a slip of gold leaf that has been touched by flint glass, excited by silk, will be repelled by a ball or slip that has been touched by silk, excited by sulpur, or by a ball or slip that has been touched by sulphur excited by metals, so that the attractive and repellent states depend entirely upon the actions of the two substances, and not upon any power peculiar to, and inherent in each.

6. It is upon this circumstance, that the *electrometer*, which might be called the *differential* one, is framed; it consists of two

gold leaves attached to a metallic plate, and included in a hollow cylinder of glass*, fixed upon another metallic plate, which is connected with two pieces of tin foil, pasted upon the glass opposite to the leaves. When any electrified body is made to touch the upper plate, the gold leaves diverge; if their divergence is increased by the approach of flint glass excited by silk, they are said to have the same state as the glass, the vitreous or the positive; if their divergence is diminished, they are said to be in the opposite state, or to possess the resinous or negative electricity.

7. When luminous phænomena are connected with electrical excitation, the different states may be known by presenting a metallic point to the excited body; if rays of light issue from the point to the body, it is said to be negatively electrified: but if the point appears simply luminous, without sending off any rays, the electricity is said to be positive.

8. For measuring small degrees of electricity of bodies, as compared with those of others of the same kind, the *electrical balance* of Coulomb is applied; it consists of a gilt pith ball, placed upon a metallic rod, on the opposite extremity of which, is a thin leaf of metal; the rod is suspended horizontally, by a fine metallic wire, which passes into a glass tube, to the top of which it is attached; the glass tube is inserted into a cylinder of glass, which contains a copper ball, connected with a small bar of metal, which is carried through an aperture in the glass cylinder, into the atmosphere; a very small force only is required to twist the wire, and when the two balls are brought in contact, and the bar touched by the electrified body, they gain the same kind of electricity, and repel each other; and the degree of their repulsion may be measured by a scale of degrees, made on the circumference of the cylinder†.

9. Bodies receive the electrical influence in different manners. If a rod of glass be brought in contact with any excited electrical body, it will receive the electrical influence in the part where it touched the body, and will be electrical, to a little distance, round the point of contact; but its remote parts will not be affected. A rod of metal,

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* Plate II. fig. 10. † Plate II. fig. 11.

on the contrary, suspended on a rod of glass, and brought in contact with an electrical surface, instantly becomes electrical throughout. The glass, in common philosophical language, is said to be a *nonconductor* of electricity, or an *insulating* substance; the metal a *conductor.* Some bodies are affected to a much greater extent than glass, but not nearly so much as metals; such are animal and vegetable substances, water, and fluids containing water; they are said to be *imperfect conductors.* According to the statements of Mr. Cavendish, iron conducts 400 millions of times better than water, sea water 100 times better than distilled water, and water saturated with salt, 720 times better. The mineral acids are the best fluid conducting substances known, and after them, saline solutions, the powers of which appear to be nearly in proportion to the quantities of salts they contain. Charcoal and metals, and the greater number of inflammable metallic compounds, are conductors. Alcohol and ether are very imperfect conductors; and sulphur, oils, resinous substances, metallic oxides, and compounds of chlorine, nonconductors.

10. There is a stone found in many parts of the world, called tourmaline, which is sometimes crystallized as a nine-sided prism, terminated by a three-sided and a six-sided pyramid; when this substance is gently heated, it becomes electrical, and one extremity, that terminated by the six-sided pyramid, is positive, the other is negative; to a certain extent, its electricities are exalted by increasing the temperature; when it begins to cool, it is still found electrical; but the electricities are changed, the pyramid, before positive, is now negative, and *vice versa.* When the stone is of considerable size, flashes of light may be seen along its surface.

There are other gems and crystallized substances, which possess a property similar to that of the tourmaline. The luminous appearance of some diamonds, when heated, probably depends upon their electrical excitation. The substance called the boracite, which is a cube, having its edges and angles defective, becomes electrical by heat, and in one variety presents no less than eight sides, in different states, four positive, four negative; and the opposite poles are in the direction of the axes of the crystal.

11. It would appear, that in all cases of electrical action, the two electrical states are always coincident, either in different parts of the

same body, or in two bodies; and that they are always equal, and capable of neutralizing each other. If a connection be made by a wire, between the positive and negative conductors of the electrical machine, during the time of its action, all electrical effects cease; and to produce a succession of effects, both conductors must be brought near bodies connected with the ground, which gain the opposite state, in consequence of what may be called *induction*, and which will be explained in the next paragraph.

12. When a nonconductor, or imperfect conductor, provided it be a thin plate of matter, placed upon a conductor, is brought in contact with an excited electrical body; the surface, opposite to that in contact, gains the opposite electricity from that of the excited body; and if the plate be removed from the conductor and the source of electricity, it is found to possess two surfaces in opposite states. If a conductor be brought into the neighbourhood of an excited body, the air, which is a nonconductor, being between them; that extremity of the conductor, which is opposite to the excited body, gains the opposite electricity, and the other extremity, if opposite to a body connected with the ground, gains the same electricity, and the middle point is not electrical at all. This is easily proved, by examining the electricity of three sets of gilt pith balls raised on wires on the different parts of the conductor, which is thus affected by *induced* electricity.

If, instead of air, a plate of mica or glass be between the two conductors, the same phænomena will occur; so that it would appear that the conductor merely gains two opposite electricities, or polar electricities, of the same kind as those of the nonconductor. The phænomena of sparks, of discharges, and of accumulated electricity, depend upon this law. In the case of the common electrical spark, a stratum of air is charged in the same manner as a glass bottle, partially coated with tin foil, is charged in the Leyden experiment*; when the hand is held near the positive conductor of an electrical machine, the person standing on the ground, the hand is rendered negative, and the states become exalted, till the polarities, as they may be called, are annihilated through the air, producing a spark,

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* Plate II. fig. 12.

a snap, and a distinct sensation. If a number of small pith balls, placed upon a surface of metal, are caused to approach an electrified body, they are brought into the opposite state by induction, and are attracted towards the body; but when they come in contact with it, this state is destroyed, they gain the same state, and are repelled; and if they are properly placed, their alternate attractions and repulsions may be produced, as long as the machine is in action.

13. If a number of cylinders of metal, *insulated* on glass, be placed in a line with each other, but not in contact, and the last be connected with the ground*; when a powerfully electrified conductor of a machine is brought opposite to the first, they will all become electrical, and every insulated cylinder will present two poles; the negative pole of one being opposite to the positive pole of the other; and if a spark is produced by means of the last, sparks occur throughout the whole arrangement. In like manner a series of Leyden jars may be made to charge each other, the outer surface of the first rendering negative the inner surface of the second, and so on; and by connecting the surfaces, that have the same kind of electricity, in the first place, and then connecting two opposite surfaces in the series, a powerful explosion† may be produced.

14. When a point connected with the ground, is brought near an electrified substance, it rapidly gains the opposite state, and an immediate discharge takes place, which continues till the equilibrium is restored. Large surfaces are electrified by induction much more slowly than small ones, and are capable of accumulating much more electricity; which renders the discharge from them much more violent. Indeed the electrical powers seem entirely to belong to the surfaces of bodies, and not to be connected with the quantity of solid matter they contain.

15. It is in consequence of the principle of induction, that the condensing electrometer is so much more sensible than the common electrometer; this instrument consists of two plates of polished metal‡, the surfaces of which are parallel, one connected with the plate of the electrometer, the other moveable, in connexion with the ground, and the plates are very near each other. When the body

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* Plate III. fig. 13.

† Plate III. fig. 14.

‡ Plate III. fig. 15.

supposed to be electrical, is made to touch the top of the electrometer, and is afterwards removed, in separating the plates, the effect will be perceived.

16. The difference in what are called the conducting powers of bodies, seems to depend entirely upon the different manner in which they receive the electrical polarities, or in which their parts become capable of communicating attractive or repellent powers, to other matter. Nonconductors appear to receive polarities, only with great difficulty, but retain them for a long while, and present probably a number of different alternations of poles, within a small space, and cannot be effected to any great distance. Imperfect conductors receive polarity with more facility, but present fewer alternations, and preserve their electricities for a shorter time. Perfect conductors are easily effected throughout; but present at most only two poles, and the powers rapidly destroy each other. The difficulty with which nonconductors receive polarity, is shewn in the phænomena of charging thick and thin coated plates of glass and mica. The thin plates are capable of being charged much more highly than the thick ones, and the accumulation on the opposite surfaces is much greater.

Rarefied air or gaseous matter, is much more susceptible of receiving polarities, than dense air or gaseous matter; and hence, the electrical spark will pass much further through rarefied air or light gasses, than through dense air or heavy gasses; it passes much further likewise in gasses, than in nonconducting fluids.

17. If a nonconducting surface, coated with two conducting surfaces, and charged so as to give a spark of an inch in length, through air, be connected by both its conducting surfaces, with a similar apparatus not charged; then both systems may be discharged together; but the spark they will give, will be only half as long as the single one would have given, if discharged alone. The *quantity* of the electricity in this case, is conceived not to be altered, but its *intensity* is said to be only half as great when it is discharged from a double surface; and these expressions of intensity and quantity, though it is not easy to attach any very definite ideas to them, are nevertheless useful, in giving more facility to the arrangement of some important electrical phænomena.

18. When very small conducting surfaces are used for conveying very large quantities of electricity, they become ignited; and of the different conductors that have been compared, charcoal is most easily heated by electrical discharges*, next iron, platina, gold, then copper, and lastly zinc. The phænomena of electrical ignition, whether taking place in gaseous, fluid, or solid bodies, always seem to be the result of a violent exertion of the electrical attractive and repellent powers, which may be connected with motions of the particles of the substances affected. That no subtile fluid, such as the matter of heat has been imagined to be, can be discharged from these substances, in consequence of the effect of the electricity, seems probable, from the circumstance, that a wire of platina may be preserved in a state of intense ignition in vacuo, by means of the Voltaic apparatus, (an instrument which will be immediately described,) for an unlimited time; and such a wire cannot be supposed to contain an inexhaustible quantity of subtile matter.

19. Certain changes in the forms of substances, are always connected with electrical effects. Thus when vapour is formed or condensed, the bodies in contact with the vapour, become electrical. If, for instance, a plate of metal, strongly heated, be placed upon an electrometer, and a drop of water be poured upon the plate, at the moment the water rises in vapour, the gold leaves of the electrometer diverge with negative electricity. Sulphur, when melted, becomes strongly electrical during the time of congelation; and the case seems to be analogous, with respect to nonconducting substances in general, when they change their forms.

20. As electricity appears to result from the general powers or agencies of matter, it is obvious, that it must be continually exhibited in nature, and that a number of important phænomena must depend upon its operation. When aqueous vapour is condensed, the clouds formed are usually more or less electrical; and the earth below them being brought into an opposite state, by induction, a discharge takes place when the clouds approach within a certain distance, constituting lightning; and the undulation of the air, produced

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* The conclusions are drawn from experiments made by the electricity of the Voltaic apparatus.

by the discharge, is the cause of thunder, which is more or less intense, and of longer or shorter duration, according to the quantity of air acted upon, and the distance of the place where the report is heard from the point of the discharge. It may not be uninteresting to give a further illustration of this idea: electrical effects take place in no sensible time; it has been found, that a discharge through a circuit of four miles, is instantaneous; but sound moves at the rate of about twelve miles in a minute. Now, supposing the lightning to pass through a space of some miles, the explosion will be first heard from the point of the air agitated, nearest to the spectator; it will gradually come from the more distant parts of the course of the electricity, and last of all, will be heard from the remote extremity; and the different degrees of the agitation of the air, and likewise the difference of the distance, will account for the different intensities of the sound, and its apparent reverberations and changes.

21. In a violent thunder storm, when the sound instantly succeeds the flash, the persons who witness the circumstance are in some danger; when the interval is a quarter of a minute, they are secure. In a thunder storm, the lowest ground is the safest place, and a horizontal posture, the least dangerous; the neighbourhood of trees, or buildings, should be avoided, particularly of trees, the living juices of which are calculated to conduct the electricity, and make part of a circuit. In a house, the cellars are the safest places, and in a room the person should stand as far as possible from the fire. The means adopted by Franklin have, however, to a great extent, averted the destructive effects of atmospheric electricity; and by pointed conductors, the thunder cloud is disarmed of its terrors, and the lightning slowly discharged in harmless corruscations.

If a school-boy's kite be mounted high in the atmosphere, by means of a string, containing filaments of metal, fastened to a conductor, fixed on a glass rod; the conductor usually gives signs of electricity, which will be greatest, when clouds are floating in the atmosphere; and it was by means of a simple apparatus of this kind, that the American philosopher effected his grand discovery of the identity of electricity and lightning.

The water-spout is probably the result of the operation of a weakly electrical cloud, at an inconsiderable elevation above the sea, brought into an opposite state; and the attraction of the lower part of the cloud for the surface of the water, may be the immediate cause of this extraordinary phænomenon.

The corruscations of the aurora borealis and australis, precisely resemble strong artificial electricity discharged through rare air; and as the poles are nonconductors, being coated with ice or snow, and as vapour must be constantly formed in the atmosphere above them, the idea of Franklin is not improbable, that the auroras may arise from a discharge of electricity, accumulated in the atmosphere near the poles, into its rarer parts; though other solutions of the phænomena may be given on the idea, that the earth itself is endowed with electrical polarity; or that the motions of the atmosphere produce the effect: but all views on this subject must be hypothetical, and the light may result from other causes than electrical action.

22. The common exhibition of electrical effects is in attractions and repulsions, in which masses of matter are concerned; but there are other effects, in which the changes that take place operate in a manner, in small spaces of time imperceptible, and in which the effects are produced upon the chemical arrangements of bodies.

If a piece of zinc and a piece of copper be brought in contact with each other, they will form a weak electrical combination, of which the zinc will be positive, the copper negative; this may be learnt by the use of a delicate condensing electrometer; or by pouring zinc filings through holes, in a plate of copper, upon a common electrometer; but the power of the combination may be most distinctly exhibited in the experiments called *Galvanic experiments*, by connecting the two metals, which must be in contact with each other, with a nerve and muscle in the limb of an animal recently deprived of life, a frog for instance; at the moment the contact is completed, or the circuit made, one metal touching the muscle, the other the nerve, violent contractions of the limb will be occasioned. If a piece of zinc or copper, in contact with each other in one point, be placed in contact in other points with the same portion of water; the zinc will corrode and attract oxygene from the water, much more rapidly than if it had not been in contact with the copper; and if a small quantity of sulphuric acid be added to the water, it will be seen that globules of inflammable air are given off from the copper, though it is not dissolved nor acted upon.

23. The connection of chemical effects, with the exhibition of electrical powers, is, however, best witnessed in combinations in which these powers are accumulated by alternations of different metals and fluids. If plates of copper and zinc, two or three inches square, and pieces of cloth of the same size, soaked in a solution of salt, or sal ammoniac, or nitre, be arranged in the order of copper, zinc, moistened cloth, and so on, and made into an insulated pile, of which the series are 200*, several remarkable phænomena will occur.

When one hand is applied to the bottom of the pile, and the other to the top, both hands being moistened, a shock will be perceived.

When a metallic wire, having a bit of well-burned charcoal at its extremity, is made to connect the two extremities of the pile, a spark will be perceived, or the point of the charcoal will become ignited.

A wire connected with the top of the pile, brought in contact with a sensible electrometer, will cause the leaves to diverge; and, by removing the wire, and applying excited glass to the electrometer, it will be found that the electricity is positive; a wire connected with the bottom of the pile will affect it with negative electricity; a wire from the middle of the pile will have no influence on the instrument.

If wires of platina from the extremities of the pile be introduced into water, or into two portions of water connected by moist substances, oxygene gas will separate at the wire exhibiting the positive electricity, and hydrogene gas at the wire exhibiting the negative electricity; and the proportions are such, when the proper circumstances exist, that they will produce water when exploded by the electrical spark, that is, the volume of hydrogene will be to that of oxygene as two to one.

If the same wires be introduced into a strong solution of sulphuric or phosphoric acid, or into metallic solutions, oxygene will separate at the positive surface, the inflammable or metallic matter contained in the solution at the negative surface.

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* See Plate III. fig. 15, 16.

When any substance rendered fluid by heat, consisting of water, oxygene, and inflammable or metallic matter, is exposed to those wires, similar phænomena occur.

When any solution of a neutral salt containing acid, united to alkaline, earthy, or common metallic matter, is used; besides the other phænomena that take place, acid matter collects round the positively electrified surface; alkali, earth, or oxide, round the negative surface; and if two separate vessels are employed to contain the solution, connected by moist asbestus, it is found, that the acid collected in the vessel containing the wire positively electrified, will be in definite proportion to the matter collected in the other cup; that is, it will form with it a neutrosaline compound.

If a solution of muriatic acid in water be acted on by the wires, hydrogene will separate at the negative surface, and chlorine or oxymuriatic gas, at the positive surface.

24. This apparatus, which exhibits in so distinct a manner the relations of electrical polarities to chemical attractions, is the grand invention of Volta, made known in the first year of this century; its electrical effects have been long known, but the phænomena of its operation in decomposing bodies are of more recent discovery.

Several modes of constructing it have been adopted, some of which are much superior, in point of convenience, to that which has been just described.

One mode is by soldering the plates of zinc and copper together, and by cementing them into troughs of baked wood, covered with cement, in the regular order, so as to form cells to be filled with the fluid menstruum; each surface of zinc being opposite to a surface of copper; and this combination is very simple and easy of application.

Another form is that of introducing plates of copper and of zinc, fastened together by a slip of copper, into a trough of porcelain, containing a number of cells corresponding to the number of the series. The different series may be introduced separately into the troughs, and taken out without the necessity of changing the fluid, or they may be attached to a piece of baked wood, and (when the number is not very large) introduced into the cells, or taken out together*.

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* Plate III. fig. 17.

25. Similar polar electrical arrangements to those formed by zinc and copper may be made by various alternations of conducting and imperfect conducting substances; but, for the accumulation of the power, the series must consist of three substances or more, and one at least must be a conductor. Silver or copper, when brought in contact with a solution of a compound of sulphur and potassa, at one extremity, and in contact with water, or a solution of nitric acid, at the other extremity, some saline solution being between the sulphuretted and the acid solutions, forms an element of a powerful combination, which will give shocks when fifty are put together; the order is copper, cloth of the same size moistened with solution of nitric acid, cloth moistened in solution of common salt, cloth moistened in solution of the compound of sulphur, copper, and so on; the specific gravities of the solutions should be in the order in which they are arranged, to prevent the mixture of the acid and sulphuretted solution; that is, the heaviest solution should be placed lowest.

The tables annexed contain some series, which form Voltaic electrical combinations, arranged in the order of their powers; the substance most active being named first in each column.

Table of some Electrical Arrangements, which, by Combination, form Voltaic Batteries, composed of two Conductors, and one imperfect Conductor.

Zinc	Each of these is the positive pole to all the metals below it, and negative with respect to the metals above it in the column.	Solutions of nitric acid
Iron		of muriatic acid
Tin		of sulphuric acid
Lead		of sal-ammoniac
Copper		of nitre
Silver		other neutral salts
Gold		
Platina		
Charcoal		

Table of some Electrical Arrangements, consisting of one Conductor and two imperfect Conductors.

Solution of sulphur and potash	Copper	Nitric acid
of potash	Silver	Sulphuric acid
of soda	Lead	Muriatic acid
	Tin	Any solutions containing acid
	Zinc	
	other metals	
	Charcoal	

The metals having the strongest attraction for oxygene are the metals which form the positive pole, in all cases in which the fluid menstrua act chemically by affording oxygene; but when the fluid menstrua afford sulphur to the metals, the metal having the strongest attraction for sulphur under the existing circumstances, determines the positive pole; thus in a series of copper and iron, introduced into a porcelain trough, the cells of which are filled with water or with acid solutions, the iron is positive, and the copper negative; but when the cells are filled with solution of sulphur and potash, the copper is positive, and the iron negative.

In all combinations in which one metal is concerned, the surface opposite the acid is negative, that in contact with solution of alkali and sulphur, or of alkali, is positive.

26. The energy of a combination to give repulsive or attractive powers to masses of matter, or to affect the electrometer, seems to increase with the number of the series, as does the power to give shocks, and to decompose bodies; but as long as the surface of the gold leaves in the electrometer, or of the human body, or of the water acted upon, is the same, and less than that of the acting plates, increase of surface of the plates is connected with no increase of power. In the operation upon metallic substances or charcoal, or upon good imperfect conductors, the case, however, is different. Thus, though a battery composed of plates of copper and zinc a foot square, will not affect the condensing electrometer more, nor decompose more water, nor give greater shocks to the fingers, than a battery containing plates of an inch square, yet it will ignite more than 100 times as much fine platina wire, and decompose sulphuric

acid, and the water in strong saline solutions, with infinitely more rapidity. This has been expressed by Mr. Cavendish in the statement, that the intensity is the same in both cases; but that the quantity is in some ratio as the surface. The quantity in the small plates is as much or more than such imperfect conductors as water and the human body can carry off by a small surface; whilst better conductors can transmit the whole quantity afforded by the large plates, even when used in very thin laminæ or wires. The correctness of this view may be shown by a very simple experiment. Let two platina wires, from the extremities of a battery composed of plates of a foot square, be plunged into water, the quantity of gas disengaged from the wires will be nearly the same as from an equal number of plates of an inch square; let the fingers of each hand, moistened with water, be applied to the two extremities of the battery, a shock will be perceived nearly the same as if there had been no connection between the wires and the water. Whilst the circuit exists through the human body and through water, let a wire attached to a thin slip of charcoal be made to connect the two poles of the battery, the charcoal will become vividly ignited. The water and the animal substance discharge the electricity of a surface, probably not superior to their own surface of contact with the metals; the wires discharge all the residual electricity of the plates; and if a similar experiment be made on plates of an inch square, there will scarcely be any sensation, when the hands are made to connect the ends of the battery, a circuit being previously made through water; and no spark when charcoal is made the medium of connection, imperfect conductors having been previously applied.

The first distinct experiment upon the igniting powers of large plates was performed by M. M. Fourcroy, Vauquelin, and Thenard. But the grandest combination ever constructed for exhibiting the effects of extensive surface, was made by Mr. Children: it consists of twenty double plates four feet by two; of which the whole surfaces are exposed, in a wooden trough, in cells covered with cement, to the action of diluted acids. This battery, when in full action, had no more effect on water or on the human body than one containing an equal number of small plates; but when the circuit was made through metallic wires, the phænomena were of the most brilliant kind. A platina wire of one thirtieth of an inch in thickness, and eighteen inches long, placed in the circuit between bars of copper, instantly became red hot, then white hot, the brilliancy of the light was soon insupportable to the eye, and in a few seconds the metal fell fused into globules. The other metals were easily fused or dissipated in vapour by this power. Points of charcoal ignited by it produced a light so vivid, that even the sunshine compared with it appeared feeble.

Mr. Children has another battery in construction, the plates of which are double the size of that just described, and which are to be arranged in pairs in single troughs, and connected by means of plates of lead in regular order.

27. The most powerful combination that exists in which number of alternations is combined with extent of surface, is that constructed by the subscriptions of a few zealous cultivators and patrons of science, in the laboratory of the Royal Institution. It consists of two hundred instruments, connected together in regular order, each composed of ten double plates arranged in cells of porcelain, and containing in each plate thirty-two square inches; so that the whole number of double plates is 2000, and the whole surface 128000 square inches. This battery, when the cells were filled with 60 parts of water mixed with one part of nitric acid, and one part of sulphuric acid, afforded a series of brilliant and impressive effects. When pieces of charcoal about an inch long and one sixth of an inch in diameter, were brought near each other (within the thirtieth or fortieth part of an inch), a bright spark was produced, and more than half the volume of the charcoal became ignited to whiteness, and by withdrawing the points from each other a constant discharge took place through the heated air, in a space equal at least to four inches, producing a most brilliant ascending arch of light, broad, and conical in form in the middle*. When any substance was introduced into this arch, it instantly became ignited; platina melted as readily in it as wax in the flame of a common candle; quartz, the sapphire, magnesia, lime, all entered into fusion; fragments of diamond, and points of charcoal and plumbago, rapidly disappeared, and seemed to

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* Plate III. fig. 18.

evaporate in it, even when the connection was made in a receiver exhausted by the air pump; but there was no evidence of their having previously undergone fusion.

When the communication between the points positively and negatively electrified was made in air, rarefied in the receiver of the air pump, the distance at which the discharge took place increased as the exhaustion was made, and when the atmosphere in the vessel supported only one fourth of an inch of mercury in the barometrical gage, the sparks passed through a space of nearly half an inch; and by withdrawing the points from each other, the discharge was made through six or seven inches, producing a most beautiful corruscation of purple light, the charcoal became intensely ignited, and some platina wire attached to it, fused with brilliant scintillations, and fell in large globules upon the plate of the pump. All the phænomena of chemical decomposition were produced with intense rapidity by this combination. When the points of charcoal were brought near each other in nonconducting fluids, such as oils, ether, and oxymuriatic compounds, brilliant sparks occurred, and elastic matter was rapidly generated; and such was the intensity of the electricity, that sparks were produced, even in good imperfect conductors, such as the nitric and sulphuric acids.

When the two conductors from the ends of the combination were connected with a Leyden battery, one with the internal, the other with the external coating, the battery instantly became charged, and on removing the wires, and making the proper connections, either a shock or a spark could be perceived; and the least possible time of contact was sufficient to renew the charge to its full intensity.

28. The general facts of the connection of the increase of the different powers of the battery with the increase of the number and surface of the series, are very distinct; but to determine the exact ratio of the connection is a problem not easy of solution.

M. M. Gay Lussac and Thenard have announced, that the power of chemical decomposition increases only as the cube root of the number of plates; but their experiments were made with parts of piles of a construction very unfavourable for gaining accurate results; and in various trials made with great care in the laboratory of the Royal Institution, the results were altogether different. The batteries employed were parts of the great combination, carefully insulated, and similarly charged; arcs of zinc and silver presenting equal surfaces, and arranged in equal glasses filled with the same kind of fluid, were likewise used; and the tubes for collecting the gasses were precisely similar, and filled with the same solution of potassa*. In these experiments ten pairs of plates produced fifteen measures of gas; twenty pairs in the same time produced forty-nine: again, ten pairs produced five measures; forty pairs in the same time produced seventy-eight measures. In experiments made with arcs, and which appeared unexceptionable, four pairs produced one measure of gas; twelve pairs in the same time produced nine and $\frac{7}{10}$ of gas; six pairs produced one measure of gas; thirty pairs, under like circumstances, produced 24.5 measures; and these quantities are nearly as the squares of the numbers.

It would appear from the experiments of Vanmarum and Pfaff, confirmed by those of Messrs. Wilkinson, Cuthbertson, and Singer, that the increase of power of batteries, the plates of which have equal surfaces, is as the number. I found that ten double plates, each having a surface of a hundred square inches, ignited two inches of platina in wire of one eightieth of an inch; twenty plates, five inches; forty plates, eleven inches; but the results of experiments on higher numbers were not satisfactory; for one hundred double plates of thirty-two square inches each, ignited three inches of platina wire of one seventieth, and one thousand ignited only thirteen inches, and the charges of diluted acid were similar in both cases.

The power of ignition for equal numbers of plates, seems to increase in a very high ratio with the increase of surface, probably higher than even the square; for twenty double plates, containing each two square feet, did not ignite one sixteenth as much wire as twenty, containing each eight square feet, the acid employed being of the same strength in both cases.

Numerous circumstances are opposed to the accuracy of experiments, made with high numbers, or very large surfaces; the activity of combinations rapidly diminishes in consequence of the decom-

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* Plate IV. fig. 19.

position of the menstruum used; and this decomposition is much more violent, the greater the number and surface of the alternations; the vapour rising likewise, when the action is intense, interferes by its conducting power, and the gas by its want of conducting power; and when series containing above five hundred double plates are used, unless the insulation is very perfect, there is a considerable loss of electricity: thus the great battery of two thousand double plates belonging to the Royal Institution, will scarcely act by its true poles, when arranged on a floor of stone, and requires not merely the insulation of porcelain, but likewise of dry wood; and when arranged on a stone floor, it is hardly possible to walk near any of the approaching series without receiving shocks. In cases of the ignition of wire, the cooling influence of the substances in contact, and of that part of the chain not ignited, interferes most, when small quantities of wire are employed and with feeble powers; and hence the effect is at first in a lower and then in a higher ratio than the number, when the whole range is small, as in the experiments above stated. If there is an imperfect connection in any of the series, a great diminution of power is the consequence. If one plate is corroded, or covered with more oxide than the rest, there is a general loss of effect. If copper is substituted for zinc, or zinc for copper, in a single series, the result is similar: and I find that a platina wire, introduced in the place of an arc of silver and zinc, in a series of thirty, diminished its power of producing gas so much, that it was equal only to that of four.

29. The circumstance most important in electricity, perhaps, is its connection with the chemical powers of matter, and the manner in which it modifies, exalts, or destroys these powers. Most of the substances that act distinctly upon each other electrically, are likewise such as act chemically, when their particles have freedom of motion: this is the case with the different metals, with sulphur and the metals, with acid and alkaline substances; and the relations of bodies are uniform; those that have the highest attracting powers being in the relation of positive, in arrangements in which chemical changes can go on. Thus, as is shewn in the tables, page 82, zinc is positive with respect to iron, iron with respect to copper, copper with respect to silver, and so on in all combinations in which oxy-

gene is capable of being combined with the metal; but copper is positive with respect to iron in compound menstrua containing sulphur; the electrical power being in all cases apparently connected with the power of chemical combination.

Crystals of oxalic acid touched by dry quick-lime exhibit electrical powers; and the acid is negative, the lime positive.

All the acid crystals, upon which I have experimented, when touched by a plate of metal, render it positive. And in Voltaic combinations with single plates or arcs of metal, as is stated in page 83, the metal is negative on the side opposed to the acid, and positive on the side or pole opposed to the alkali.

Bodies that exhibit electrical effects previous to their chemical action on each other, lose this power during combination. Thus, if a polished plate of zinc is made to touch a surface of dry mercury, and quickly separated, it is found positively electrical, and the effect is increased by heat; but if it be so heated as to amalgamate with the surface of the mercury, it no longer exhibits any marks of electricity. The case is analogous with copper and sulphur; and iron acts more powerfully than zinc with quicksilver in a permanent electrical combination, as in the experiments of Colonel Haldane; apparently, because under common circumstances it is incapable of amalgamating with that metal. When any conducting substance, capable of combining with oxygene, has its positive electricity increased, it will attract oxygene with more energy from any imperfect conducting medium; and metallic bodies that in their common state have no action upon water, such as silver, attract oxygene from it easily, when connected with the positive pole in the Voltaic circuit; and bodies that act upon water, such as zinc and iron, so as to decompose it slowly, refuse to attract oxygene from it when they are negatively electrified in the Voltaic circuit.

Acids, which are negative with respect to alkalies, metals, and earths, are separated from these bodies in the Voltaic circuit at the positive surface; and alkalies, metals, and earths, are separated from acids at the negative surface: and such are the attracting powers of these surfaces, that acids are transferred through alkaline solutions, and alkalies through acid solutions, to the surfaces where they have their points of rest. It is easy to shew this by making a combination of three agate cups[*], one containing sulphate of potassa, one weak nitric acid, and the third distilled water, and connecting them by asbestus moistened in pure water, in such a manner, that the surface of the acid is lower than the surface of the fluid in the other two cups. When two wires of platina from a powerful Voltaic apparatus are introduced into the two extreme cups, the solution of the salt being positively electrified, a decomposition will take place, and in a certain time a portion of potassa will be found dissolved in the cup in contact with the negative wire, though the fluid in the middle cup will still be sensibly acid.

30. Such are the decomposing powers of electricity, that not even insoluble compounds are capable of resisting their energy; for even glass, sulphate of baryta, fluor spar, &c. when moistened and placed in contact with electrified surfaces from the Voltaic apparatus, are slowly acted upon, and the alkaline, earthy, or acid matter carried to the poles in the common order. Not even the most solid aggregates, nor the firmest compounds, are capable of resisting this mode of attack; its operation is slow, but the results are certain; and sooner or later, by means of it, bodies are resolved into simpler forms of matter.

31. It is in consequence of the phænomena of electrical decomposition, in which metals, inflammable bodies, alkalies, earths, and oxides, are determined to the negative surface, and oxygene, chlorine, and acids to the positive surface, that for some time it was conceived, that various substances might be composed from pure water, by means of electricity, such as potassa, soda, and muriatic acid. A strict investigation of the circumstances under which these substances appeared, led me to discover that they were always furnished from the vessels, or from impurities in the water, and enabled me to determine the general principles of electrical decomposition, and to apply this power to the resolution of some species of matter, of unknown nature, into their elements.

32. The connection of electrical phænomena and chemical changes is evident likewise in the general phænomena of the battery. The most powerful Voltaic combinations are formed by substances that

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[*] Plate IV. fig. 20.

act chemically with most energy upon each other; and such substances as undergo no chemical changes in the combination, exhibit no electrical powers. Thus zinc, copper, and nitric acid form a powerful battery; whilst silver, gold, and water, which do not act chemically on each other, in series of the same number, produce no sensible effect. These circumstances led some philosophers to suppose, at an early period of the investigation of the electrical powers of metals, that they were entirely the result of chemical changes: that as heat was produced by this action, when exerted under common circumstances, so electricity resulted from it under other circumstances; and many of the phænomena were conformable to such an idea, and some ingenious enquirers adopted it to such an extent, as to suppose electricity in all cases owing to this cause.

This generalization, whether applied to Voltaic or to common electricity, seems, however, to be incorrect. Zinc and copper, as has been stated, different metals and oxalic acid, different metals and sulphur, or charcoal, exhibit electrical effects after mere contact, and that in cases when not the slightest chemical change can be observed; and if in these experiments chemical phænomena are produced by the action of menstrua, all electrical effects immediately cease: and it is not philosophical to assume a cause to account for an effect, when no such cause can be perceived.

It has been supposed that the action of the common electrical machine depends upon the oxidation of the amalgam; but I found by mounting a small machine in a glass vessel, in such a manner that it could be made to revolve in any species of gas, that it was active in hydrogene gas, and more active in carbonic acid gas than in the atmosphere (probably owing to its greater density). The experiment has been several times repeated under different circumstances, and uniformly with the same results; and may be regarded as decisive in this important question.

33. Electrical effects are exhibited by the same bodies, when acting as masses, which produce chemical phænomena when acting by their particles; it is not therefore improbable, that the primary cause of both may be the same, and that the same arrangements of matter, or the same attractive powers, which place bodies in the relations of positive and negative, *i. e.* which render them attractive of each

other electrically, and capable of communicating attractive powers to other matter, may likewise render their particles attractive, and enable them to combine, when they have full freedom of motion.

It is not a little in favour of this hypothesis, that heat, and sometimes heat and light, result from the exertion of both electrical and chemical attractive powers; and that by rendering bodies, which on contact are in the relation of positive to others, still more highly positive, as has been stated, page 89, their powers of combination are increased; whereas, when they are placed in a state corresponding to the negative electrical state, their powers of union are destroyed. That acids can be detached from alkalies, oxygene and chlorine from inflammable matter by metallic substances, or by a fluid menstruum highly positive, is likewise favourable to the supposition.

34. This view of the possibility of the dependance of electrical and chemical action upon the same cause, has been much misrepresented. It has been supposed that the idea was entertained, that chemical changes were occasioned by electrical changes; than which nothing is further from the hypothesis, which I have ventured to advance. They are conceived, on the contrary, to be *distinct* phænomena; but produced by the *same power*, acting in one case on masses, in the other case on particles. The hypothesis has been attempted to be controverted by experiments which are far from satisfactory, and some of which have no connection with it. It has been said that acids rendered positive by the common machine, will still combine with alkalies, and that other contradictory results may be obtained; but a nonconducting acid, though brought in contact with a positive surface, electrified by the common machine, is not rendered positive throughout; but gains a polar electricity, which extends only to a certain depth into the crystals, and the exterior surface, if electrical at all, is negative: and if a wire, positively electrified by the common machine, be introduced into an acid solution, this solution, if at all affected, when made to act upon another solution, will be negative at its point of action; that is, it will be positive near the wire, but will be in the opposite state with regard to another surface. And common electricity is too small in quantity, in its usual form of application, to influence chemical changes; for it requires a very strong

machine acting upon a very small surface, to produce any sensible polar decompositions of bodies.

35. The power of action of the Voltaic apparatus, seems to depend upon causes similar to those which produce the accumulation in the Leyden battery, namely, the property of nonconductors and imperfect conductors to receive electrical polarities from, and to communicate them to conductors; but its permanent action is connected with the decomposition of the chemical menstrua between the plates. Each plate of zinc is made positive, and each plate of copper negative, by contact; and all the plates are so arranged with respect to each other as to have their electricities exalted by induction, so that every single polar arrangement, heightens the electricity of every other polar arrangement; and the accumulation of power increases with the number of the series. When the battery is connected in a circle, the effects are demonstrated by its constant exhibition of chemical agencies, and the powers exist as long as there is any menstruum to decompose: but when it is insulated, and the extreme poles of zinc and copper are unconnected, no effects whatever are perceived to take place, no chemical changes go on, and it exhibits its influence only by communicating very weak charges to the electrometer, the end terminated by zinc communicating a positive charge, that terminated by copper, a negative charge.

That each plate of the most oxidable metal in the apparatus, is in the relation of positive, and each plate of the least oxidable, in the relation of negative, and that every series is possessed of similar and equal polarity, is shewn by a very simple experiment: forty rods of zinc of the same size, connected with forty silver wires precisely similar, were introduced in the regular order into similar glasses filled with a solution of muriate of ammonia, rendered slightly acid by muriatic acid; as long as the extreme parts remained unconnected, no gas was disengaged from the silver, and the zinc was scarcely acted upon; when they were connected, all the plates of zinc were dissolved much more rapidly, and hydrogene gas was evolved from every silver wire. And in another experiment, in which several of these wires at equal distances were introduced into small glass tubes, it was found that equal quantities of hydrogene were produced.

36. It seems absolutely necessary for the exhibition of the powers of the Voltaic apparatus, that the fluid between the plates should be susceptible of chemical change, which appears to be connected with the property of double polarity, of being rendered positive at one surface, and negative at the other. There are substances that are imperfect conductors, which are capable of receiving only one kind of electricity, when made parts of the Voltaic circuit, and which M. Ehrman, who discovered them, has named *unipolar* bodies. Perfectly dry soap, and the flame of phosphorus, when connected with the two extremities of the Voltaic apparatus, and with the ground, discharge only the negative electricity. The flames of alcohol, hydrogene, wax, and oil, discharge under like circumstances only the positive electricity; but all these bodies when connected with one pole only of the pile, and with the ground, destroy the divergence of the leaves of the electrometer connected with that end. It is not difficult to exhibit these phænomena when the atmosphere is dry, by means of two hundred pair of plates carefully insulated: an insulated gold leaf electrometer having a moveable wire attached to it, should be connected with each end of the pile: when either electrometer is brought in contact with soap, the soap being connected with the ground, the slight divergence of the leaves will cease; when the soap is connected with both electrometers and with the ground, the divergence of the leaves of the electrometer connected with the end terminated by the zinc, will continue, the leaves of the other electrometer will collapse. The opposite effect occurs when the flame of a taper is connected with both electrometers and with the ground.

The unipolar conductors are incapable of being active in any part of the pile, and in this respect agree with nonconductors; many of which, it is probable, if examined in their relations to electricities of low intensity, would exhibit similar differences.

37. There are no fluids known, except such as contain water, which are capable of being made the medium of connection between the metals, or metal of the Voltaic apparatus; and in cases in which Voltaic batteries have been said to be contructed by metals and paper, or metals and starch, or other like substances, the feeble effects produced, are merely owing to the small quantity of water adhering to these substances, which will not act when carefully

dried. The instrument, called by M. de Luc, the electrical column, formed of zinc, Dutch leaf, and paper, and which he appears to consider as a different combination from the pile of Volta, seems to be merely a feeble Voltaic apparatus, in which the quantity of electricity is not sufficiently great to produce any chemical changes, or distinct phænomena of ignition; but in which the intensity of the small quantity existing, when the combination amounts to 400 or 500, is sufficient to enable it to affect the electrometer, and to act through a plate of air.

It is very probable that the power of water to receive double polarities, and to evolve oxygene and hydrogene, is necessary to the constant operation of the connected apparatus; and that acids, or saline bodies, increase the action, by affording elements which possess opposite electricities to each other, when mutually excited; the action of the chemical menstrua exposes continually new surfaces of metal; and the electrical equilibrium may be conceived in consequence, to be alternately destroyed and restored, the changes taking place in imperceptible portions of time.

The manner in which aqueous fluids receive and communicate electrical polarity, is shewn by a very simple experiment: let a number of fine metallic surfaces or flattened wires (of tin for instance) be made to swim in a narrow trough containing water; and let two wires from the extremities of a Voltaic battery of 1000 double plates, be plunged into the remote ends of the trough, one into one end, the other into the other end. The metals swimming on the water will immediately acquire electrical polarity; and the positive and negative poles will be regularly opposed to each other, the pole of the metal opposite to the wire positively electrified, will be found to be negative, giving off hydrogene, the other pole will deposite oxide; the next wire to this will present the alternate order, which will be preserved in all of them; those most remote from the right line of the circuit, will be least affected. If the battery be in a highly active state, the different wires will attract each other by their opposite poles, and the circle will at length be closed with the production of brilliant sparks. The phænomena are precisely analogous to those phænomena in *magnetism*, presented by a number of flattened wires of soft iron, made to swim upon water, and rendered magnetic by the opposite poles of two powerful magnets; each wire has a north pole and a south pole; and in the alternation, the different poles are attractive of each other.

38. That the decomposition of the chemical agents is connected with the energies of the pile, is evident from all the experiments that have been made; as yet no sound objection has been urged against the theory that the contact of the metals destroys the electrical equilibrium, and that the chemical changes restore it; and in consequence that the action exists as long as the decompositions continue; and this conclusion is confirmed by the late researches made by M. M. Gay Lussac and Thenard, on the great pile constructed by order of the French government. The manner in which chemical changes tend to restore the electrical equilibrium, is shewn by a remarkable experiment on the electrization of mercury, which I have very lately made. A few globules of mercury are placed in a vessel containing common pump water; or any water that contains a small quantity of saline impregnation; wires from a battery of 1000 double plates, not very strongly charged, are introduced into the vessel opposite to each other, so as to reach the bottom; as soon as the circle is completed, the mercury will be violently agitated, each globule will become elongated towards the positive pole, but will retain its circular outline in the part opposite to the negative pole; oxide will be given off from this part, which is positive, but no hydrogene from the part which is negative, and the oxide will pass in a rapid current from the positive towards the negative pole. As long as no hydrogene is given off, the globule is in continued agitation, and a stream of oxide flows with great rapidity from the positive to the negative surfaces; and the negative surfaces of the mercury approach rapidly towards the positive, which are at rest; if the conducting power of the water is exalted by the addition of more of the saline impregnation, or if the charge of the battery be increased, hydrogene will be given off from the negative poles; and the instant this happens the globules become stationary; as if the same power which gave motion to the mercury was neutralized by, or employed in, the evolution of the hydrogene. There are many other remarkable phænomena connected with the operation of electricity on mercury, in contact with

water; which may be urged in favour of the idea, that chemical and electrical attraction depend upon the same cause, and which will possibly lead to new views respecting the elements of matter; but the consideration of them properly belongs to a more advanced division of this work.

39. The illustrious inventor of the new electrical apparatus, has given it the name of the electromotive apparatus, and has founded his theory of its operation upon the Franklinian idea of an electrical fluid, for which certain bodies have stronger attractions than others: and he conceives, that in his pile the upper plate of zinc attracts electricity from the copper, the copper from the water, the water again from the next plate of zinc, the next plate of zinc from the next plate of copper, and so on.

This hypothesis applies very happily to most of the phænomena of the action of the insulated pile, and the pile connected by either of its extremities with the ground; but does not explain with the same facility, the powers of the apparatus connected in a circle, in which each plate of zinc must be supposed to have the same quantity of electricity as each plate of copper; for it can only receive as much as the copper can give, unless indeed the phænomena of the circular apparatus be considered as depending upon the constant and rapid circulation of the natural quantity of electricity, in the different series; which requires the proof of a constant power to attract electricity from one body, at the same time that it is giving it off to another.

40. Whatever may be the happiest approximation to the true theory of the Voltaic instrument, it can scarcely be doubted that the electrical organs of certain animals depend upon similar arrangements of exciting bodies. The shock of the *Gymnotus Electricus*, and the *Torpedo*, resemble the Voltaic shock; and the power resides in organs which consist of a number of similar alternations of different substances. The effects are analogous to those which a Voltaic apparatus of small surface, consisting of very numerous but not very powerful series, would produce. It has been conceived that other phænomena of living action may be connected with the operation of weak electrical powers; such as secretion; and some ingenious hints on this subject have been advanced by Dr. Wollas-

ton and Mr. Home, and some experiments relating to the subject instituted by Mr. Brande. Such enquiries are worthy of further pursuit, as they may tend to elucidate some important functions of the animal œconomy: but they must not be confounded with certain vague speculations, that have been advanced by some authors, on the general dependence of nervous or sensitive action, and muscular or irritable action, upon electricity; such speculations are mere associations of words derived from known phænomena, and applied illogically to unknown things. The laws of dead and living nature appear to be perfectly distinct: material powers are made subservient to the purposes of life, and the elements of matter are newly arranged in living organs; but they are merely the instruments of a superior principle.

As electrical changes are almost constantly taking place in the atmosphere, and as the different substances composing the exterior of the globe, bear different electrical relations to each other, it is very probable that many of the chemical changes taking place on the surface, are influenced by the action of weak electrical powers: such as the decomposition of the surfaces of rocks, the modifications of soils, the formation of acid, and developement of alkaline compounds; and the mutual agencies of the elements in the earth, the sea, and the atmosphere, may be assisted or modified by the circumstances of general electrical action.

41. With regard to the great speculative questions, whether the electrical phænomena depend upon one fluid, in excess in the bodies positively electrified, and in deficiency in the bodies negatively electrified, or upon two different fluids, capable by their combination of producing heat and light, or whether they may be particular exertions of the general attractive powers of matter, it is perhaps impossible to decide in the present imperfect state of our knowledge. The application of electricity as an instrument of chemical decomposition, and the study of its effects, may be carried on independent of any hypothetical ideas concerning the origin of the phænomena; and these ideas are dangerous only when they are confounded with facts. Some modern writers have asserted the existence of an electrical fluid with as much confidence as they would assert the existence of water, and have even attempted to shew that

it is composed of several other elements; but it is impossible in sound philosophy to adopt such hasty generalizations; Franklin, Cavendish, Epinus, and Volta, the illustrious advocates for the idea of a single electrical fluid, have advanced it only as hypothetical, as accounting in a happy way for most of the phænomena; and none of the facts that have been brought forward in favour of the actual existence either of one or of two fluids, can be considered as conclusive.

From a very ingenious experiment of Mr. Cuthbertson, it appears that when a stream of electrical sparks is passed through the flame of a candle between two electrified surfaces, the surface which is negative is most heated; and it has been argued that a current must pass from the positive surface to the negative.

But it is more probable, that this phænomenon depends upon the positive *unipolar quality* of the flame of wax or tallow referred to above; for supposing this flame to become positive, which would seem to be the case, it must be attracted by the negative, and not by the positive surface; and this view is confirmed by an experiment I made on an arch of flame between the two poles of the great Voltaic apparatus of 2000 plates. Platina melted with more facility in the arch at the positive than at the negative extremity, and this arch was common air intensely ignited, through which the electricity was discharged; and if any mechanical current existed from the positive pole to the negative, the maximum of heat must have been produced at the negative. When a wire of platina was made positive, and brought in contact with charcoal rendered negative, it became ignited much sooner, and fused into larger globules, than when made negative, and brought in contact with the charcoal rendered positive; and that the effect did not depend upon the greater heat of the charcoal, appears from the circumstance, that similar phænomena occurred when the experiment was made by contact with mercury. But when an imperfectly conducting fluid, such as sulphuric acid, was used, the result was reversed. The wire being negatively electrified, and the acid positively, the point in contact with the surface of the acid instantly became white hot; in the opposite case a spark of blue light only was produced.

The different appearance of the light on points positively and negatively electrified, has been urged in favour of the idea of a fluid proceeding from the positive to the negative surface. This phænomenon occurs as well in the Voltaic, as in the common discharge: for when the arch of flame passes between two points of charcoal, a vivid spot of white light is always perceived on the negative point, and rays seem to diverge from the positive point. The effect of the difference of the appearance of differently electrified points, I find, does not depend upon the nature of the elastic medium, for it takes place in hydrogene, carbonic acid, and chlorine, though it is less distinct in the heavier gasses, probably from their being worse conductors; but the affections of light in passing from the different parts of the circuit, can with no more propriety be urged in favour of a specific fluid, than the chemical changes produced by the different poles.

When folds of paper are perforated by a discharge from an electrical jar, there is a burr on both sides, which may be urged as an argument against any fluid passing through, for it could penetrate in one direction only; and the experiment is favourable to the idea that electricity is an exhibition of attractive powers acting in peculiar combinations; for the substance of the paper which was negative, may be conceived violently attracted to the positive surface, and the part which was positive, to the negative, at the moment the discharge takes place.

It will be useless to pursue any further this recondite part of the subject; whatever view is taken, active powers must be supposed to be bestowed upon some species of matter, and the impulse must be ultimately derived from the same source. In the universe, nothing can be said to be automatic, as nothing can be said to be without design. An imperfect parallel may be found in human inventions; springs may move springs, and wheels, indexes; but the motion and the regulation must be derived from the artist; sounds may be produced by undulations in the air, undulations of the air by vibrations of musical strings; but the impulse and the melody must arise from the master.

VIII. *On Analysis and Synthesis ; on the Circumstances to be attended to in these Operations, and on the Arrangement of undecompounded Bodies.*

1. When a substance is capable of being resolved into other forms of matter, it is said to be compounded ; thus, if mild magnesia (subcarbonate of magnesia) be strongly heated for an hour in a green glass retort, having its beak connected with a flaccid bladder, elastic matter will collect in the bladder ; and the magnesia, when examined, will be found to have lost in weight, and to be altered in its properties ; it will not effervesce with acids, and it is harsher to the feel. The weight of the elastic matter collected in the bladder is exactly equal to that lost by the magnesia ; it cannot by any means be converted into magnesia, and the mild magnesia gives only a limited quantity of it ; so it is evident that mild magnesia consists of a matter which can be rendered permanently gaseous, and a fixed substance ; it is a *compounded body.*

The metal called zinc, if heated strongly in close vessels, rises in the elastic form, but when condensed by cold, it appears unaltered in its properties. It may be distilled any number of times, but it will be still the same : nothing permanently elastic will be given off from it ; and if the operations be conducted with care, it will be found undiminished in weight. Not even the intense heat of the Voltaic battery applied in a vessel exhausted of air, effects any change in it ; it easily enters into new combinations, but can be resolved into no other forms of matter ; it is considered as an *undecompounded* body.

The term *element* is used as synonymous with *undecompounded* body ; but in modern chemistry its application is limited to the results of experiments. The improvements taking place in the methods of examining bodies, are constantly changing the opinions of chemists with respect to their nature, and there is no reason to suppose that any real *indestructible principle* has been yet discovered. Matter may ultimately be found to be the same in essence, differing only in the arrangement of its particles ; or two or three *simple* substances may produce all the varieties of compound bodies. The results of our operations must be considered as offering at best approximations only to the true knowledge of things, and should never be exalted as a standard to estimate the resources of nature.

2. By *analysis* compounded bodies are resolved into their constituents; by *synthesis* they are produced in consequence of the union of these constituents; and when the weight of the compound corresponds to that of the constituents, the processes are considered as accurate.

The words analysis and synthesis are applied in cases when bodies are resolved into, or compounded from, any other forms of matter, without relation to the elementary nature of these forms;—thus crystals of Glauber's salt may be resolved analytically into sulphate of soda and water, or compounded synthetically from these substances; and sulphate of soda may be formed by synthesis from sulphuric acid and soda, both of which are compounded bodies.

3. In all conclusions upon the results of analytical and synthetical experiments, it is of the greatest importance that the agencies of all the substances concerned, should be accurately known, that no circumstance should be taken for granted, and that the nature of the real constituents of the body should be shewn to be unchanged during the process.

Whatever instruments of experiments be used, their relations to the substances acted upon should be well known, and their influence (if any) estimated. Thus, if a hard stone be pulverized in a mortar of porcelain, agate, or iron, the comparison of weights before and after the process, should be carefully made, to ascertain what quantity of matter may have been abraded from the mortar. When substances are fused, or heated, in vessels on which they are capable of acting, the same precautions should be taken. It should either be shewn, that the vessel has been unchanged during the operation, or the nature and extent of the change should be demonstrated.

Many celebrated chemists have been led into error in the infancy of their investigations, from a want of attention to these circumstances. Thus the illustrious Scheele for some time supposed that silicious earth was composed of fluoric acid and water, because he obtained it by mixing together an acid gas (procured from fluor spar) and water; but subsequent experiments, by demonstrating the loss of weight of the glass vessels, in which his operations were conducted, shewed that the silicious earth was derived from these vessels, and dissolved in the gas.

4. Water is the great solvent employed in chemical processes, and its operation, therefore, should be strictly attended to. It has been too much the custom to consider its elements as almost passive in the processes of dissolution and decomposition; but there are a number of instances in which these elements are newly arranged, and in which their transfer and changes produce very important phænomena.

When oxymuriatic or chlorine gas is exposed to light, it undergoes no change; but when a solution of it in water is placed under the same circumstances, oxygene gas is given off, and a solution of muriatic acid is found in the water. Hence it was concluded, without any reference to weights, that oxymuriatic gas consists of muriatic acid gas and oxygene, and that the water acted in no other way than in assisting the expulsion of the oxygene, by its attraction for the muriatic acid gas.

This inference, however, is now known to be incorrect, and it affords a striking instance of the present object of discussion. If aqueous vapour in small quantities, and chlorine gas, be passed through an ignited tube of glass, the steam entirely disappears, and oxygene gas, and muriatic acid gas are formed; therefore the water must have entered into the composition of the muriatic acid gas, or must have been decomposed; its hydrogene combined with the chlorine, to form muriatic acid gas, and the oxygene gas set free; and that hydrogene actually enters into the composition of muriatic acid gas, is proved by the experiment detailed in page 62; nor can oxygene gas be procured in any experiments upon chlorine, in which bodies not known to contain oxygene, alone are concerned; nor have any means been found by which this substance can be decompounded.

To give another example: when concentrated oil of vitriol, which consists of sulphuric acid and water, is poured upon common salt, and they are heated together, muriatic acid gas flies off, and sulphate of soda is obtained; hence it was concluded, that common salt consists of muriatic acid gas and soda; and that the sulphuric acid merely displaced the muriatic acid gas; and no account was taken of the water of the sulphuric acid in the operation; yet the whole change depends upon this water, and no soda and no muriatic acid can be procured from common salt without water; and common salt is made directly by heating sodium, the metal which I discovered to be the basis of soda, and chlorine together, and these are both as yet undecompounded bodies; and if 92 parts of oil of vitriol, which consists of 75 parts, by weight, of sulphuric acid, and 17 parts of water, be made to act upon 111 parts of common salt, which consists of 44 sodium, and 67 chlorine, the water will be decomposed, 15 of oxygene will combine with the sodium to form 59 of soda, and 2 of hydrogene will combine with 67 of chlorine to form 69 of muriatic acid gas, and the sulphate of soda will be 134 parts.

5. There are numbers of substances which possess an attraction of a peculiar kind for water; they absorb water without undergoing any remarkable change in their properties, and in small proportions. Such are charcoal, different earths, and animal and vegetable substances. If well-burnt charcoal be exposed to the atmosphere for some days, it will increase in weight from 10 to 14 grains per cent., and the increase is almost entirely owing to its absorbing water, which existed in the form of vapour in the air; and by heating charcoal that has been exposed to air, in close vessels, the water may be collected unaltered. Baryta, strontia, and lime, absorb definite proportions of water, and form what are called hydrates, in which the water is in chemical combination, and requires an intense heat for its expulsion; and magnesia, alumina, silica, glucina, and zircona, likewise increase in weight by attracting aqueous vapour from the atmosphere, and seem to form analogous combinations; they give off all the water they had absorbed at the temperature of dull ignition, so that it is retained in them by a very weak attraction; and that the water absorbed in this way is in true chemical union with the earths, is still farther proved by the circumstance that a hydrate of one of these bodies exists in nature, namely, the wavellite or hydrate of alumine, and this is a crystallized body, and requires a strong red heat for the expulsion of its water.

Compounds of the earths in fine powder, that have been heated red, increase in weight, from the absorption of atmospheric moisture; and the case is the same with almost all substances, except the metals, and certain inflammable bodies: so that, in all experiments of analysis, the solid products obtained should be strongly heated, and weighed whilst warm, and before they have been long exposed to the atmosphere, or the quantity of water they have absorbed should be exactly known. And the same precautions should be used, and more strictly, with respect to alkaline, acid, and saline bodies that enter into chemical combination with water, and attract it rapidly from the atmosphere.

6. Gaseous bodies are usually procured from substances that contain water, and many of them are collected over water; it is therefore of considerable importance, in analytical processes, that their relations to this substance should be distinctly understood.

It has been already stated, that common air contains aqueous vapour, or water in an invisible elastic form, which is greater in proportion as the temperature is high, air at the temperature of 65° Fahrenheit, containing about $\frac{1}{50}$ of its volume. From the experiments of Desormes and Clement, it appears that all the gasses not absorbable to any extent by water, such as oxygene, azote, carbonic acid, and hydrogene gasses, contain, in equal volumes, the same quantity of vapour as common air; so that vapour, when it exists in these bodies, can only be regarded as mixed with them; and it is separated by substances that have a strong chemical attraction for water, such as lime, muriate of lime, sulphuric acid, hydrate of potassa, &c.; and in all accurate experiments in which gasses are examined, they should be previously freed from vapour by exposure for some hours to substances that have a strong attraction for water, but possessed of no chemical action on the gas.

The relations of water to gasses with which it is capable of combining chemically (which gasses will be described hereafter), are very different. It is evident that no pure aqueous vapour can exist in them in a state of *mixture*, but they may, and probably in almost all cases do contain a gaseous compound of water, and the peculiar elastic fluid. If a drop of water be introduced into a flask filled with ammoniacal gas, it rapidly absorbs the gas, and increases in size; but if a minute drop of a concentrated solution of ammonia be introduced, and the temperature of the flask be gently raised, the drop disappears, and continues invisible, as long as the heat is preserved uniform. The instances are similar when analogous experiments are made upon muriatic acid and silicated fluoric acid gasses; and I have found that these elastic fluids collected at the temperature of 75° deposited a slight dew, consisting of strong solution of acid in water, when intensely cooled by a freezing mixture. There is reason to believe that the case must be the same with fluoboric acid, and that this body may contain a minute quantity of the compound which may be called hydrate of fluoboric acid; and this is confirmed by the phænomena of the action of potassium upon the gas, for I have never been able to decompose it by this substance, without procuring small quantities of hydrogene.

The quantity of water in the gasses for which it has a chemical attraction, must depend upon the degree of volatility of the fluid compound of the gas and water, and upon the proportion of water it contains. Sulphureous acid gas, which has only a weak attraction for water, would, there is every reason to believe, contain most of the gaseous hydrate; but even in this it is most likely there must be less water than in common air at the same temperature; ammonia would probably be next in order, then silicated fluoric gas, muriatic acid gas, nitrous acid gas, and, last of all, fluoboric gas.

The temperatures at which the compounds of water and gasses rise in vapour, seem to depend upon the strength of the attraction, by which they are combined, and upon the degree of volatility of the gaseous element. All solutions of sulphureous acid, and ammonia, boil at temperatures which differ very little from the boiling point of water. The highest point of the ebullition of solution of muriatic acid gas in water is about 232° Fahrenheit; that solution of nitric acid which gives a compound vapour, does not boil at a temperature below 248°; the temperature at which hydrated fluoric acid boils, according to M. M. Gay Lussac and Thenard, is not very high; but the vapour contains a considerable quantity of water, compared with other acid vapours.

Whether substances will attract water from the absorbable gasses, must depend upon the strength of their affinity for water, as compared with that of the gas. Dry hydrate of potassa will slowly attract moisture from ammonia, and dry muriate of lime from sulphureous acid gas; but muriate of lime does not appear to act upon the water in muriatic acid gas. Silicated fluoric acid gas and fluoboric gas, instantly render cloudy sulphureous acid gas by attracting moisture from it, and fluoboric gas, if mixed with fluoric acid gas, renders it very slightly cloudy. Probably there are no substances which will attract water from the vapour of hydrated fluoboric acid; but the quantity is too minute to influence, to any extent, the results of experiments on gasses containing it.

In cases when elastic fluids are produced in contact with substances which afford peculiar vapours, such as volatile oils, alcohol, ether, &c.; these vapours should be separated either by agitating the gasses in water, or solutions of substances which are capable of absorbing them, such as solution of potassa, &c. and the aqueous vapour separated afterwards by the means above mentioned.

7. In stating the weights, of bodies which are the results of analytical experiments, the temperature should be noticed; and in the case of elastic fluids, the degree of pressure of the atmosphere, as indicated by the barometer. When gaseous compounds are resolved into simpler gaseous bodies, or when gasses are compared with each other, as they are all similarly affected by heat and pressure, there is no necessity for any specific statements of these circumstances, and in describing the specific gravity of a gaseous body, it is necessary only to give the relation of its weight to that of air; thus the weight of air being 1000, that of oxygene gas will be 1097. As hydrogene gas is much lighter than any other elastic fluid, and as it is the body which combines with other substances in the smallest proportions, it would perhaps assist the progress of chemical enquiry to denote its specific gravity by unity, which would harmonize with the idea of representing the proportion in which it combines likewise by unity, and would facilitate the means of comparing the absolute weights of gaseous bodies concerned in experiments, with the numerical symbols representing their elements. The specific gravity of hydrogene being considered as 1, that of common air will be 13.7, and that of oxygene, as has been stated in page 63, 15.

8. In treating of the different substances which, by their agencies, combinations, or decompositions, produce the phænomena of chemistry—*radiant* or *etherial matters* will be first considered, as their

principal effects seem rather to depend upon their communicating motion to the particles of common matter, or modifying their attractions, than to their actually entering into combination with them; and as from the laws of their motions, or from their extreme subtileness, they are incapable of being weighed.

The *undecompounded* substances which are permanent in their forms, will be considered in an order of arrangement depending upon their electrical relations; *those* determined to the *positive surface* in the Voltaic electrical circuit, being arranged in one class, and *those* determined to the *negative* surface in another; and the subdivisions of the classes will be made according to their natural relations.

The general principle adopted will be, that no compounded body shall be treated of, till its constituents have been described.

The relations of bodies derived from their electrical powers, are coincident with those dependent upon their agencies in combustion; that is, one class contains supporters of combustion, and the other class combustible bodies; but as the heat and light produced in combustion, seem to be merely indications of the strength of attraction of the acting substances; and as these phænomena occur in cases in which inflammable matters act upon each other, combustibility can scarcely be considered as a definite idea; though the importance of the common phænomena of combustion, have made them the grand objects in all the early theories of chemistry.

DIVISION II.

OF RADIANT OR ETHEREAL MATTER.

I. *Of the effects of radiant Matter, in producing the phænomena of Vision.*

1. THE phænomena of vision depend upon the presence of the sun, of the heavenly bodies, or on the mutual action of certain substances on the surface of the earth.

2. It has been demonstrated by Roemer, and confirmed by the discoveries of Bradley, that the motion of light is progressive; it is about eight minutes in passing from the sun to the earth.

3. When light is entirely intercepted by a body placed between the luminous object and the eye, that body is said to be opaque; and the manner in which the light is intercepted, proves that it proceeds in right lines or rays from the luminous body as a centre.

4. Luminous objects may be seen through certain substances; and these bodies are said to be transparent. Bodies differ considerably in the degree of their transparency; some transmit many more rays than others, and there are gradations from perfect opacity, when all the rays are intercepted, to a high degree of transparency, when by far the greater number are transmitted.

5. Of the rays that are not transmitted, some are lost, as it were absorbed by the body; others are thrown back again, or reflected from its exterior or inner surfaces, and these rays are called reflected rays.

6. The rays of light, in their transmission through bodies, or reflection from their surfaces, undergo certain modifications, of great importance in their connection with the laws of vision, and the general properties of radiant matter.

7. If rays of light pass from one transparent substance not crystallized into another, in an oblique direction, their path is altered, and they are bent downwards or upwards, according as the medium is more or less dense, or according as it differs in chemical qualities; inflammable substances, or compounds containing inflammable substances, having the highest power of bending towards the perpendicular or of refracting, as it is called, the rays of light; and, in the same substances, the sines of the angles of refraction bear always the same relations to those of the angles of incidence.

8. The rays of light, in passing through obliquangular crystalline bodies, follow different laws. If a ray of light be received perpendicularly upon a plain surface of island crystal, or rhomboidal carbonate of lime, one part of it passes through without altering its direction; another part, on the contrary, is refracted in a plane parallel to the diagonal, joining the two obtuse angles of the crystal, so that images seen through the crystal appear double; and this phænomenon, first scientifically reasoned upon by Huygens, is called the phænomenon of double refraction.

If a ray of light which has suffered double refraction from one crystal, be received by another crystal placed in a similar and parallel position, there will be no new division of rays, and no change in their direction; but if the second crystal be placed, so that its planes of perpendicular refraction are at right angles to those of the first crystal, then there will be a new phænomenon, and that part of the ray which before passed through the ordinary refraction, will receive the extraordinary refraction, and reciprocally that which underwent the extraordinary will suffer the ordinary refraction. If the second crystal be turned gradually round in the same plane, when it has made a quarter of a revolution, there will be four divisions of the ray, and they will be reduced to two in the half of the revolution, so that the refracting power depends upon the relations of the position of the particles of the crystals, to the rays passing through them.

Similar phænomena to those presented by island crystal, are exhibited in a greater or less degree by other crystalline bodies, and probably would belong to all of them, if they were sufficiently transparent to admit of the passage of light through strata of considerable thickness. Very thin pieces of the rhomboidal carbonate of lime even do not give perceptible, double images.

9. When light is reflected from bodies, under most circumstances it is unaltered in its relations to the refractive powers of transparent substances, and the angle of reflection is equal to the angle of incidence. But, in certain cases, at angles which differ for different bodies, the reflected rays have the same property as the extraordinary refracted rays that have passed through island crystal. This important fact, discovered by M. Malus, is easily exemplified. If the flame of a taper reflected at an angle of 52° 45′ from the surface of water, be viewed through a piece of double refracting spar, one of the images will vanish every time that the crystal makes a quarter of a revolution.

If a ray of light be reflected from a surface of glass, at an angle of 54° 35′, and fall upon another plane of glass at the same angle, it will suffer no new reflection, and will pass through the glass unaltered, provided that the planes of reflection or refraction be perpendicular to each other; but if they are in the same direction, nothing remarkable will happen.

Direct light is most copiously reflected, as its incidence is less perpendicular; but light once reflected follows different laws, and the quantity that suffers the second reflection, depends entirely upon the relations of the angles made by the reflecting surfaces with the rays.

10. When a ray of light is made to pass through a triangular prism of glass, and the transmitted light is received upon a sheet of white paper, it is found to be of different colours; the most distinct of which are red, orange, yellow, green, blue, indigo, and violet. Newton has ascertained, that if the coloured image, or spectrum, as it is called, be divided into 360 parts, the red will occupy 45 of these parts, the orange 27, the yellow 48, the green 60, the blue 60, the indigo 40, and the violet 80. The red rays are least refracted, the violet rays most, and the other coloured rays are refrangible inversely, in the order in which they have been named.

According to Dr. Wollaston, when the beam of light is only $\frac{1}{20}$ of an inch broad, and received by the eye at the distance of ten feet, through a clear prism of flint glass, four colours only appear, red, yellowish green, blue, and violet.

If the differently coloured rays of light separated by the prism, be concentrated upon one spot by means of lenses, they produce white light; and Newton has beautifully explained the different colours of bodies, by supposing that they retain certain of the coloured rays of light, and reflect others; thus red bodies are supposed to reflect red light, and to absorb all the other coloured rays.

The different coloured rays of light, as has been shewn by Dr. Herschel, differ in their power of rendering objects visible; at least in the state of division, which is obtained by means of a prism. If an equal portion of these rays be made to illuminate a printed page, the words may be seen from the greatest distance, when exposed to the lightest green or deepest yellow light; and the effects of illumination for equal quantities of the rays, diminish from the central parts towards the extremities of the spectrum. It may, however, be said that there are *more* green rays in a given part of the spectrum than blue rays, and the difference of illuminating power may depend on this circumstance.

11. The rays separated by one prism are not capable of being further divided by being passed through another; and in their relations to double refraction and reflection, they appear to agree with direct light: an object illuminated by any of the rays in the spectrum, is seen double through island crystal, in the same manner as if it had been visible by white light.

12. The minute investigation of the properties of radiant matter, in their relations to the phænomena of vision, constitutes the object of a particular branch of science—*Optics*. The few statements that have been made on this subject, it will be found in the following pages, are connected with the chemical effects and nature of radiant matter; and it will immediately be seen, that the same causes which produce the most numerous and important of our sensations, and which give, as it were, language to the external world, are likewise subservient to the orderly succession of events in the œconomy of nature.

II. *Of the Operation of radiant Matter in producing Heat.*

1. When similar thermometers are placed in the different parts of the solar beam, separated by the prism, it is found that different effects are produced in the different coloured rays. The greatest heat is exhibited in the red rays, the least in the violet rays; and in a space beyond the red rays, where there is no visible light, the increase of temperature is greatest of all. This important discovery was made by Dr. Herschel*. He estimates the power of heating in the red rays, to be to that of the green rays as 55 to 26, and to that of the violet rays as 55 to 16. A thermometer, in the full red rays, indicated an increase of temperature of 7° Fahrenheit in ten minutes; beyond the red rays, in an equal time, the increase was 9° Fahrenheit.

2. From these facts, which have been confirmed by Sir H. Englefield, and other good observers, it is evident that matter set in motion by the sun, has the power of producing heat without light, and that its rays are less refrangible than the visible rays.

Some persons have concluded from the phænomena, that all the rays which produce heat in the solar beam, are distinct from those that produce light; but this does not seem to be warranted by the experiments, for if it were the case, they would, probably, be entirely separated from the coloured rays by the prism, as the coloured rays are from each other. It has been used as an argument, in favour of the distinctness of the rays producing light, and those producing heat, that the beams from the moon illuminate without heating; but it is possible that a greater number of the most heat-making rays, than of the other rays, may be absorbed by that planet; and supposing *all* the rays reflected that fall upon the moon, yet still their intensity would be 95890 times less than that of the solar rays, at the surface of the earth: and it appears from experiment, that the real intensity of the light of the moon to that of the sun is less than 1 to 300,000, and such rays concentrated by the most powerful lenses, could not be expected to produce any effect on common thermo-

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* Philosophical Transactions, 1800, p. 261.

meters; and as yet no very delicate experiments have been published on the subject.

3. The invisible rays that produce heat, are capable of reflection as well as refraction, in the same manner as the visible rays. It is well known that an intense degree of heat may be produced by the concentration of the solar beams upon a single spot, by a concave mirror, or by several mirrors; and there is no reason to disbelieve the *possibility* of the inventions ascribed to Archimedes, who, it is said, by the combined effect of a number of plane mirrors, set fire to the Roman ships during the siege of Syracuse; though the immense means and labour required for such an operation, renders the narrative very doubtful.

4. Rays capable of producing heat with and without light proceed from bodies at the surface of the globe under peculiar agencies or changes, as well as from the sun; and the phænomena that are usually called the phænomena of the *radiation of terrestrial heat* are of great extent and importance, and well worthy of being studied.

5. If a thermometer be held near an ignited body it receives an impression connected with an elevation of temperature: this is partly produced by the conducting powers of the air; but it is likewise produced by another impulse which is instantaneously communicated, even to a considerable distance. If a large concave metallic mirror be placed upon the ground, and the hot body be raised some feet above it, a thermometer will instantly rise in the focus of the mirror, though it is evident that no current of hot air can pass downwards from the body.

This effect is commonly called the radiation of terrestrial heat. It is best observed, by employing two mirrors parallel to each other, and to the surface of the earth. If the mirrors be of copper tinned, and be well polished, and as much as 2 feet in diameter, and distant only 12 feet, a small pan of red hot charcoal, placed in the focus* of the upper mirror, will cause gunpowder to explode in the focus of the lower mirror.

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* In the usual form of the experiment, the mirrors are placed opposite to each other on the ground. This arrangement, which I have been long in the habit of employing, in the demonstrations in the theatre of the Royal Institution, more distinctly exhibits the effect. See Plate IV. fig. 21.

6. In cases when no light is emitted from a hot body, the effect of the concentration of heat by the mirrors may still be produced. Thus, if a vessel filled with boiling water, be placed in the focus of the upper mirror, a thermometer placed in the focus of the lower one will have its temperature increased.

These phænomena of the radiation of terrestrial matter producing heat, were made known by the academicians Del Cimento, Hooke, Scheele, and Pictet: and there is another fact, still more extraordinary, which has been called *the radiation of cold*, first observed by the Italian philosophers, and afterwards by Pictet. If in the arrangement of the two parallel mirrors, a piece of ice be introduced into the lower focus, the thermometer in the upper focus will indicate a diminution of temperature.

7. All these phænomena coincide with the phænomena of the reflection of the solar beams; and even the *apparent radiation of cold* is in harmony with them; for if it be supposed, that rays capable of producing heat, emanate from all terrestrial bodies, but in quantities greater in some increasing proportion as their temperatures are higher, then the introduction of a cold body into the focus of one mirror, ought to diminish the temperature of a thermometer in the focus of the other, in the same manner as a black body placed in one focus, would diminish the quantity of light in the other focus; and the eye is to the rays producing light, a measure, similar to that which the thermometer is to rays producing heat.

8. If a large lens be placed before an ignited body, and the light be refracted to a focus, a thermometer placed in the focus will be very slowly affected. The increase of temperature will be infinitely less than that produced in the focus of a mirror of the same size, and is such as may be principally ascribed to the increased *radiation* of heat by the lens itself. Likewise, if glass screens be placed between the two mirrors, in the experiments in which the ignited coals, or water, or ice are used, the effect is in great measure destroyed. This establishes a difference between the agency of the radiant matter producing heat on the surface of the earth, and of that from the sun. Mr. Leslie has supposed that the phænomena of the radiation of terrestrial heat, depend upon certain pulsations or undulations of the atmosphere capable of being reflected, but not of being refract-

ed; but none of his facts prove this ingenious hypothesis, though many of them are favourable to it. I had an apparatus made, by which platina wire could be heated in any elastic medium, or in vacuo; and by which the effects of radiation could be distinctly exhibited by two mirrors, the heat being excited by a Voltaic battery. In several experiments, in which the same powers were employed to produce the ignition, it was found that the temperature of a thermometer rose nearly three times as much in the focus of radiation, when the air in the receiver was exhausted to $\frac{1}{120}$, as when it was in its natural state of condensation*. The cooling power, by contact of the rarefied air, was much less than that of the air in its common state, for the glow of the platina was more intense in the first case than in the last; and this circumstance perhaps renders the experiment not altogether decisive, but the results seem favourable to the idea, that the terrestrial radiation of heat is not dependent upon any motions or affections of the atmosphere.

9. Another fact coinciding with this opinion, is found in the effects of the refraction of the rays from charcoal, ignited by Voltaic electricity. When a small lens was placed before the brilliant star of light, produced by the battery of two thousand double plates, and its focus thrown upon the ball of a small differential thermometer, the instrument instantly indicated an elevation of temperature.

10. The manner in which the temperatures of bodies are affected by rays producing heat, is different for different substances, and is very much connected with their colours. The bodies that absorb, as it is called, most light, and of course that reflect least, are most heated when exposed either to solar or terrestrial rays. Black bodies in general are more heated than red; red more than green; green more than yellow; and yellow more than white.

Metals are less heated than earthy or stony bodies, or than animal or vegetable matters. Polished surfaces are less heated than rough surfaces.

11. The bodies that have their temperatures most easily raised by the action of rays producing heat are likewise those that are most easily cooled by their own radiation, or that at the same temperature

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* See Plate IV. fig. 22.

emit most heat-making rays. Metals radiate less heat than glass; glass less than vegetable substances; and charcoal has the highest radiating powers of any body as yet made the subject of experiment.

From Mr. Leslie's ingenious researches, it appears that the radiating power of lamp-black, being taking as 100, the following substances radiate in a proportion that may be thus expressed: sealing-wax 95; crown glass 90; China ink 88; ice 85; minium 80; isinglass 80; plumbago 75; tarnished lead 45; clean lead 19; polished iron 15; tin plate, gold, silver, and copper 12.

12. There are some practical applications of the doctrines of radiant heat, to the œconomy of some of the useful arts and processes of common life.

Vessels that are intended to retain their heat, should be metallic and highly polished; and, independent of elegance and delicacy, there is a reason obvious, from the preceding facts, why metallic vessels, for the purposes of the table, should be kept as bright as possible. Steam or air pipes for warming houses, should be polished in those parts where the heat is not required to be communicated, and covered with some radiating substance, such as lamp black, or plumbago, in those rooms which are to be heated by them.

Culinary implements should be blackened, and not polished on those parts, which are to receive heat. The heated surfaces of fire-places or stoves should not be metallic; but of stony or earthy materials, and in this case much more heat will be communicated by radiation*.

III. *Of the Effects of radiant Matter in producing chemical Changes.*

1. A number of the effects of radiant matter in producing chemical changes, may be ascribed to its powers of heating bodies. The heat produced by the concentration of rays has been already referred to, and the focus of a powerful lens or mirror exposed to the sun, offers means of exciting heat inferior only to those afforded by Voltaic electricity. In some cases the direct solar light produces effects similar to those produced by a degree of heat much higher

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* Count Rumford. Phil. Trans. 1804, page 178.

than could be excited by their influence upon an opaque body; thus, as M. M. Gay Lussac, Thenard, and Dalton have shewn, chlorine and hydrogene detonate when a mixture of them is exposed to the solar beams, though the same effect is not produced by the application of a heat below that of ignition. This has been explained by supposing that the temperature of *particles* of substances is raised *considerably* and *instantaneously* by the rays; but it may likewise, and with more probability, be supposed to depend upon a specific and peculiar influence of radiant matter, and that such an influence exists, is proved by many circumstances.

2. If moist horn silver, muriate of silver F N, be exposed to the different rays in the prismatic spectrum; it will be found that no effect is produced upon it in the least refrangible rays, which occasion heat without light; a slight discoloration only will be occasioned by the red rays; the effect of blackening will be greater towards the violet part of the spectrum; and in a space beyond the violet, where there is no sensible heat or light, the chemical effect will be very distinct.

This observation, made by M. Ritter and Dr. Wollaston, proves, that there are rays more refrangible than the rays producing light and heat; and, from the observations of M. Berthollet, it appears, that muriatic acid gas is formed when horn silver is blackened by light, so that they may be called hydrogenating rays.

3. It has been supposed that these invisible rays are mixed with the other rays throughout the coloured part of the spectrum; but it seems equally probable, that the same rays that produce light, may likewise produce chemical effects, and effects of heat; and Dr. Young has shewn that the invisible rays are liable to the same affections as visible rays, when they are reflected from thin plates of air, as in the phænomona of coloured rings.

4. I found that a mixture of chlorine and hydrogene acted more rapidly upon each other, combining without explosion, when exposed to the red rays, than when placed in the violet rays; but that solution of chlorine in water, became solution of muriatic acid most rapidly, when placed in the most refrangible rays in the spectrum.

I found that the puce-coloured oxide of lead, when moistened, gradually gained a tint of red in the least refrangible rays, and at last became black, but was not affected in the most refrangible rays; and the same change was produced by exposing it to a current of hydrogene gas. The oxide of mercury procured by solution of potassa and calomel, exposed to the spectrum, was not changed in the most refrangible rays, but became red in the least refrangible rays, which must have depended upon its absorbing oxygene. The violet rays produced upon moistened red oxide of mercury, the same effects as hydrogene gas.

6. The general facts of the refraction and effects of the solar beam offer an analogy to the agencies of electricity. In the Voltaic circuit the maximum of heat seems to be at the positive pole where the power of combining with oxygene is given to bodies, and the agency of rendering bodies inflammable is exerted at the opposite surface; and similar chemical effects are produced by negative electricity, and by the most refrangible rays of the solar beam.

7. In general, in nature, the effects of the solar rays are very compounded. Healthy vegetation depends upon the presence of the solar beams, or of light, and whilst the heat gives fluidity and mobility to the vegetable juices, chemical effects likewise are occasioned, oxygene is separated from them, and inflammable compounds formed. Plants deprived of light become white, and contain an excess of saccharine and aqueous particles; and flowers owe the variety of their hues to the influence of the solar beams.

Even animals require the presence of the rays of the sun, and their colours seem materially to depend upon the chemical influence of these rays; a comparison between the polar and tropical animals, and between the parts of their bodies exposed, and those not exposed, to light, shews the correctness of this opinion.

IV. *Of the Nature of the Motions or Affections of radiant Matter.*

1. Two hypotheses have been inverted to account for the principal operations of radiant matter. In the first it is supposed that the universe contains a highly rare elastic substance, which when put into a state of *undulation*, produces those effects on our organs of sight, which constitute the sensations of vision, and the other phænomena occasioned by solar and terrestrial rays. In the second it is

conceived that *particles* are *emitted* or sent off from luminous or heat-making bodies with great velocity, and that they produce their effects by communicating their motions to substances, or by entering into them, and changing their composition.

2. The first of these suppositions was adopted by Hooke, Huygens, and Euler;—the second by Newton, and the philosophers of the Newtonian school. Many of the phænomena may be accounted for by either hypothesis, but the Newtonian doctrine applies much more happily to most of the facts discovered respecting the modifications of light by double refraction and reflection. Indeed it does not seem possible, as Newton has shewn, to account for the circumstance, that a ray which has suffered extraordinary refraction in passing through one crystal, should suffer ordinary refraction in passing in another direction, through another like crystal, on the idea of the effect being a mere undulation of an ethereal medium; but it may explained by supposing the rays to consist of particles endowed with rectilineal motion, and possesed of a certain polarity, that is, parts attractive with respect to some surfaces of the crystal, and repulsive with respect to others.

3. M. Malus has supposed, in his ingenious speculations on these remarkable phænomena, that the molecules producing light, are possessed of three rectangular axes, of which one is always in the direction of the ray, and the other two are made by the influence of the repulsive forces exerted by the crystalline medium, perpendicular to the direction of these forces; and such a form, and such an effect would correspond with the idea of the luminous particles being octaedrons.

4. As the coloured rays separated by the prism, bear the same relation to double refraction, that direct light bears, it follows that the polarity of the different particles must be of the same kind, and this is what might be expected. The same crystalline substance always affects the same primary forms. When a tourmaline is broken into pieces, the pieces are found to possess similar electrical powers to the original crystal, and a large rhomb of calcareous spar, easily breaks into a number of small rhombs.

5. Newton has attempted to explain the different refrangibility of the rays of light, by supposing them composed of particles differ-

ing in size, and this hypothesis is not contradictory to the idea of their being regular solids endowed with similar polarities. The same great man has put the query whether light and common matter are not convertible into each other; and adopting the idea that the phænomena of sensible heat depend upon vibrations of the particles of bodies, supposes that a certain intensity of vibrations may send off particles into free space, and that particles in rapid motion in right lines, in losing their own motion, may communicate a vibratory motion to the particles of terrestrial bodies*.

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* The views of Newton are so clearly developed in the following passages, and they are so much connected with the refined philosophy of chemistry, that the reader probably will require no apology for the insertion of them in a note.

Quere 29. Are not the rays of light very small bodies emitted from shining substances? For such bodies will pass through uniform mediums in right lines, without bending into the shadow, which is the nature of the rays of light. They will also be capable of several properties, and be able to conserve their properties unchanged, in passing through several mediums, which is another condition of the rays of light. Pellucid substances act upon the rays of light at a distance, in refracting, reflecting, and inflecting them; and the rays mutually agitate the parts of those substances at a distance for heating them; and this action and re-action at a distance, very much resembles an attractive force between bodies. If refraction be performed by attraction of the rays, the sines of incidence must be to the sines of refraction in a given proportion; as we shewed in our principles of philosophy, and this rule is true by experience. The rays of light in going out of a glass into a *vacuum*, are bent towards the glass; and if they fall too obliquely on the *vacuum*, they are bent backwards into the glass, and totally reflected; and this reflection cannot be ascribed to the resistance of an absolute *vacuum*, but must be caused by the power of the glass attracting the rays at their going out of it into the *vacuum*, and bringing them back. For if the farther surface of the glass be moistened with water, or clear oil, or liquid and clear honey, the rays which would otherwise be reflected, will go into the water, oil, or honey, and therefore are not reflected before they arrive at the farther surface of the glass, and begin to go out of it. But if they go out of it into a *vacuum*, which has no attraction to balance that of the glass, the attraction of the glass either bends and refracts them, or brings them back and reflects them. And this is still more evident by laying together two prisms of glass, or two object-glasses of very long telescopes, the one plain, the other a little convex, and so compressing them that they do not fully touch, nor are too far asunder. For the light, which falls upon the further surface of the first glass, where the interval between the glasses is not above the ten hundred thousandth part of an inch, will go through that surface, and through

6. As particles of any gaseous medium when put into a state of undulatory motion are capable of producing the sensation of sound by acting upon the auditory organs, so it may be conceived, that cer-

the air, or *vacuum* between the glasses, and enter into the second glass, as was explained in the first, fourth, and eighth observations of the first *part* of the second book. But if the second glass be taken away, the light, which goes out of the second surface of the first glass into the air, or *vacuum*, will not go on forwards, but turns back into the first glass, and is reflected; and therefore it is drawn back by the power of the first glass, there being nothing else to turn it back. Nothing more is requisite for producing all the variety of colours, and degrees of refrangibility, than that the rays of light be bodies of different sizes; the least of which may make a violet, the weakest and darkest of the colours, and the more easily diverted by refracting surfaces from the right course; and the rest as they are bigger and bigger, may make the stronger and more lucid colours, blue, green, yellow, and red, and be more and more difficultly diverted. Nothing more is requisite for putting the rays of light into fits of easy reflection and easy transmission, than that they be small bodies, which by their attractive powers, or some other forces, stir up vibrations in what they act upon; which vibrations being swifter than the rays, overtake them successively, and agitate them, so as by turns to increase and decrease their velocities, and thereby put them into those fits. And lastly, the unusual refraction of island crystal, looks very much as if it were performed by some kind of attractive virtue, lodged in certain sides, both of the rays, and of the particles of the crystal, and not in their other sides; for were it not for some kind of disposition or virtue lodged in some sides of the particles of the crystal, and which inclines and bends the rays towards the coast of unusual refraction; the rays which fall perpendicularly on the crystal, would not be refracted towards that coast rather than towards any other coast, both at their incidence, and at their emergence, so as to emerge perpendicularly, by a contrary situation of the coast of unusual refraction, at the second surface; the crystal acting upon the rays, after they have passed through it, and are emerging into the air, or, if you please, into a *vacuum*. And since the crystal, by this disposition, or virtue, does not act upon the rays, unless when one of their sides of unusual refraction, looks towards that coast; this argues a virtue or disposition in those sides of the rays, which answers to, and sympathises with that virtue or disposition of the crystal, as the poles of two magnets answer to one another. And as magnetism may be intended and remitted, and is found only in the magnet and in iron, so this virtue of refracting the perpendicular rays is greater in island crystal, less in crystal of the rock, and is not yet found in other bodies. I do not say, that this virtue is magnetical; it seems to be of another kind; I only say, that whatever it be, it is difficult to conceive how the rays of light, unless they be bodies, can have a permanent virtue in two of their sides which is not in their other sides; and this tain particles or aggregates of particles from any matter moving with great and equal velocity may occasion the sensations of vision, and the other effects of the solar beams; and the difficulty of refracting terrestrial radiant heat, may be conceived to depend upon the greater size of the aggregated particles; and according to the Newtonian hypothesis, any matter moving with considerable quickness in right lines may be conceived capable of communicating an expansive motion to the particles of bodies.

7. If specific highly rare imponderable fluids be assumed to account for the phænomena, as many must be adopted as there are different series of effects produced by different rays. There must be a matter of violet light, a matter of blue light, and so on; and likewise a deoxidating ethereal matter, a calorific solar matter, and a calorific terrestrial matter, which is very contradictory to the usual simplicity of causes observable in the economy of things; and the idea likewise is rendered improbable, by experiments on solar phosphori. When a mixture of calcined oyster shells and sulphur, that have been heated together, is exposed to the solar rays, it forms a good solar phosphorus, it becomes luminous, and continues so for some minutes in the dark; and to whichever of the prismatic rays it be exposed, its light is always the same, pale yellow. It is easy to explain the phænomenon, on the idea that vibratory motion is communicated to particles of the substance by the rays, in consequence of which, some of its own particles are slowly sent off, or that the particles have been formed into new aggregates, in consequence of the attraction of the substance; but if light be supposed specific in its kind, and absorbed and emitted; then, when the

without any regard to their position to the space, or medium, through which they pass." Optics.

May not the experiments of Dr. Young, Phil. Trans. 1804, page 2, which he considers as proving that homogeneous light at certain equal distances, in the direction of its motion, is possessed of opposite qualities capable of neutralizing each other, and of extinguishing the light when they happen to be united; be explained on the idea of attractive poles in opposite sides of the particles of light? That able philosopher considered them as favourable to the theory of undulation; but if the attractions of other matter can destroy the motions of light, as in the case of its action on black bodies, may not the same result be produced by the attractions of its particles for each other?

phosphorus is exposed to blue rays, blue rays alone ought to be emitted, which is not the case.

8. Many authors have written of the *combinations* of light and heat; but from the views that have been developed, even taking the Newtonian theory of emission for granted, it is evident that such combinations are merely hypothetical. When the solar rays are *absorbed*, as it is called, by a black body, it must be conceived, on this theory, that their motion is communicated to the particles of the body, but whether they adhere to it, or are thrown off in new aggregates, as radiant heat, cannot well be discussed, for we have no means accurate enough to determine whether in such cases there is an increase of weight; and this is the only test to be depended upon, of true chemical combination, or of mechanical mixture.

The fire produced in a number of chemical processes, particularly in combustion, on the Newtonian view, may be ascribed to particles sent into free space, in consequence of the repulsion exerted by other particles at the moment of their entering into chemical union. Any solid bodies may be made to emit light, when exposed to a blast of air very hot, though not luminous; the light is always of the same kind, and this circumstance is favourable to the idea of the possibility of the conversion of common matter into radiant matter.

Many phænomena, which have been attributed to combined light, appear to be electrical, or to be merely the effect of the ignition of the substances, for, whenever heat rises beyond a certain degree, bodies become luminous; pieces of quartz rubbed together are rendered electrical; and by percussion or friction, any hard bodies may be intensely heated.

During the putrefaction of certain animal and vegetable substances, light is emitted; and this is no more difficult to account for, than the heat produced during similar operations.

The light emitted by certain living insects appears to depend upon the secretion of a substance very easy of decomposition; and any chemical change may be supposed adequate to the production of light.

It has been sometimes supposed, that a specific imponderable substance, capable of producing light, is contained in oxygene gas;

and it has been also imagined, that such a substance exists in inflammable bodies; but the facts are contradictory to the hypothesis. Iron, when heated to whiteness, burns with amazing brilliancy in oxygene gas, throwing off sparks intensely luminous; but, when heated to 600° Fahrenheit, it combines slowly with the oxygene, producing heat without light; the chemical change is of the same nature in both cases; the only difference is in its rapidity and energy.

9. The later investigations on light teach us that there is still much to learn with respect to the affections and motions of radiant matter; and this subject, when fully understood, promises to connect together chemical and mechanical science, and to offer new and more comprehensive views of the corpuscular arrangements of matter.

In radiant matter, the particles act almost independently of the common laws of attraction; and by prismatic refraction, the difference of their actions is determined, and it seems probable that the relations of the different particles to the crystalline arrangements of matter, will be found connected with those powers which they possess analogous to electrical qualities.

If that sublime idea of the ancient philosophers, which has been sanctioned by the approbation of Newton, should be true, namely, that there is only one species of matter, the different chemical, as well as mechanical forms of which are owing to the different arrangement of its particles, then a method of analysing those forms may probably be found in their relations to radiant matter. Newton supposed that the luminous particles at the violet end of the spectrum were smallest in size, and those at the red end, largest in size, and those producing the intermediate colours, intermediate. On this idea, the calorific invisible particles would be the largest in the solar beam, and the calorific particles emitted by terrestrial bodies may be imagined of still greater size, so as to be incapable of passing through the pores of dense transparent media. The rays at the red end of the spectrum, in their chemical powers, tend to burn bodies, or to combine them with oxygene; those at the opposite end tend to restore inflammability to bodies; and negative electricity, which exercises the same function, produces hydrogene gas from water;

and this is the lightest chemical element in nature, and may be conceived to be composed, on the corpuscular hypothesis, of the smallest particles.

10. The idea that light is not a specific fluid is confirmed by some practical results relating to the œconomy of light. Count Rumford has lately shewn, that the quantity of light emitted by a given portion of inflammable matter in combustion, is proportional in some high ratio to the elevation of temperature; and that a lamp having many wicks very near each other, so to communicate heat, burns with infinitely more brilliancy than the Argand's lamps in common use.

DIVISION III.

OF EMPYREAL UNDECOMPOUNDED SUBSTANCES, OR UNDECOMPOUNDED SUBSTANCES THAT SUPPORT COMBUSTION, AND THEIR COMBINATION WITH EACH OTHER.

I. *General Observations.*

1. IT has been mentioned, that almost all cases of vivid chemical action are connected with the increase of temperature of the acting bodies, and a greater radiation of heat from them; and, in a number of instances, light is also produced. See p. 51, and 92.

The strength of the attraction of the acting bodies determines the rapidity of combination, and in proportion as this is greater, so likewise is there more intensity of heat and light. In the phlogistic doctrine of chemistry, all changes in which heat and light are manifested were explained, by supposing that the acting bodies contained the principle of inflammability; in the antiphlogistic doctrine, most of them have been accounted for by imagining the position or transfer of oxygene: but all the later researches seem to shew that no *peculiar* substance, or form of matter is necessary for the effect; that it is a *general* result of the actions of any substances possessed of strong chemical attractions, or different electrical relations, and that it takes place in all cases in which an intense and violent motion can be conceived to be communicated to the corpuscles of bodies.

2. Many bodies which have not yet been decompounded, and which cannot well be conceived to contain oxygene, produce heat and light by their mutual chemical action: such are some metallic substances, potassium, for instance, in combining with arsenic and tellurium; and sulphur and certain metals become ignited during their union. In naming a class of bodies by their relations to combustion, or to

their efficacy in producing the phænomena of fire, it is only intended to signify that the production of heat and light is more characteristic of their actions, than those of any other substances; and they are likewise opposed to all other undecompounded substances by their electrical relations, being always in Voltaic combinations attracted to, or elicited from the positive surface; whereas all other known undecompounded substances are separated at the negative surface. Only two undecompounded empyreal substances have been as yet discovered. They will be described, and their actions on each other discussed in the two following sections.

II. *Of Oxygene Gas.*

1. *Oxygene* gas was discovered by Dr. Priestley, in August, 1774. To procure it, a quantity of manganese (a mineral substance found in abundance near Exeter, and in many other places) is introduced into a glass retort furnished with a ground stopper, a quantity of oil of vitriol (sulphuric acid) sufficient to moisten the manganese, is added, and they are mixed together by means of a glass rod; the bottom of the retort is then gently heated by means of a lamp, and the extremity of its neck introduced under an inverted cylinder filled with water in the hydro-pneumatic apparatus*. Globules of gas will soon rise through the water; the first portions collected must be thrown away, being principally the common air contained in the retort; when a quantity equal to the capacity of the retort has been thus disposed of, the remainder may be preserved for use.

There are many other modes of obtaining oxygene gas; the same manganese heated to redness in an iron tube, such as a gun-barrel, the touch-hole of which is closed, will afford a considerable quantity of the substance, which may be collected by means of a tube fastened into the neck of the barrel, and having its extremity in the hydro-pneumatic apparatus†.

Nitre heated strongly in a porcelain retort, gives off oxygene gas; puce-coloured, or red oxide of lead offers a similar result; and from any of the salts called hyperoxymuriates, oxygene is procured by a

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* See Plate IV. fig. 23.

† See Plate IV. fig. 24.

dull red heat; a retort of glass may be employed in the process; and a charcoal fire in a small chaffing-dish.

100 grains of the hyperoxymuriate of potassa, afford about 114 cubical inches of oxygene gas, under common circumstances.

The oxygene gas procured from nitre and the metallic substances above mentioned, is mixed with larger or smaller quantities of other permanent gaseous matter; the gas from hyperoxymuriate of potassa is free from such adulteration, and when collected over mercury, contains nothing but aqueous vapour, from which it may be purified by means of the salt called dry muriate of lime, or by sticks of common potash. The elastic fluid from nitre contains more foreign gaseous matter than that from the metallic oxides. The gas from manganese and sulphuric acid, when collected in the mercurial apparatus, seldom affords more than $\frac{1}{50}$ of adulteration; when collected over water, it is mixed with from $\frac{1}{20}$ to $\frac{1}{30}$, in consequence of mixture with the common air expelled from the water.

The degree of purity of oxygene gas produced in these modes, is easily ascertained by filling a small curved tube closed at one end, with mercury, and passing into it some of the dry gas, so as to occupy about $\frac{1}{4}$ of its capacity, which is measured; a bit of phosphorus in the proportion of half a grain to a cubical inch of gas, is introduced and made to pass into the curved part of the tube; the phosphorus is inflamed by the application of the heat of a spirit lamp; at the moment of the expansion of the gas, the open extremity of the tube is closed under the mercury by the finger, and heat is applied till no light can be perceived in the tube; when the tube is cool the finger is taken off. The mercury will instantly rise into the tube; all the oxygene will have been absorbed, and the gas remaining, when measured and compared with the original quantity, will indicate the impurity.

2. Oxygene gas is distinguished from all other gaseous matter by several important properties.

Inflammable substances burn in it under the same circumstances as in common air, but with infinitely greater vividness.

If a taper, the flame of which has been extinguished, the wick only remaining ignited, be plunged into a bottle filled with it, the flame will be instantly rekindled, and will be very brilliant, and accompanied by a crackling noise.

If a steel wire, or thin file, having a sharp point, armed with a bit of wood in inflammation, be introduced into a jar filled with the gas, the steel will take fire, and its combustion will continue producing a most brilliant phænomenon.

The specific gravity of oxygene gas has been already referred to, page 63; it is to that of hydrogene gas, as 15 to 1; 100 cubical inches under an atmospherical pressure equal to that of 30 inches of mercury, and at the temperature of 60° Fahrenheit, weigh about 34 grains. Its power of refracting light, is stated by Biot and Arago to be to that of hydrogene, nearly as 1958 to 1000. Its capacity for heat, according to Dr. Crawford, is nearly as 4.7 to 21.4.

Oxygene gas is slightly absorbable by water. From Dr. Henry's experiments, it appears that this fluid takes up $\frac{1}{27}$ of its bulk at 60° Fahrenheit, whatever be the density of the gas.

Oxygene gas is respirable; a small animal confined in a jar filled with this gas, lives four or five times as long as in an equal quantity of common air;—hence it has been called vital air.

3. The proportion in which oxygene gas unites to bodies, has been referred to, page 63, and the number representing it may be considered as 15; various elucidations of the correctness of this conclusion, will be found in the following pages.

4. Oxygene gas forms the most important part of our atmosphere. It is easy to prove this by many very simple experiments.

If phosphorus be inflamed in a tube half filled with atmospherical air, in the same manner as in the experiment for ascertaining the purity of oxygene, a quantity of elastic matter will be absorbed equal to about one-fifth of the volume of the confined air, and the same substance will be produced as that formed by burning phosphorus in oxygene: the remaining elastic fluid will not support flame, and animals will not live in it; it is called azote or nitrogene gas; and if four parts of it be mixed with about one part of pure oxygene gas, they constitute a mixture resembling exactly atmospheric air. That the oxygene obtained artificially is the same chemical substance as that found in the air, is proved by the phænomena of the calcination of mercury. If running mercury be preserved in a heat at which it boils slowly, in a retort, the beak of which is plunged in mercury, and the process be continued for some days, there will be a gradual diminution of the air, and after a certain time, the remainder will not support flame, and a part of the mercury will be found converted into a red powder. It will have gained in weight, as much as the air has lost; and the red powder, if heated to ignition, will give off a quantity of oxygene, that, added to the residual elastic substance, will reconstitute common air, and it will be restored to the state of mercury. And this oxygene, if a part of it be compared with the oxygene procured in other modes from mineral substances, or artificial compounds, is found in no respect different; its specific gravity, refractive power, and chemical properties, are precisely identical.

There have been several substances proposed for ascertaining with facility the quantity of oxygene in air; they have been called eudiometrical substances; and the instruments in which they have been employed, are named eudiometers. The solution obtained by water from sulphur and pearl ashes, or sulphur and lime that have been fused together, slowly absorbs oxygene; a solution of tin in muriatic acid, has a similar property; and likewise solutions of iron, into which nitrous gas has been passed till they become coloured. A tube of glass graduated to 100 parts, forms a good eudiometer; and when filled with air, it is plunged into any solution that will absorb oxygene, and suffered to remain there, till the process is complete.

It was formerly supposed that there are great differences in the quantity of oxygene in air, in different places, and at different times; but all late researches shew that this opinion is erroneous.

Air, analysed in different quarters of the globe, in cities, and in the country, on sea and land, has been found not perceptibly different in composition; the accurate proportions of oxygene and azote are 21 and 79.

It has been shewn by the experiments of Dr. Priestley, Mr. Dalton, and M. Berthollet, that different elastic fluids have a tendency to rapid equable mixture, even when at rest, and exposed to each other on small surfaces only; and the mixture of the parts of the atmosphere is constantly assisted by winds, by currents of air, and by all the motions taking place on the surface of the earth.

5. In all processes of combustion in the atmosphere, oxygene is either fixed in the combustible body, or it dissolves it, or forms a new compound with it. In respiration, as will be more fully explained in the last part of this work, the volume of air is not changed: but a part of its oxygene disappears, and an equal bulk of carbonic acid gas is found in its place.

As the constitution of the atmosphere constantly remains the same, it is evident that there must be some processes in nature, by which a quantity of oxygene is produced equal to that consumed. One principal cause of the renovation of oxygene appears to be in the process of vegetation; healthy plants exposed in the sunshine, to air containing small quantities of carbonic acid gas, destroy that elastic fluid and evolve oxygene gas; so that the two great classes of organized beings are dependent upon each other. Carbonic acid gas, which is formed in many processes of combustion, as well as in respiration, if not removed from air, by its excess would be deleterious to animals, but it is a healthy food of vegetables; and vegetables produce oxygene, which is necessary to the existence of animals, and thus this part of the œconomy of nature is preserved, by the very functions to which it is subservient; and the order displayed in the arrangement, demonstrates the intelligence by which it was designed.

6. No other forms of matter have been produced from oxygene by any processes to which it has been submitted; but it readily enters into combination, and no substance is more active as a chemical agent. It is known to be a constituent part of most of the acids and earths, and of all the alkalies except one, and the history of its compounds forms the most extensive and important part of modern chemistry.

Its operations, as will be seen hereafter, are connected with many of the arts; with the processes of bleaching, dyeing, colour-making, and metallurgy; and in its various applications to the production of fire, it is absolutely essential to cultivation, and to the comforts and enjoyments of social life.

In the phænomena of nature, it occasions a wonderful diversity of effects. It is active in most of the changes taking place on the surface of the globe, and its constant tendency is to unite different substances in forms adapted for the purposes of organized life.

II. *Chlorine, or oxymuriatic Gas.*

1. This elastic substance was discovered by Scheele in 1774. It may be procured in the hydro-pneumatic apparatus, by a process very similar to that first described in the last section for procuring oxygene gas, but the manganese is to be mixed with common salt, and the oil of vitriol diluted with an equal quantity of water. The best proportions are three parts of common salt in weight, one part of manganese finely powdered, and two parts of oil of vitriol; instead of manganese, red oxide of mercury, or puce-coloured oxide of lead may be used, and instead of the common salt, and oil of vitriol, a solution of muriatic acid in water (spirits of salt. C.).

2. *Chlorine* is of a yellowish green colour, and it is this property which suggested its name*. Its odour is extremely disagreeable. It is not capable of being respired, and even when mixed, in very small quantities, with common air, renders the air extremely pernicious to the lungs.

Its specific gravity is to that of hydrogene, nearly as 33.5 to 1, and 100 cubical inches of it weigh at mean temperature and pressure between 76 and 77 grains.

It is absorbable to a certain extent by water: at the temperature of 60° Fahrenheit, water dissolves about double its volume, and acquires a strong acrid taste, and a disagreeable smell.

When an inflamed taper is introduced into a phial filled with it, the light continues, but of a dull red colour, and a dark carbonaceous smoke rises from the flame.

Many of the metals introduced into it in thin filaments, or leaves, or powder, take fire, and burn spontaneously at common temperatures; such are copper, tin, arsenic, zinc, antimony, and the alkaline metals.

Phosphorus burns in it spontaneously, with a pale white light, producing a white volatile powder.

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* χλωρος, green.

Sulphur melted or sublimed in it, does not burn, but forms with it a volatile red liquor.

The gas does not change by any action of heat or cold; but its aqueous solution freezes more readily than water, namely at about 40° Fahrenheit.

When freed from vapour by muriate of lime, the gas does not act upon perfectly dry substances tinged with vegetable colours; but when moisture is present in the gas or the coloured bodies, their colours are speedily destroyed, they are rendered white, or brought to a dull yellow; and this last tint is almost the only one not changed by the combined action of water and chlorine.

3. Chlorine and oxygene are capable of existing in combination, and they form a peculiar gaseous matter. They do not unite, when mixed together, but when existing in certain solids, they may be detached in union.

To make the compound of chlorine and oxygene, hyperoxymuriate of potassa is introduced into a small retort of glass; and twice as much muriatic acid as will cover it, diluted with an equal volume of water. By the application of a gentle heat, the gas is evolved, and it must be collected over mercury.

I discovered this elastic substance in its pure form in January, 1811, and gave to it the name of Euchlorine*, from its bright yellow-green colour.

Its tint is much more lively than that of chlorine, and more inclined to yellow.

Its smell is very different, being not unlike that of burnt sugar.

It is not respirable.

It is soluble in water, to which it gives a lemon colour; water takes up 8 or 10 times its volume.

Its specific gravity is to that of hydrogene, nearly as 33 to 1. 100 cubical inches weigh at mean temperature and pressure between 74 and 75 grains.

It must be collected and examined with great care, and only in small quantities at a time; a very gentle heat causes it to explode,

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* Ευ and χλωρος.

sometimes even the heat of the hand; and its elements separate from each other with great violence, producing light.

From the facility with which euchlorine decomposes, it is not easy to ascertain the action of combustible bodies upon it. None of the metals that burn in chlorine, act upon this gas at common temperatures; but when the oxygen is separated, they then inflame in the chlorine. It is easy to witness this. Let a little Dutch foil be introduced into a bottle filled with euchlorine, it will undergo no change, and will not even tarnish. Let a heated glass tube be applied to the gas in the neck of the bottle, a decomposition will take place, and the oxygene and chlorine will be detached from each other, and at the same moment the foil will inflame, and burn with great brilliancy.

Chlorine is rapidly absorbed by mercury; euchlorine has no action upon it, and chlorine may be separated from euchlorine, by agitation over mercury, and the last obtained pure.

When phosphorus is introduced into euchlorine, it is instantly decomposed, and the phosphorus burns as it would do in a mixture of 2 parts in volume of chlorine, and one part of oxygene.

The inflamed taper, and inflamed sulphur, instantly decompose it, and exhibit the same phenomena as in a mixture of two parts of chlorine, one part of oxygene.

That the gas is actually composed of these elements, is shewn by causing it to detonate in a glass tube over pure mercury. It loses its brilliant colour, and becomes chlorine and oxygene. 50 parts treated in this way, expand so as to become about 60 parts, which consist of 40 parts of chlorine, and 20 parts of oxygene.

When euchlorine freed from water, is made to act upon dry vegetable colours, it gradually destroys them, but first gives to the blues, a tint of red; from which, and its absorbability by water, and the taste of its solution, which is strongly acrid approaching to sour, it may be considered as approximating to an acid in its nature.

4. The proportion in which chlorine combines with bodies, may be learnt from the decomposition of euchlorine; the oxygene in which is to the chlorine, as 15 to 67 in weight. If euchlorine be considered as consisting of one proportion of oxygene to one of chlorine, then 67 will be the number representing chlorine, which is most convenient, as being a whole number. If euchlorine be sup-

posed to contain two proportions of chlorine and one of oxygene, then the number representing chlorine will be 33.5. It will hereafter be shewn that whichever of these data be assumed, the relations of the number will harmonize with those gained from various other combinations.

5. Scheele considered chlorine as an element of the muriatic acid, and hence called it dephlogisticated marine acid. By that chemist, it was regarded as an undecompounded body.

Lavoisier and Berthollet asserted that it was a compound of muriatic acid gas, and oxygene. This idea is now universally given up; but some chemists in France and Scotland, conceive that it is a compound of oxygene, and an unknown body, which they call dry muriatic acid. The weight of chlorine, its absorbability by water, its colour, and the analogy of some of its combinations to bodies, known to contain oxygene, are arguments in favour of its being a compound; and it is possible that oxygene may be one of its elements, or that oxygene and chlorine are similarly constituted. I have made a number of experiments with the hopes of detecting oxygene in it, but without success; none of its compounds with inflammable bodies or metals will afford this principle; charcoal intensely ignited in it, undergoes no change, nor is it altered by the strongest powers of electricity. Should oxygene ever be procured from it, some other form of matter, possibly a new one, will at the same time be discovered, as entering into its constitution, and till it is decompounded, it must be regarded, according to the just logic of chemistry, as an elementary substance*.

6. Chlorine has never been found pure in nature; but exists in many compounds, particularly in common salt, as is evident from the mode of its production from that substance. It is a substance of

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* M. M. Gay Lussac, Thenard, and Curaudau, since 1808, have laid claim to the ideas of oxymuriatic gas being a simple body, and of muriatic acid gas being composed of this substance and hydrogene. But these opinions were started by the illustrious discoverer of the gas, in 1774. In the papers in the Philosophical Transactions in which I have endeavoured to shew that it is a peculiar acidifying and solvent principle, I have merely followed and extended his views, and I referred to them in the first paper I published on the subject.

considerable importance in its relation to the art of bleaching, an application first made by the sagacity of M. Berthollet.

In the ancient process of bleaching, the cloths of linen and cotton, after being treated with alkaline lixivia, to free them from resinous and oily matters, and in some cases with very diluted oil of vitriol, to cleanse them from stains produced by iron, were exposed upon grass to dew and air, and some weeks, or even months, were required to give them their perfect whiteness.

By a warm solution of chlorine in water, they are bleached in a very short period; but their texture is injured; for at the same time that oxygene is added to the colouring matters, muriatic acid gas is formed and dissolved in the water, which corrodes the vegetable fibres.

The gas has been condensed in alkaline lixivia, and in lime water. The substance called oxymuriate of lime is commonly used for bleaching; but though the solution of this substance does not injure so much as that of the gas, yet it tends to weaken the texture of linen.

I have found that the fluid produced by the condensation of the gas in water containing magnesia diffused through it, bleaches without injuring the vegetable fibre. It acts much more slowly and gradually than any of the other compounds employed for the same purpose, and has been applied at my suggestion in Ireland, within the last few months*, with success, in whitening printed calicoes, and, when properly used, it does not destroy even reds or yellows fixed by mordants. Magnesia may be easily procured from sea-water, or from the residual liquor of salt works; and there is a probability that this new bleaching fluid may, at no very distant period, come into common use.

M. Berthollet supposed that chlorine destroyed colours by parting with its oxygene; the new experiments shew that the oxygene is derived from the water, which is decomposed by double affinity; that of hydrogene for chlorine, and of the colouring matters for oxygene.

The salts which are called hyperoxymuriates, and oxymuriates, are compounds of metallic bodies with chlorine and oxygene; and the

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* By Mr. Duffy of Dublin, a very enlightened calico-printer.

oxygene is held in them by a very weak attraction, and therefore is easily given off to colouring or inflammable matters.

The great circumstance, in bleaching with these compounds, is that the salt remaining after the abstraction of oxygene, should not act upon the linen; linen boiled in a strong solution of the salt called muriate of lime, the substance remaining in the solution, when oxymuriate of lime is used, I have found is considerably weakened. Solution of muriate of magnesia has no action of this kind, and therefore the new bleaching liquor can hardly be injurious to the manufacture.

These general views respecting chlorine, and the uses and mode of agency of the combinations of chlorine and oxygene, will be found to be confirmed by a number of statements, to be given in the progress of this work. Certain conclusions have been anticipated,—but the most important application of chlorine could not with propriety be separated from its history, as an undecompounded body, though depending upon its power of detaching oxygene, which appears to be the true bleaching principle, from compounds.

DIVISION IV.

OF UNDECOMPOUNDED INFLAMMABLE OR ACIDIFEROUS SUBSTANCES NOT METALIC, AND THEIR BINARY COMBINATIONS WITH OXYGENE AND CHLORINE, OR WITH EACH OTHER.

I. *Preliminary Observations.*

THE bodies to be considered in this division, are six, hydrogene, azote, sulphur, phosphorus, carbon, and boracium or boron. Amongst these, hydrogene is distinguished from all the rest by very singular properties. Sulphur and phosphorus are the most analogous to each other. All these substances are capable of combining with oxygene, and all except azote and charcoal, with chlorine. They are separated in Voltaic combinations, at the negative surface, and in their electrical relations, as well as chemical powers, are opposed to oxygene and chlorine.

II. *Hydrogene Gas, or inflammable Air.*

1. This elastic substance was first examined in its pure form, by Mr. Cavendish, in 1766.

It may be procured in the hydropneumatic apparatus from zinc or iron filings, by means of oil of vitriol diluted with 8 times its weight of water; a retort, or a bottle furnished with a tube may be used; no artificial heat is required in the process. It may likewise be produced by passing steam over turnings of iron heated to redness in a gun-barrel.

2. *Hydrogene* is distinguished from all other gaseous bodies, by its extreme lightness. The relation of its weight to that of oxy-

gene and air, has been already stated. 100 cubical inches of it at mean temperature, and pressure, weigh about two grains and a quarter.

It is very slightly absorbable by water; that fluid takes up $\frac{1}{50}$ only of its volume.

Hydrogene gas has no taste, a slight but disagreeable smell. It is capable of being taken into the lungs, but cannot be breathed by man, for more than a minute. Small animals die in it in a much shorter time.

When an inflamed taper is plunged into a long narrow jar filled with hydrogene, and opened in the atmosphere, it is extinguished; but the gas takes fire, and burns in contact with the atmosphere.

One part mixed with two or three parts of air explodes violently by the action of an inflamed body, or an electrical spark.

3. Hydrogene gas, as has been stated, combines with oxygene gas, and to this circumstance its inflammation in the air is owing. If the two gasses be pure, *water* is the only result, and the proportions are 2 of hydrogene to 15 of oxygene in weight, or 2 to 1 in volume.

The union may be effected by the electric spark as described in page 58, over mercury, or the hydrogene may be introduced into a vessel full of oxygene through a narrow tube, by means of pressure, and inflamed by electricity, or the oxygene may be made to burn in the hydrogene in a similar manner*. When a stream of oxygene is thrown into a stream of inflamed hydrogene, the heat produced is very intense, and far exceeds the highest heat of our furnaces, and may be used to fuse bodies, intractable by any other fire raised by combustion.

The nature of water may be shewn synthetically as well as analytically.

It is separated into 2 of hydrogene in volume and 1 of oxygene in the Voltaic circuit; the oxygene appears at the positive, the hydrogene at the negative metallic surfaces; and by means of platina wires, hermetically sealed into glass tubes, the products are collected.

When 10 grains of the metal called potassium are added to about 2 grains of water in a glass tube, there is a violent action, much

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* See Plate V. fig. 25.

hydrogene is disengaged, and by heating the results, the operation is completed. The same effect is produced upon the potassium, as would be produced by heating it strongly in contact with a small quantity of oxygene; it becomes united to oxygene, and its increase of weight is in proportion to the weight of the hydrogene, as 15 to 2.

It will be needless to dwell upon the properties of water; it is scarcely ever found in nature pure, usually holding saline or gaseous matters in solution. It becomes solid at 32° Fahrenheit, and elastic at 212°, and in the state of steam has been applied for the production of the most important mechanical effects in the steam engine.

To describe the uses of water in the operations of nature, or to point out its applications to the purposes of the arts, and common life, would demand a volume. Animals and vegetables depend upon it for their existence. Water occupies nearly two-thirds of the surface of the globe; and whether existing in the ocean united to salts, or in the atmosphere as vapour, or poured down upon the surface as rain, dew, hail or snow, or collected in lakes, rivers, and springs, its effects are constantly connected with the order of the œconomy of our system.

4. Hydrogene and chlorine unite with still more readiness than hydrogene and oxygene. To make the combination, as has been stated page 62, it is only necessary to expose a mixture of equal parts of the two gasses to common day light, over dry mercury, or in a vessel furnished with a stop cock previously exhausted. In a certain time, the chlorine will have lost its colour, and have combined with the hydrogene. If the gasses have been freed from aqueous vapour, there will be no notable condensation, and the result is a peculiar elastic fluid, *muriatic acid gas*. By exposure to direct solar light, as has been stated before, they explode; they likewise explode by the electrical spark; the results in this case, as I have found, are the same, 1 in volume of hydrogene unites to 1 in volume of chlorine, or 1 in weight to 33.5.

The nature of muriatic acid gas may be proved by analysis, as well as synthesis. If some pure grain tin be kept melted for some time, in a little curved tube containing muriatic acid gas over dry mercury, the tin will be converted into the same substance as that produced by its direct action upon chlorine, Libavius's liquor, and the hydrogene gas, when accurately measured, will be found to be equal to one-half the volume of the muriatic acid gas.

Those persons who suppose chlorine to be a compound of an unknown body, and oxygene, conceive muriatic acid gas to be a compound of $\frac{1}{4}$ of its weight of water, and the same hypothetical substance; but as no oxygene has yet been shewn to exist in chlorine, so no such combined moisture has been proved to exist in muriatic acid gas. It contains minute quantities in the vapour of hydrated muriatic acid; but no water except this can be procured from it, unless by substances that contain oxygene; and the quantity produced, is exactly proportional to the oxygene contained in the substance, and the hydrogene in the muriatic acid gas, and the other result is the same as the substance combined with the oxygene would produce *directly* by its action upon chlorine.

Five grains of red oxide of mercury, heated to redness, gave off a cubical inch, and $\frac{1}{8}$ of oxygene gas. Five grains of the same substance were made to act on muriatic acid gas by a spirit lamp in a curved tube over mercury; corrosive sublimate was formed, and water which absorbed muriatic acid gas, and 5 cubical inches of muriatic acid gas disappeared; and of these 4 cubical inches, and $\frac{1}{2}$ at least, must have been decomposed by the oxide of mercury, their chlorine united to the metal, and their hydrogene to the oxygene; and the additional half a cubic inch, as will appear from the facts about to be stated, is nearly the quantity that ought to be obsorbed by the water; the barometer in this experiment stood at 30.3; the thermometer at 54° Fahrenheit. Corrosive sublimate is produced by the direct combination of mercury and chlorine; and the result of this experiment can only be logically explained, on the idea of muriatic acid gas being composed of hydrogene and chlorine.

For the purpose of experiments, muriatic acid gas is procured by the action of oil of vitriol on certain salts, such as common salt, or sal ammoniac. It rises without the application of heat, when the substances are mixed together; a glass retort should be used with a ground stopper, the salt should be in large pieces, not in powder, and some bibulous paper should be introduced into the neck of the retort, to prevent any fluid acid from soiling the mercury, over which it must be collected.

Muriatic acid gas instantly extinguishes flame. It reddens dry litmus paper. When suffered to pass into the atmosphere, it produces a white smoke by uniting to the aqueous vapour in the air. Its taste is intensely acid. Its smell, pungent and disagreeable.

The specific gravity of muriatic acid gas is to that of hydrogene, nearly as 17 to 1; 100 cubical inches of it weighs at mean temperature and pressure, between 39 and 40 grains. Muriatic acid gas is rapidly absorbed by water; at the temperature of 40° Fahrenheit, water absorbs about 480 times its bulk of gas, and forms solution of muriatic acid gas in water, the specific gravity of which is 1.2109.

The table which follows, exhibits the quantity of muriatic acid gas in solutions of different specific gravities constructed after experiments made at my request by Mr. E. Davy, in the laboratory of the Royal Institution[*], the results of which I witnessed.

At temperature 45° Fahrenheit.   Barometer 30.

100 parts of solution of muriatic acid gas in water of specific gravity.		Of Muriatic acid gas, parts.
1.21	Contain	42.43
1.20		40.80
1.19		38.38
1.18		36.36
1.17		34.34
1.16		32.32
1.15		30.30
1.14		28.28
1.13		26.26
1.12		24.24
1.11[*]		22.3
1.10		20.20
1.09		18.18
1.08		16.16
1.07		14.14
1.06		12.12
1.05		10.10
1.04		8.08
1.03		6.06
1.02		4.04
1.01		2.02

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[*] 47.25 grains of water at 43° Fahrenheit, barometer being at 30.2, absorbed 34.8 grains of gas, and formed a solution of specific gravity, 1.21, and the whole precipitated by nitrate of silver, afforded about 132 grains of dry horn silver.

The compound of water, and muriatic acid gas existing in vapour in muriatic acid gas, alluded to page 106, is probably of the same constitution as the most saturated solution at the same temperature, and at 45° must contain 57.57 per cent. of water; but in common cases the quantity of this vapour is too small to influence to any extent the results of experiments on muriatic acid gas; for I found that 200 cubical inches of gas at 75° passed slowly through a thin tube of glass cooled to 10° below 0 of Fahrenheit, did not increase its weight $\frac{1}{18}$ of a grain, but the deposition of fluid was very distinct.

4. The number representing hydrogene, as is evident from the details given page 63, and those just stated, and as will appear from a number of other evidences, may be considered as unity.

5. Of all gaseous substances, hydrogene is most distinctly characterized as an element; and in its relations it is opposed to oxygene.

Its extreme lightness, and the small quantities in which it enters into combination, render it unlikely that it should be resolved into other forms of ponderable matter, by any instruments or processes at present within our power. Some extraordinary phænomena which have been explained in the idea of its being a compound, and which will be referred to towards the end of this volume, are more satisfactorily accounted for on the idea of its being simple, or at least a form of elementary matter.

Again, 57.5 grains of water at 44°, barometer being 30.1, gained nearly 38 grains by absorbing acid gas, and formed a solution of specific gravity, 1.2.

Thermometer, 49° Fahrenheit; barometer 29; 46.5 grains of water by absorbing 13.4 grains of gas gained a specific gravity of 1.114. The two last results, which are marked in the table, agree with those gained by calculation from the first experiment. When about 150 grains of the strongest solution of muriatic acid in water, were mixed with distilled water, both being at 63°, the temperature rose to 75°; so that the real specific gravity of solutions mixed with water, is probably a little greater than the mean, though to no amount that can interfere with the use of the table. To find the composition of an acid of specific gravity not marked in the table, find the difference between the two specific gravities nearest to it in the table *d*, and the difference between their quantities of gas *b*, likewise the difference between the given specific gravity, and that nearest to it, *c*, then *d* is to *b* : : *c* : *x*, which added to the quantity of the lower specific gravity, is the quantity of acid gas sought.

Hydrogene gas is employed for filling balloons, and its low specific gravity renders it well fitted for aerostatic purposes. It is an important principle in animal and vegetable bodies; and exists in larger or smaller quantities in all organized compounds. It is the body which gives the power of burning with flame to all the substances used for the œconomical production of heat and light.

III. *Of Azote, or nitrogene Gas.*

1. *Azote* was discovered by Dr. Rutherford in 1772. It may be procured by extracting oxygene from common air, in the manner described page 130. It is formed directly by dissolving animal matters, such as glue or muscular fibre, in diluted acquafortis, or fuming nitrous acid mixed with ten or twelve times its weight of water. It may be collected over water.

Azote extinguishes flame. It is very slightly absorbable by water; that fluid, according to Dr. Henry's experiments, takes up only $\frac{1}{75}$ part of its volume. Its specific gravity, as was mentioned in page 63, is to that of hydrogene as 13 to 1. 100 cubical inches of it, at mean temperature and pressure, weigh between 29 and 30 grains. According to Biot and Arrago, its refractive power is 58976.

Its capacity for heat, according to Dr. Crawford, is .7936.

2. There are several compounds containing azote and oxygene in different proportions; three of which have been already referred to, page 63. Their nature is more easily demonstrated by analysis than synthesis; though the most important of them, nitrous acid, in its union with water, may be made by the direct combination of azote and oxygene with that fluid.

Dr. Priestley ascertained that acid matter was formed by passing electrical sparks through a mixture of azote and oxygene over water, and Mr. Cavendish, by a series of beautiful experiments, proved that the two gasses combined with the water, and formed the same acid as that procured from nitre by oil of vitriol. The other compounds of azote and oxygene are always formed from the decomposition of this acid, or some of its compounds; but as *nitrous acid* exists in different states, its properties will be best understood after the more simple combinations of azote and oxygene have been described.

3. *Nitrous oxide*, the compound containing the smallest quantity of oxygene, was discovered by Dr. Priestley in 1772, and named by him dephlogisticated nitrous air.

It is a gaseous body, which, as has been stated, page 59, may be produced by heating nitrate of ammonia; a glass retort is employed to contain the salt; the flame of an Argand lamp is sufficient to produce the gas. It may likewise be obtained during the solution of zinc in very weak nitric acid; but in this case it is not pure.

Nitrous oxide may be preserved over water; but it is absorbed by this fluid, which takes up $\frac{9}{10}$ of its volume nearly, and, for accurate experiments, it should be collected in the mercurial apparatus.

Its degree of purity may be learnt from the quantity absorbed by water.

Nitrous oxide exhibits the following properties. A taper, plunged into it, burns with great brilliancy, and the flame gradually becomes surrounded with a blueish halo. Phosphorus may be melted and sublimed in it without inflaming; but, when introduced into it in a state of vivid combustion, the brilliancy of the flame is greatly increased. Sulphur, and most other combustible bodies, require a higher degree of heat for their combustion in it than they require in oxygene, or in the atmosphere.

Its specific gravity, according to my experiments, is to that of hydrogene, nearly as 21 to 1. A hundred cubical inches of it at mean temperature and pressure, weigh between 48 and 49 grains.

Its taste is sweetish, its odour slight but agreeable.

It is respirable, but not fitted to support life. I ascertained, in 1799, that, when it was respired, it produced effects analogous to those produced by drinking fermented liquors,—usually a transient intoxication, or violent exhilaration. Individuals that differ in temperament are, however, as might be expected, differently affected.

The nature of nitrous oxide is shewn by the experiment referred to, page 59. One in volume of this gas is decomposed by one volume of hydrogene, water is formed, and one in volume of azote remains.

Or, if well-burnt charcoal be inflamed in a volume of it, by a burning glass, one in volume of it affords as much carbonic acid as half a volume of oxygene, and when this carbonic acid is absorbed, a volume of azote remains; so that it consists of 26 in weight of azote, and 15 of oxygene.

4. *Nitrous gas* was noticed by Dr. Hales, but its properties as a specific elastic fluid were first described by Dr. Priestley, in 1772; it is procured during the solution of various bodies in nitric acid; sugar, silver, mercury, copper, bismuth, afford it very readily. Filings of copper are usually employed; and a retort, or a bottle having a tube inserted into it is used; the acid (if the common acid of commerce) should be diluted with 6 or 8 times its weight of water; the production of the gas may be assisted by a gentle heat.

It may be collected over water, which absorbs only about $\frac{1}{20}$ of its volume; but for accurate purposes, mercury should be employed.

The degree of purity of nitrous gas may be known by agitating it in contact with an aqueous solution of green sulphâte of iron. Nitrous gas is quickly absorbed by this substance.

When a jar of nitrous gas is opened in the atmosphere, red fumes appear. When an inflamed taper is plunged into it, the light is instantly extinguished.

Inflamed sulphur is extinguished by it; but inflamed phosphorus burns in it with great brilliancy. It cannot be made to detonate when mixed with hydrogene, by the electric spark.

Its specific gravity is to that of hydrogene, as 14 to 1. A hundred cubical inches of it weigh about 32 grains.

Whether it is respirable, or has taste or smell, cannot be ascertained, as it instantly unites with the oxygene in air, producing red fumes, which are nitrous acid gas.

The composition of nitrous gas has been already referred to, page 59.

It is decomposable by several of the metals when they are heated in it, such as arsenic, zinc, potassium in excess; it oxidates them, and affords half its volume of azote. In an experiment in which I decomposed a small quantity, by igniting charcoal in it by a burning glass, I found that it afforded about half a volume of carbonic acid*, and half a volume of azote; so that it consists of 26 of azote to 30 of oxygene.

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* See page 58.

When it is exposed to certain bodies, such as the salts called sulphites, solution of tin in muriatic acid, or solutions of alkaline sulphurets, it is converted into nitrous oxide ; I have found that, in accurate experiments of this kind, two in volume of nitrous gas become one in volume of nitrous oxide ; a circumstance harmonizing precisely with their relative proportions of oxygene and nitrogene.

5. It has been mentioned that the red fumes, produced by the action of oxygene and nitrous gas, are owing to the production of *nitrous acid gas.*

It is not easy to ascertain the exact nature of this change, as the substance formed acts both upon mercury and upon water; and over water very different proportions of the gasses may be made to condense each other. When large quantities of nitrous gas are added to small quantities of oxygene, in vessels of large diameter, from two to three in volume of nitrous gas disappear for one of oxygene. When large quantities of oxygene are added to small quantities of nitrous gas in narrow tubes, the absorption is from 1 to 1.5 of oxygene in volume, and 2 of nitrous gas. From a series of experiments on the decomposition of nitre, and others on the mixture of nitrous gas and oxygene, executed with great care in exhausted vessels furnished with glass stop-cocks, I am inclined to believe that the acid obtained over water by the condensation of mixtures of nitrous gas and oxygene is never fully saturated with oxygene, and that the pale fluid called nitric acid consists of water united to two in volume of nitrous gas, and one and a half of oxygene ; and this acid, according to its different degrees of dilution, may be made to absorb different quantities of nitrous gas, when it becomes yellow, orange, blue, or blueish green ; and in this last state it is saturated with nitrous gas.

When two of nitrous gas, and one of oxygene freed from moisture, are mixed together in a vessel previously exhausted of air, they become condensed to about one half of their volume, and form a deep orange-coloured elastic fluid, which may be called *nitrous acid gas.*

This substance has the following properties : a taper burns in it with considerable brilliancy. Sulphur inflamed does not burn in it; but the combustion of phosphorus continues with great vividness.

Tin, copper, and mercury act upon it slowly ; iron ignited to whiteness is rapidly cooled in it.

Charcoal inflamed continues to burn in it with a dull red light.

When a portion of water is exposed to it, there is a rapid absorption, and the water gains a tint of green.

Its smell is very disagreeable, its taste sour; when applied to animal substances, it renders them yellow; it reddens litmus paper.

Calculating from the condensation, the specific gravity of nitrous acid gas is to that of hydrogene, as about 28 to 1; and 100 cubical inches of it weigh 65.3 grains, at mean temperature and pressure.

6. I have attempted to procure a permanent elastic fluid, consisting of two parts in volume of nitrous gas, and 1.5 oxygene, by mixing oxygene in excess with nitrous gas; but the condensation was always such as to indicate the formation of nitrous acid gas, and the colour was deep orange; so that the existence of nitric acid as a *pure body*, consisting of 1.5 of oxygene and 2 of nitrous gas, is problematical; the gaseous combination of nitrous gas and oxygene probably always contains 2 of nitrous gas, and 1 of oxygene; and some basis seems necessary for the union of two of nitrous gas and 1.5 of oxygene; such as water, alkalies, or oxides.

M. Gay Lussac supposes that there is a compound of three of nitrous gas*, and one of oxygene, capable of combining with water and alkalies without decomposition. I have tried many experiments on this subject, but have never been able to make a strong coloured aquafortis containing more than 2 of nitrous gas to 1 of oxygene in volume; when nitrous acid gas is passed into alkaline solutions, a portion of nitrous gas is always evolved; and when one in volume of oxygene is added to two of nitrous gas, and dry azote introduced to mark the condensation, no change takes place on the mixture of the gas with fresh portions of dry nitrous gas.

Aquafortis, or *nitric acid*, is procured for the purposes of chemistry by the distillation of nitre and oil of vitriol; about 2 parts of nitre should be used to 1 part of oil of vitriol, and the retort heated in a sand bath connected with a receiver kept cool by moistened cloths.

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* It is stated that this combination can only be made over a large surface of water, which shews either that the air in the water is concerned in the condensation, or that the water itself absorbs nitrous gas: the *size* of the vessel can have no influence on the compound formed, and it is supposed by M. Gay Lussac, readily absorbable by water. Mem. D'Arcueil, T. II. page 241.

The acid thus obtained is usually coloured, but becomes pale by exposure to air. If the nitre is dry, its specific gravity is from 1.520 to 1.55. This substance acts with great violence on all the metals anciently known, except gold and platina, and causes volatile oils to inflame. When it is passed through a porcelain tube heated to redness, oxygene is given off from it, and nitrous acid gas; and the same effect is produced upon the residual acid, as if it had been mixed with water; so that it is proved by this experiment to be composed of nitrous acid gas, oxygene and water; and 4 in volume of nitrous gas, and 2 of oxygene gas condensed in water, I find, absorb 1 in volume of oxygene to become nitric acid.

7. To enter upon a description of all the experiments that have been made to ascertain the quantities of water in acids of different strengths, would be unfitted to the nature of an elementary treatise.

From my own experiments compared with those of Kirwan, Wenzel, and Berthollet, I am inclined to believe that the strongest acids contain from 14 to 15 per cent. of water, and according to the principles of the French nomenclature, they ought to be called *hydronitric acids*.

Aquafortis, or hydro-nitric acid, when its specific gravity is below 1.4, strengthens by being boiled; when stronger than 1.45, it becomes weaker by boiling. According to Mr. Dalton, the acid of 1.42 distills unaltered at 248° Fahrenheit. It is probable that the acid of 1.55 consists of one proportion of water and one of acid, and that which rises unaltered at 248° of one proportion of acid and two of water.

If nitrous gas be considered as represented by 56, that is, by one proportion of azote, and two of oxygene, 26 and 30, then nitrous acid gas will be represented by 86, or one of azote, 26, and four of oxygene, 60; and 101 will be the number for the acid contained in the pale acids, and in the salts called nitrates, and it will consist of one of azote and five of oxygene.

And the strongest acid will contain 17 water and 101 acid, and the acid of 1.42, 34 water and 101 acid.

Hydro-nitric acid is of great use in many of the common arts. It is employed in medicine, for dissolving metals, for etching, for making compounds used in dyeing, and it is one of the constituent parts of nitre, a substance essential in the manufacture of gun-powder.

8. Azote and chlorine have no chemical action on each other in any circumstances to which they have been hitherto exposed.

I caused the Voltaic flame from 1000 double plates to pass through a mixture of them in a close vessel for some minutes; but the azote underwent no change, nor was any combination effected.

9. Azote and hydrogene exist in combination in *ammonia* or the *volatile alkali.* It is not easy to produce their union, yet when azote is exposed to moist substances giving off hydrogene, a little ammonia is found after some time in the water;—for instance, when azote is placed in contact with moist iron filings above mercury. Priestley first procured ammonia in its pure form; and his experiments, and those of Scheele, repeated and illustrated in an elaborate manner by Berthollet, led to the knowledge of its elements; indeed the last chemist must be considered as the true discoverer of the composition of ammonia.

To procure ammonia, equal parts of well burnt dry lime and dry salammoniac or muriate of ammonia, are heated in a retort of glass, the beak of which is plunged under dry mercury. Gaseous matter comes over, which when the common air of the retort has been all expelled, must be collected in inverted jars filled with mercury.

Ammonia at common temperatures is a permanent gas; according to Guyton de Morveau it becomes a liquid at about 70 below 0 of Fahrenheit's scale: but his experiments were made in glass balloons, and the conclusions drawn from the appearance of fluid; so that the evidence, though strong, cannot be regarded as perfectly satisfactory, as ammonia contains vapour which must be condensed to a great extent by so intense a cold*.

The specific gravity of ammonia is to that of hydrogene, nearly as 8 to 1. 100 cubical inches of it weigh at mean temperature and pressure about 18 grains.

When an inflamed taper is plunged into a jar of ammonia the light is extinguished; but a slight inflammation of the gas occurs where it is in contact with air.

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* Annales de Chimie, XXIX. page 292.

Its taste is extremely acrid: it cannot indeed be safely applied to the organs of taste or smell except when mixed with much common air. It is the principle which gives pungency to the common concrete volatile alkali.

It instantly reddens paper tinged with turmeric, and gives a green colour to most vegetable blues and reds; and this property, and its other properties, characterise it as an alkaline body.

It is rapidly absorbed by water. At the temperature of 50°, under a pressure equal to 29.8 inches, water, I find, absorbs about 670 times its volume of gas, and becomes of specific gravity .875.

The following table containing approximations to the quantities of ammoniacal gas in aqueous solutions of different specific gravities, was constructed after experiments made with great care for the purpose.

100 parts of specific gravity.		Of Ammonia.
*8750	Contain	32.5
8875		29.25
9000		26.00
9054*		25.37
9166		22.07
9255		19.54
9326		17.52
9385		15.88
9435		14.53
9476		13.46
9513		12.40
9545		11.56
9573		10.82
9597		10.17
9619		9.60
9692*		9.50

The constitution of ammonia may be easily demonstrated by analytical experiments; it is decomposed by electrical sparks, or by being passed through a tube heated to redness; its volume is increased, and it becomes hydrogene and azote.

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[*] The three results marked by the asterisk, were gained by experiments, the other numbers by calculation.

M. Berthollet, jun. conceives that its volume is doubled when it is decomposed over mercury by electrical sparks. In Dr. Henry's experiments and those that I have made, the expansion is a little less; but this is probably owing to the unavoidable imperfection of the process. I once thought that a small quantity of water was formed in the operation, but very delicate experiments have convinced me that this is not the case. I decomposed a quantity of ammonia by electric sparks in a close vessel, in which its elements could not expand, and yet no moisture was deposited.

In the most accurate experiments in which the hydrogene has been separated from the azote by successive detonations with small quantities of oxygene, the volumes have been 3 of hydrogene to 1 of nitrogene, so that ammonia consists in weight of 3 of hydrogene and 13 of nitrogene, and supposing the number representing hydrogene unity, the same number is gained to represent azote as from the proportions of the elements in its compounds with oxygene; and ammonia consists of one proportion of azote and six of hydrogene, and is represented by 32. That all these conclusions are correct is shewn by the decomposition of the compound made from nitric acid and ammonia.

When this salt, which is called nitrate of ammonia, is exposed to a heat gradually raised, it is decomposed into water and nitrous oxide; and this could not happen unless it were constituted by definite proportions, which must be 101 of acid and 32 of alkaline matter; for 6 of hydrogene require 45 of oxygene to produce water, and 52 of azote, i. e. 26 in the acid, and 26 in the alkali, require 30 of oxygene to produce nitrous oxide.

Ammonia is employed in medicine, and its compounds are used in processes of dyeing, and in some of the metallurgical arts.

10. Azote has not as yet been resolved into any other forms of matter. I volatilized the highly combustible metal potassium in azote over mercury, and passed the Voltaic flame of 2000 double plates through the vapour; but the azote underwent no change. I have made many other attempts to decompose it, but they have been unsuccessful.

The strongest arguments for the compound nature of azote are derived from its slight tendency to combination; and from its being found abundantly in the organs of animals which feed on substances that do not contain it.

Its uses in the œconomy of the globe are little understood; this likewise is favourable to the idea that its real chemical nature is as yet unknown, and that it is not actually an undecomposable substance.

It would appear that azote and oxygene combine slowly under certain circumstances in natural operations, when lime or alkaline substances are present; thus nitrous salts are produced in nitre beds, in warm climates, and the process is assisted by, or the combination formed during the fermentation of animal and vegetable substances.

III. *Of Sulphur.*

1. Sulphur is a well known substance, found native in many parts of the world, and it may be procured by the distillation of the mineral, called pyrites.

It is brittle, moderately hard, and of a yellowish colour, and has a peculiar taste and smell. It is a nonconductor of electricity. Its specific gravity is 1990. It is often found in regular solid forms, usually octohedral, when it is more or less transparent. Its power of refracting light, according to Dr. Wollaston, is to that of water as .204 to .1336: its capacity for heat is stated to be as 1.9 to 1. It fuses at about 220° Fahrenheit, and volatilizes slowly even before it fuses; at the temperature of 560° it becomes an elastic fluid, and in this state inflames if in contact with air, and burns with a pale blue flame.

2. If sulphur be heated above 300° Fahrenheit, it gradually becomes thick and viscid, when if it be poured into a bason of water, it will be found of a red colour, and ductile like wax. In this state it is used for receiving impressions of seals or medals. Its specific gravity is increased, according to Dr. Thomson, to 2325 during this process; from which it seems probable that its parts undergo a new arrangement, and approach nearer, than in its common crystalline form. It has been supposed that the change depends upon its combining with oxygene; but in some experiments made expressly to ascertain this point, it was not found that any oxygene was absorbed when sulphur was long kept heated in contact with it in close ves-

sels, and I have observed after Dr. Irvine, jun. that the change of colour takes place independent of the presence of air.

3. The only well known compound consisting of sulphur and oxygene alone, is a gaseous substance, called in the modern nomenclature, *sulphureous acid gas.* It may be procured by heating sulphur in oxygene gas ; the experiment may be performed in a glass retort, and the sulphur inflamed by a spirit lamp ; it burns with a beautiful violet flame, and if the oxygene gas has been carefully freed from water, sulphureous acid gas will be the product. It may be formed likewise by heating mercury or copper filings, in oil of vitriol, and collected over mercury.

Sulphureous acid gas has a very disagreeable smell. It is the smell of burning sulphur. It reddens vegetable blues, and gradually destroys most of them. It whitens many animal and vegetable substances, silk and straw for instance, and hence the vapours of burning sulphur are employed in bleaching.

Its specific gravity is to that of hydrogene as 30 to 1., and 100 cubical inches of it at mean temperature and pressure, weigh about 68 grains.

It is absorbed by water ; this fluid takes up about 30 times its bulk, gains a nauseous subacid taste, and, according to Dr. Thomson, becomes of specific gravity 1.0513.

That sulphureous acid gas consists of sulphur and oxygene, is evident from the phænomena of its production by combustion.

In several experiments in which I burnt sulphur, procured from iron pyrites out of the contact of air or moisture, in dry oxygene gas over mercury, I found that the volume of the oxygene was very little altered ; the condensation was never more than $\frac{1}{12}$, and seldom so much as $\frac{1}{15}$, and I am inclined to attribute the loss to the formation of a little oxide of sulphur, or to a little hydrogene loosely combined with the sulphur, so that there is every reason to believe that sulphureous acid is constituted by sulphur dissolved in a volume of oxygene.

This conclusion is confirmed by some experiments on the action of cinnabar, which consists of mercury united to sulphur, and sulphur itself, on metallic oxides.

Two equal quantities of red oxide of mercury, each weighing 10 grains, were heated, one alone, the other mixed with sulphur. They afforded nearly equal volumes of gas. One, which equalled 2 cubical inches and $\frac{2}{10}$, was oxygene, the other, which equalled 2 cubical inches and $\frac{1}{10}$, was pure sulphureous acid gas. Similar experiments were made, cinnabar being substituted for sulphur, with like results.

If the specific gravities of sulphureous acid gas and oxygene be compared, and the last subtracted from the first, it will appear that sulphureous acid consists nearly of equal parts of oxygene and sulphur by weight.

4. If a solution of sulphureous acid gas in water be exposed to the air, it loses its peculiar flavour, and becomes strongly sour; and experiments on the action of the solution on air, shew that oxygene is absorbed.

Sulphureous acid gas is easily driven off from water in the recent solution, but after it has been changed by exposure to air, water only rises when it is heated; and if the evaporation is carried on till the temperature is 546°, the residuum is found to be the same substance as *oil of vitriol;* nothing but water will have been given off; and therefore oil of vitriol contains sulphur combined with more oxygene than in sulphureous acid. That it likewise contains water, is shewn by another experiment, which, if made with accuracy, affords perfect evidence of its nature and composition. Let a porcelain tube be heated red, and the strongest oil of vitriol passed through it in vapour, a part of it will be decompounded, the gaseous products will be two parts of sulphureous acid gas, and one part of oxygene gas; and the fluid product will be a weaker acid, such as would be produced by diluting the acid which is the subject of experiment.

The compounds made by adding oil of vitriol to the alkaline earths, free, as far as our knowledge extends, from water, give off moisture when they are heated to redness, and if the quantity of water in the strongest oil of vitriol, be estimated from experiments of this kind, it may be concluded that it contains about 19 per cent. of water; and its composition may be thus expressed, 30 of sulphur, 45 of oxygene, and 17 of water.

In the common process of manufacture, oil of vitriol is made by burning sulphur mixed with about $\frac{1}{7}$ of its weight of nitre in pans of iron or lead communicating with a chamber of lead, the bottom of which is covered to the depth of several inches with water. The true theory of this process is not given in any chemical book.

The sulphur by burning, forms sulphureous acid gas, and the acid in the nitre is decomposed, giving off nitrous gas; this coming in contact with the oxygene of the atmosphere, produces nitrous acid gas, which has no action upon sulphureous acid, to convert it to sulphuric acid, unless water be present, and if this substance be only in a certain proportion, the water, the nitrous acid gas, and the sulphureous acid gas combine, and form a white crystalline solid. By the large quantity of water usually employed, this compound is instantly decomposed, oil of vitriol formed, and nitrous gas given off, which in the air again becomes nitrous acid gas, and the process continues according to the same principle of combination and decomposition, till the water at the bottom of the chamber is become strongly acid. It is easy to prove the truth of these reasonings; let dry sulphureous acid gas, and nitrous acid gas be mixed together, by suffering the sulphureous gas to pass into a glass globe partially exhausted, and containing nitrous acid gas. There will be no action between the gasses. But if a drop of water be introduced, there will be an immediate condensation, and a beautiful white crystalline solid will line the interior of the vessel. Whereas if the globe contain plenty of water, nitrous gas will be given off with great violence, and the water will be found to be a solution of oil of vitriol.

In the solid crystalline compound, it is evident, from the products of its decomposition by water, there must be four volumes of sulphureous acid gas, and three of nitrous acid gas, probably in two or three proportions with a single proportion of water; for nitrous acid gas contains $\frac{2}{3}$ of its volume of loosely combined oxygene, and sulphureous acid gas requires half its volume of oxygene to become, when condensed in water, solution of oil of vitriol.

Mr. Dalton, who has adopted M. M. Clement's and Desormes' idea of nitrous acid gas being decomposable by sulphureous acid gas, which is not correct, supposes that there is a solid sulphuric acid, the oxygene in which is to that in sulphureous acid, as 3 to 2; but the body which he supposes to be sulphuric acid is the crystalline substance, the nature of which is demonstrated above: and no substance to which the name of pure sulphuric acid ought to be given, i. e. a substance consisting of 30 of sulphur and 45 of oxygene, has yet been discovered in an insulated state.

The term sulphuric acid, is improperly applied to the strongest oil of vitriol; this substance, according to the principles of the French nomenclature, ought to be called *hydrosulphuric* acid.

The oil of vitriol of commerce, which is of specific gravity 1.85, rises in vapour at about 550° Fahrenheit, and distils unaltered; whereas weaker acids, by being boiled, lose water, and are brought to this state of concentration. There is a diluted acid of specific gravity 1.78, which congeals at any temperature below 46° Fahrenheit. It is very curious, as Mr. Dalton has stated, that this acid contains exactly twice as much water as the acid of 1.85. It is composed, according to my experiments, of 30 of sulphur, 45 of oxygene, and 34 of water.

Pure oil of vitriol is a corrosive substance. It acts with great energy upon animal and vegetable matter. It rapidly attracts moisture from the air, and produces much heat when mixed with water. It reddens vegetable blues; and acts with great violence upon alkaline substances, and upon certain earths and metallic oxides; and neutral salts are produced by the union of its sulphur and oxygene with these bodies.

The number representing sulphur, as learnt from the constitution of sulphureous acid gas, is nearly 30; and as this gas contains two proportions of oxygene twice 15, it would seem probable that an oxide of sulphur may exist, consisting of 30 of sulphur, and 15 of oxygene.

I have examined some highly coloured specimens of Sicilian sulphur, which seemed to contain a little oxygene, and, as has been just stated, it is possible that a little oxygene may be condensed in the combustion of sulphur in the residuum; but as yet no body is known that can with propriety be called *oxide of sulphur*.

5. Sulphur and chlorine are possessed of a chemical attraction for each other. The first combination of them was made by Dr. Thom-

son in 1804, by passing chlorine over flowers of sulphur. It may be made more expeditiously by heating sulphur in a retort filled with chlorine. The sulphur and the chlorine unite and form a fluid substance, which is volatile below 200° Fahrenheit, and distills into the cold part of the retort. This substance, seen by reflected light, appears of a red colour, but is yellowish green, when seen by transmitted light. It smokes when exposed to air, and has an odour somewhat resembling that of sea weed, but much stronger; it affects the eyes like the smoke of peat. Its specific gravity, according to Dr. Thomson, is 1.6.

It does not redden perfectly dry paper tinged with litmus; when it is agitated in contact with water, the water becomes cloudy from the appearance of sulphur, and strongly acid, and it is found to contain oil of vitriol.

According to my experiments, 10 grains of pure sulphur absorb nearly 30 cubical inches of chlorine; so that the compound contains about 30 of sulphur to 68.4 of chlorine; 30 of sulphur to 67 of chlorine, would give one proportion of sulphur to two of chlorine; which, there is every reason to believe, must be the just estimation; for my experiments were made in retorts furnished with metallic stop-cocks, by which a little chlorine must have been absorbed.

The compound formed in the manner above described cannot be made to unite to more chlorine; but I find it dissolves a considerable portion of sulphur by heat, and becomes of a tawney yellow colour.

Dr. Thomson called this substance sulphuretted muriatic acid, but there is no proof that it contains muriatic acid. According to an idea which I ventured to propose in the Philosophical Transactions for 1811, that of calling the compounds of chlorine by the name of their bases, with a termination in "ane," its name would be *sulphurane*.

6. Sulphur and hydrogene combine. Their union may be effected by causing sulphur to sublime in dry hydrogene in a retort. There is no change of volume: but only a part of the hydrogene can be combined with sulphur in this mode of operating.

The gaseous compound of sulphur and hydrogene was discovered by Scheele, in 1777. It is usually made by the action of diluted sulphuric acid upon a mixture of three parts of iron filings, and two parts of sulphur that have been ignited together; for the purposes of accurate experiments, it should be collected over mercury.

Sulphuretted hydrogene inflames when a lighted taper is brought in contact with it, exposed to the air: it burns with a pale blue flame, depositing sulphur. Its smell is extremely fetid, resembling that of rotten eggs. Its taste is sour. It reddens vegetable blues. It is absorbable by water; that fluid takes up more than an equal volume of the gas. Its specific gravity, according to M. M. Gay Lussac and Thenard, is to that of air as 1.1912 to 1. From my experiments, it would appear to be a little less; but I am inclined to adopt the results of the French chemists rather than my own, as their gas was weighed in larger quantity, and dried. Its weight to that of hydrogene may be considered as 16 to 1, and 100 cubical inches of it, at mean temperature and pressure, weigh between 36 and 37 grains.

The composition of sulphuretted hydrogene is demonstrated by the change produced in it by electricity; if platina wires be ignited in it by the Voltaic apparatus, it is rapidly decomposed. Sulphur is deposited, and an equal volume of hydrogene remains; the same change is effected more slowly by electrical sparks.

The proportion of its elements are shewn to be the same, both by the analytical and synthetical experiments. They must be 15 of sulphur to 1 of hydrogene; and the results give as nearly as possible the same number representing sulphur, as its compounds with oxygene and chlorine: and sulphuretted hydrogene may be considered as consisting of two proportions of hydrogene 2, and 1 of sulphur, 30.

This body combines with an equal volume of ammonia; and unites to alkalies and oxides; so that it has all the characters of an acid.

7. There is another compound of hydrogene and sulphur, the proportions of the elements of which have not yet been accurately ascertained; but it probably will be found to contain at least one proportion more of sulphur.

It may be formed by passing sulphur over charcoal ignited in a porcelain tube; the experiment must be made with the exclusion of air. It is a fluid body, and was discovered by Lampadius, in 1796, and called by him *alcohol of sulphur*. Its colour is greenish yellow. Its taste pungent, its smell peculiar, its specific gravity is 1.3. It is very volatile. It does not mix with water. It burns with the same facility as spirits of wine. It dissolves sulphur with great facility by the assistance of heat; and when the saturated solution of sulphur in this substance is exposed to air, as the alcohol of sulphur evaporates, crystals of sulphur are deposited. When it is exposed to platinum ignited by the agency of Voltaic electricity, it gives off sulphuretted hydrogene. This, and the phænomena of its combustion, demonstrate its nature; for, when it burns in contact with oxygene, the products are sulphureous acid and oil of vitriol.

When quicksilver is heated in the vapour of alcohol of sulphur, a compound of sulphur and quicksilver is formed, and sulphuretted hydrogene disengaged.

8. Sulphur has no chemical attraction for azote, at least no compound of these bodies has as yet been formed.

9. Sulphur has been placed amongst the undecompounded bodies, because as yet nothing certain is known respecting its elements. When Sicilian sulphur was fused and exposed to the action of platina points intensely ignited by Voltaic electricity, excited by 1000 double plates, permanent gas was given off from it, which proved to be sulphuretted hydrogene: a small quantity of sulphuretted hydrogene is given off likewise during the action of copper filings upon sulphur; and the mode of the formation of alcohol of sulphur proves that sulphur or charcoal, or both, contain hydrogene. It may, however, be questioned whether hydrogene is essential to the constitution of sulphur. Sulphur may possibly contain, in its common forms, a little moisture, or a little of a solid compound of hydrogene and sulphur; and till the gas can be separated from it in definite proportion, and be proved to be combined with some other matter, no accurate conclusions can be formed upon the subject.

Sulphur is employed in medicine, particularly as an external application in cutaneous complaints. Its use in bleaching has been already referred to. Its most important application is in oil of vitriol, and the compounds formed from it, which are used in various processes of dyeing and calico-printing.

IV. *Of Phosphorus.*

1. *Phosphorus* was discovered by Brandt in 1669. It may be made by the following process.

A hundred parts of burnt bones in powder are to be mixed with 40 parts of oil of vitriol, and they are to be suffered to remain in contact for a couple of days, the mixture being frequently stirred. The whole is then to be poured upon a filtre of cloth, and the liquor that passes through is to be added to a nitrous solution of lead; a white powder will be formed; this must be mixed with about $\frac{1}{5}$ of its weight of charcoal powder, and exposed to a strong red heat in a porcelain retort, the beak of which is plunged in water; much gaseous matter will come over, some of which will inflame spontaneously, and at length a substance will drop out of the neck of the retort, and congeal under the water, which is phosphorus. It may be purified by melting it in water, and passing it under water through shamois leather.

2. Phosphorus is semi-transparent, and of a yellowish colour. It is as soft as and more ductile than wax. It is insoluble in water. Its specific gravity is about 1.77. It melts at the temperature of 90°, and boils at about 550°.

When phosphorus is exposed to air at common temperatures, it emits a white smoke, which appears luminous in the dark. This depends upon its combining with oxygene, and forming an acid which unites to the aqueous vapour in the atmosphere, and they fall down in the fluid form. Phosphorus, I find, does not smoke in air perfectly dry; and in this case the acid adheres to it, and in a short time prevents it from being luminous.

When phosphorus is heated to about 148°, it takes fire, and burns with intense brilliancy, throwing off dense white smoke, which is a strong solid acid that soon becomes liquid by attracting moisture from the air; and a red substance usually remains.

3. The manner in which phosphorus acts upon air, as has been shewn, page 130, proves that it is capable of combining with oxygene; and there is every reason to believe in at least three proportions.

When phosphorus is inflamed in oxygene gas over mercury, and the white substance produced strongly heated, the oxygene being in excess, for every grain of phosphorus burnt, four cubical inches and a half of oxygene gas are absorbed. The substance so procured is called *phosphoric acid*. It becomes fluid at a red heat; it is not volatile even at a white heat. It has no smell; its taste is intensely, but not disagreeably acid. It dissolves in water, producing great heat; and its saturated solution is of the consistence of syrup. It acts upon, and corrodes glass, and unites to alkalies and oxides.

4. When phosphorus is heated in highly rarefied air, three products are formed from it: one is phosphoric acid; one is easily volatile, and appearing as a white powder; and the other is a red solid comparatively fixed, and requiring a heat above that of boiling water for its fusion. The volatile substance is soluble in water, and gives it acid properties. It contains less oxygene than phosphoric acid; for it burns and becomes fixed when heated strongly in the air. Its taste is sour, with a peculiar pungency, and it emits a smell not unlike that of garlic. It is mixed with phosphorus, but is principally the substance which, according to the French nomenclature, should be called *phosphorous acid*, and which, in chemical works, is inaccurately described as a fluid body. The red substance requires less oxygene than phosphorus to convert it into phosphoric acid, and must be considered as an *oxide of phosphorus*.

I have never been able to procure phosphorous acid by combustion free from admixture or combination with other substances. In the common mode in which it is said to be obtained, namely, by exposing phosphorus to free air, there is always a large quantity of phosphoric acid formed.

A pure solid *hydro-phosphorous acid*, that is, a combination of it with water, may, I find, be produced by the following process.

Phosphorus is sublimed through corrosive sublimate in powder in a glass tube; a limpid fluid comes over, which must be mixed with water, and the solution heated till it is of the thickness of syrup. It is a combination of water and pure phosphorous acid. It reddens vegetable blues, and combines with alkalies, and has all the characters of a strong acid. It forms a white crystalline solid on cooling.

It becomes solution of phosphoric acid slowly when exposed to air, absorbing oxygene. When it is gently heated, it takes fire, and burns with great brilliancy, emitting globules of gas that inflame in contact with air; a red oxide of phosphorus is deposited in the bottom of the vessel, and solid phosphoric acid is formed.

The substance produced by passing phosphorus through corrosive sublimate, as will be immediately shewn, is a compound of phosphorus and chlorine; and, when it acts upon water, hydrogene is afforded to the chlorine, and oxygene to the phosphorus; there are no products but muriatic acid gas and phosphorous acid, and the quantity of hydrogene in the muriatic acid gas formed, being known, the quantity of oxygene in the phosphorous acid is likewise known. By two experiments made with great care, in which the quantity of chlorine in the liquor from the phosphorus and corrosive sublimate, was estimated by its combination with silver, I ascertained that ten grains of phosphorus required for their conversion into phosphorous acid, such as exists in the hydrat just described, 7.7 grains of oxygene; and it is evident from this result, compared with that on the combustion of phosphorus, in which phosphoric acid is formed, that the quantity of phosphorus being the same, it requires twice as much oxygene to become phosphoric acid, as it requires to form phosphorous acid; and from these data, the number representing phosphorus, must be regarded as about 20, and phosphorous acid will consist of 20 phosphorus, and 15 oxygene, or 35; and phosphoric acid of 20 phosphorus and 30 oxygene, or 50.

That the hydro-phosphorous acid is a compound of phosphorus, oxygene, and water, is shewn by heating it in contact with ammonia over mercury; the ammonia unites to the pure acid, and water is expelled. I find by experiments on the quantity of water it affords, that it consists of four proportions of phosphorous acid, and two of water.

I have made no experiments on the proportion of oxygene in the red oxide. It possibly will be found to consist of two proportions of phosphorus, and one of oxygene.

5. Phosphorus and chlorine combine with great facility when brought in contact with each other at common temperatures; and compounds may be formed from their union, containing different proportions of the two elements.

When chlorine is introduced into a receiver exhausted of air, and containing phosphorus, the phosphorus takes fire and burns with a pale flame throwing off sparks, and a white substance rises and condenses on the sides of the retort.

If the chlorine be in considerable quantity, as much as twelve cubical inches to a grain of phosphorus, the phosphorus will entirely disappear, and nothing but the white powder will be formed ; and about 9 cubical inches of the chlorine will be found to be absorbed ; and no new gaseous matter will be produced.

The powder is a compound of phosphorus and chlorine. I first described it as a peculiar body in 1810, and various analytical and synthetical experiments which I have made, prove that it is composed of about 1 of phosphorus and 6.8 of chlorine in weight.

Its properties are very peculiar. It is a snow white substance. It is very volatile, and rises in a gaseous form at a temperature much below that of boiling water; under pressure it may be fused, and then it crystallizes in prisms which are transparent.

It acts violently upon water, which it decomposes. Its phosphorus combines with the oxygene, producing phosphoric acid, and its chlorine with hydrogene forms muriatic acid.

It produces flame when exposed to a lighted taper; and when passed through a glass tube heated red, with oxygene, is decomposed; the oxygene forms phosphoric acid with the phosphorus, and the chlorine is disengaged. Dry litmus paper exposed to its vapour in a vessel exhausted of air is reddened. It combines with ammonia when it is introduced into a vessel containing it, with much heat ; and they form together a compound insoluble in water, indecomposable by acid or alkaline solutions, and having characters analogous to an earth.

It is evident from the analysis, that it consists of two proportions of chlorine, supposing the number representing chlorine, 67, or of four, supposing it 33.5, 134 to one of phosphorus 20, and the number representing it is 154. It is analogous to an acid in many of its properties. According to the principles of nomenclature which I have ventured to propose, its name will be *phosphorana.*

6. I have already referred to the substance produced by passing phosphorus through corrosive sublimate. It is a fluid as clear as

water; its specific gravity is to that of water as 1.45 to 1. It may be called *phosphorane*. I first obtained it in a pure form, in 1809. It appears from the circumstances already detailed, that it consists of one proportion of phosphorus 20, and one of chlorine 67, and the number representing it is 87*. It emits acid fumes when exposed to air, decomposing the vapour in the air, and if made to moisten paper, it is converted into acid in the air, without any inflammation. It does not redden dry litmus paper plunged into it; the vapour from it burns in the flame of a candle; its action upon water has been already referred to. When it is introduced into a vessel containing chlorine, it is converted into phosphorana: if made to act upon ammonia, phosphorus is produced, and the same compound as that formed by phosphorana and ammonia.

7. When phosphorus is gently heated in phophorane, a part of it dissolves, and the fluid, when exposed to the air, gives off acid fumes from its action upon its vapour it contains, and a thin film of phosphorus is left behind, which usually inflames by the heat generated from the decomposition of the vapour. The first compound of this kind was obtained by M. M. Gay Lussac and Thenard, by distilling phosphorus and calomel together in 1808, and they imagined it to be a peculiar combination of phosphorus, oxygene, and muriatic acid.

No experiments have been as yet made to determine the quantity of phosphorus which phosphorane will dissolve; probably a definite combination may be obtained, in which the proportions of chlorine will correspond to the proportions of oxygene in the oxide of phosphorus.

8. An elastic fluid, which has the peculiar property of inflaming in contact with the atmosphere, may be procured by heating together slacked lime, or strong solution of potassa or soda, and phosphorus. It is expedient to deprive the air contained in the vessel in which it is generated of oxygene, by burning phosphorus or a taper in it; the gas should be preserved over mercury; it soon becomes adulterated by exposure to water containing air.

This gas differs in properties according to the manner in which it is made; I have obtained it from phosphorus and alkaline lixivia of

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* 13 6 grains of it decomposed by nitrate of silver, afforded 43 grains of hornsilver, and 100 grains of silver absorb 32.5 of chlorine to become hornsilver.

specific gravities varying from 4 to 7, 1 being the standard of hydrogene: its smell is very disagreeable: water absorbs about $\frac{1}{40}$ of its volume of the gas. It detonates when brought in contact with chlorine, producing a brilliant green light; but the results of the detonation have never been minutely examined. It explodes with a most intense white light in oxygene gas; the heaviest spontaneously inflammable gas that I have ever made, absorbed rather less than an equal volume of oxygene.

When electrical sparks are passed through gasses of this kind for a long time, a reddish film which burns like phosphorus is deposited; ususally there is no change of volume, and the remaining gas is hydrogene. When a gas, the specific gravity of which was 6, was heated for some time over mercury in contact with zinc filings, there was an expansion of volume to more than $\frac{1}{3}$; a substance was formed superficially on the zinc, which had the characters of a compound of phosphorus and zinc. There was an expansion when finely divided platina was heated in a portion of the same gas. Potassium in excess made to act upon it by a spirit lamp produced a rapid increase of its volume; 2 parts became rather more than 3. The potassium was affected as it would have been by a union with phosphorus, and the gas was found to be pure hydrogene.

This substance, which was discovered by M. Gengembre in 1783, has been called *phosphoretted hydrogene.*

9. When solid hydrat of phosphorous acid is heated in a retort out of the contact of air, solid phosphoric acid is formed, and a large quantity of elastic fluid is generated, which has very peculiar properties; I discovered it at the same time as the solid hydrat of phosphorous acid, namely, in February 1812. This gas has a disagreeable smell, but not nearly so fetid as that of phosphoretted hydrogene: it does not explode spontaneously, but detonates violently when heated in contact with oxygene to about 300° Fahrenheit. It explodes in chlorine with a white flame. Water absorbs $\frac{1}{8}$ of its volume of this gas. In an experiment in which a small quantity only was weighed, its specific gravity appeared to be to that of hydrogene as about 12 to 1.

When potassium is heated in it, its volume is doubled, and the gas produced is pure hydrogene. When sulphur is sublimed in one volume of it, a sulphuret of phosphorus is formed*, and nearly 2 volumes of sulphuretted hydrogene produced. When detonated with oxygene in excess, three in volume of it absorb more than five in volume of oxygene, and a little phosphorus is always thrown down; when 8 of it in volume are detonated by an electrical spark with 2 of oxygene, there is a considerable deposition of phosphorus, and 9 of gas, which has the odour of common phosphoretted hydrogene, remain; one volume of it absorbed nearly four volumes of chlorine.

I venture to propose the name of *hydrophosphoric* gas for this elastic fluid. It appears to be composed of 1 proportion of phosphorus and 4 of hydrogene, two volumes of hydrogene being compressed in the space of one, and the number representing it is 24.

It is probable that the gas called phosphuretted hydrogene sometimes contains this gas, mixed with common hydrogene, and perhaps a *peculiar elastic* fluid, consisting of one proportion of phosphorus, and two of hydrogene, which has the property of spontaneous inflammation. Hydrophosphoric gas I find does not become spontaneously explosive by mixture with hydrogene.

There is not, perhaps, in the whole series of chemical phænomena a more beautiful illustration of the theory of definite proportions, than that offered in the decomposition of hydrophosphorous acid into phosphoric acid and hydrophosphoric gas.

Four proportions of the acid contain four proportions of phosphorus, and four of oxygene; two proportions of water contain four proportions of hydrogene, and two of oxygene. The six proportions of oxygene unite to three proportions of phosphorus to form three of phosphoric acid, and the four proportions of hydrogene combine with one of phosphorus to form one proportion of hydrophosphoric gas; and there are no other products.

10. Phosphorus and sulphur are capable of combining; they may be united by fusing them together in a tube exhausted of air, or under water; but in the last case they must be used only in small quantities; as at the moment of their action water is decomposed, sometimes with explosions. This compound, which has been called sulphuret of phosphorus, was described by Margraaf in 1762. He

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* See 10. below.

formed it of equal parts of the two substances, but phosphorus and sulphur may be united into one mass in a variety of proportions; and these mixtures are more fusible than either of their constituents. The most fusible compound I have found, is that formed by the two bodies united in the proportion of one and a half of sulphur, to two of phosphorus. This remains liquid at 40° of Fahrenheit; and would appear to be composed of one proportion of sulphur 30, and two of phosphorus 40. When solid its colour is yellowish-white. It is more combustible than phosphorus, and rises undecomposed by a strong heat.

The points of fusion and evaporation of phosphorus and sulphur, are so near each other, that it is not easy to ascertain the difference between true chemical combinations of these bodies in different proportions, and mixtures of the chemical compounds, with the bodies themselves; 8 parts of phosphorus in weight united to one of sulphur, remain fluid at 68° of Fahrenheit; and one of phosphorus with 3 of sulphur, congeal at about 100°.

11. When phosphorus is fused and exposed to the action of the Voltaic spark, taken by means of platina wires, phosphuretted hydrogene in small quantities is produced from it; but there are no proofs that hydrogene is essential to its existence; and phosphorus in its common state, may contain a minute portion of the hydruret of phosphorus mixed with it; it would be very difficult to detect in phosphoric acid, the small quantity of water that this hydrogene would produce; and the red colour which phosphorus sometimes possesses, seems to be owing to an admixture of small quantities of oxide of phosphorus. There are some analogies that favour the idea of the compound nature of phosphorus, which will be discussed in the progress of this work; but in the arrangements of the facts of the science, it must be still regarded as an undecompounded body.

12, Phosphorus has not as yet been applied to any of the purposes of the common arts; but various preparations of it are employed for producing quick inflammation. One of the best, is a sulphuret of phosphorus, containing two of phosphorus to one of sulphur; a little of it applied to a common brimstone match, inflames when gently rubbed.

V. *Of Carbon or Charcoal, and the Diamond.*

1. The name carbon, signifies the pure inflammable part of charcoal, lamp-black, and other similar substances. The purest known form in which it can be obtained, is by passing oils or spirits of wine through ignited tubes. It then appears as an impalpable black powder; it has no taste nor smell; it is a conductor of electricity; it is more than twice as heavy as water. For the common purposes of experiments, the charcoal of light wood, such as the alder, that has been exposed to boiling water, and afterwards ignited to whiteness, is sufficiently pure. Such charcoal, however, rapidly attracts moisture from the atmosphere, so as to increase in weight from 12 to 14 per cent., and when dry, absorbs several times its volume of any gas to which it may be exposed, and it must therefore be employed immediately after ignition, and whilst yet warm.

Carbon, whether coherent in charcoal, or in powder, is infusible by any heat that has hitherto been applied. I have exposed it to the powers of intense ignition of different Voltaic batteries; that of Mr. Children, mentioned page 84, one of 40 double plates of 18 inches square, and the battery of 2000 double plates of 4 inches, both in vacuo, and in compressed gasses, on which it had no power of chemical action. A little hydrogene was given off from it, and it slowly volatilized in these experiments, and the part remaining was much harder than before, so as in one case to scratch glass, and the lustre was greater; but its other properties were unaltered, and there was no appearance of fusion. Its capacity for heat, according to Dr. Crawford, is to that of water as .2631 to 1.

2. There are two distinct combinations of carbon and oxygene, which have been referred to, page 58.

Carbonic acid is formed whenever charcoal or carbonaceous matter is burnt in air or oxygene, and it is evolved during fermentation, by the decomposition of animal or vegetable substances, and from limestones by ignition, or the action of acids.

The most expeditious mode of procuring it for chemical purposes is by the action of weak solution of muriatic acid on powdered marble. It may be collected over water, or, for accurate experiments, over mercury.

Carbonic acid gas was the first elastic fluid certainly distinguished from air; the knowledge of its acid nature is owing to Dr. Black, who discovered it in 1755. Mr. Lavoisier, nearly 30 years afterwards, ascertained its composition.

Carbonic acid gas extinguishes flame, has a peculiar sharp taste, and a faint but agreeable smell. It is not respirable. Its specific gravity is to that of hydrogene as 20.7 to 1. 100 cubical inches weigh at the mean temperature and pressure, 47 grains.

Carbonic acid gas is absorbed by water, which unites to its own volume of the gas at 41°. By heat it is expelled from the water.

If carbonic acid gas be poured from one vessel into another vessel containing a lighted taper, the flame is extinguished.

It reddens litmus paper, and combines with alkalies, alkaline earths, and metallic oxides.

A synthetical proof of the composition of carbonic acid gas, has been already given, page 58.

Common charcoal, even when very well burnt, contains a little hydrogene, and affords a minute quantity of water in its combustion; but the charcoal from the decomposition of oil gives carbonic acid gas alone. It burns when inflamed in dry oxygene with brilliant scintillations; there is no perceptible change in the volume of the gas; and when the process is complete, the oxygene is found converted into carbonic acid gas.

The proportions of the elements in carbonic acid gas are easily learnt by the difference between its weight and that of oxygene. This difference proves, as has been stated before, that it must consist of 13 of charcoal to 34 of oxygene.

The constitution of carbonic acid gas is proved analytically by its action upon potassium. If this metal is strongly heated in a retort containing the gas, it takes fire, and burns with a red light. Charcoal in fine powder is deposited, the gas disappears, and oxygene is found added to the potassium.

3. The compound of carbon and oxygene, containing less oxygene than carbonic acid gas, may be formed in many modes besides that described in page 58; as by igniting chalk or any substance con-

taining carbonic acid with charcoal, iron, or tin; or by igniting difficultly reducible metallic oxides with charcoal, or by passing carbonic acid gas over charcoal heated to whiteness, in a porcelain tube. In this last case, the composition of the gas is shewn by the circumstances of the experiment, charcoal disappears, and the carbonic acid becomes *carbonic oxide gas*, and there is a considerable expansion. The true nature of this elastic fluid was discovered by Mr. Cruikshank in March, 1801.

Carbonic oxide may be purified from the carbonic acid with which it is usually mixed, by washing in lime water.

It is combustible, and by the contact of an inflamed or ignited body, burns in the atmosphere with a lambent blue flame. Its specific gravity, according to Cruikshank, is to that of hydrogene as 13.2 to 1. 100 cubical inches weigh about 30 grains.

Carbonic oxide may be taken into the lungs, but is fatal to animal life. I once took three inspirations of it mixed with about $\frac{1}{4}$ of common air; the effect was a temporary loss of sensation, which was succeeded by giddiness, sickness, acute pains in different parts of the body, and extreme debility; some days elapsed before I entirely recovered.

Water absorbs about $\frac{1}{50}$ of its bulk of carbonic oxide.

Chlorine has no immediate action on carbonic oxide, when they are exposed to each other in common day-light over dry mercury; not even when the electric spark is passed through them. M. M. Gay Lussac, Thenard, and Murray, have asserted that they do not act on each other even when long exposed to the direct solar beams. But experiments which I have seen made by my brother, Mr. John Davy, prove the contrary; they rapidly combine under this circumstance, and when in equal volumes, are condensed to one-half; and form a peculiar gas, which he has discovered is possessed of very curious properties, approaching to an acid in its nature.

The nature of carbonic oxide, and the proportions of its elements, are easily demonstrated by analytical experiments. When two in volume of it are mixed with one in volume of oxygene, and an electrical spark passed through the mixture, an inflammation takes place, and two in volume of pure carbonic acid are formed, and there is no other product.

When potassium is strongly heated in it, combustion takes place, charcoal is deposited, no gas is disengaged, and oxygene is added to the potassium.

From the experiments on carbonic acid and carbonic oxide, it is evident that the number representing carbon is about 11.4; and carbonic acid is represented by 30 added to 11.4, or 41.4; and carbonic oxide by 15 added to 11.4, or by 26.4.

Some chemists have been perplexed to find a reason why carbonic oxide, which contains more carbon, is lighter than carbonic acid; but, as Mr. Dalton has ingeniously and justly observed, there is no difficulty in this circumstance; carbon in the gaseous state, is probably considerably lighter than oxygene. The specific gravity of gasses bears no relation to the density of the fluids or solids, from which they are formed; ether is lighter than water; but the vapour rising from it is much heavier than steam. If carbonic oxide be supposed to be constituted by equal volumes of gaseous carbon and oxygene, occupying the space of two in volume, then the specific gravity of gaseous carbon will be to that of oxygene as 13 to 17; or if the constitution of the carbonic oxide is similar to that of the nitrous oxide, it will be only as 6.5 to 17.

4. No compound of carbon and chlorine has been as yet discovered. They have no action on each other under any circumstances to which they have been exposed.

5. There are two compounds of carbon and hydrogene, which are perfectly distinct and well characterized bodies.

One of them, which has been called *carburetted hydrogene*, is disengaged in certain natural operations, particularly during the decomposition of vegetable substances; it is the gas evolved in stagnant waters. It may be procured by the distillation of coal that burns with flame, and by decomposing the salt called acetite of potash by a red heat; it should be washed with lime water to separate it from carbonic acid.

It burns with a bright yellowish flame. It has no taste, but a disagreeable empyreumatic smell. Water absorbs about $\frac{1}{30}$ of its volume. Its specific gravity, in its purest form, is to that of hydrogene as rather less than 8 to 1. 100 cubical inches weight about 17 grains.

When one of this gas in volume is mixed with two of oxygene gas, and an electrical spark passed through them over mercury; water and about one in volume of carbonic acid are the products. Hence one in volume of carburetted hydrogene must contain two in volume of hydrogene gas, and as much carbon as will form a volume of carbonic acid. This likewise is shewn by the phænomena of its electrization. When points of platina are electrically ignited in it, or sparks passed through it, charcoal is deposited, and double its volume of hydrogene is produced. When it is mixed with twice its volume of chlorine over mercury, and acted on by the electrical spark, an inflammation takes place, charcoal is deposited, there is a considerable expansion, and about four volumes of muriatic acid gas are produced.

It is evident from these different results that carburetted hydrogene may be considered as composed of one proportion of carbon 11.4, and four of hydrogene 4, and the number representing it will be 15.4.

6. When a mixture of four parts of oil of vitriol and one part of strong spirits of wine, or alcohol, is heated in a retort, a gas is generated, which, when washed by water, is found to be a peculiar gaseous compound of carbon and hydrogene; it has been called *olefiant gas*, and likewise *super carburetted* hydrogene. It burns, when kindled, with a beautiful white flame of intense splendour. According to Dalton, water absorbs $\frac{1}{8}$ of its volume of the gas. Its specific gravity is to that of hydrogene nearly as 13 to 1; 100 cubical inches of it weigh between 29 and 30 grains.

When it is mixed with an equal volume of chlorine, the two gasses condense each other, and a peculiar fluid is formed, which has been supposed to be an oil; but which is a *peculiar compound*, not soluble in water, and composed of hydrogene, carbon, and chlorine. The nature of olefiant gas may be easily demonstrated, and likewise the proportion of its elements. If pure sulphur be sublimed in the gas in a glass tube over mercury, there is a great expansion; sulphuretted hydrogene is formed, and charcoal deposited; one volume of gas forms about two in volume of sulphuretted hydrogene: the sulphur must not be used in much larger quantity than is sufficient to unite to the hydrogene; for in this case, by the long application of heat, the volume is more than doubled; two grains of sulphur and a cubical inch of gas are proper proportions.

The gas is decomposed by electrical sparks; one volume of it expands to about two; charcoal is deposited, and the expanded gas is found to be hydrogene.

It detonates with great violence by the electrical spark, when mixed with three times its volume of oxygene; water and nearly two volumes of carbonic acid are formed in this process.

When it is detonated with an equal volume of oxygene, it expands greatly, and the two gasses together become more than three volumes and a half. In this case only the $\frac{1}{8}$ or $\frac{1}{10}$ of a volume of carbonic acid gas is formed, but more than a volume and a half of carbonic oxide; a little hydrogene is consumed, but the greatest part remains untouched and mixed with the carbonic oxide; and it may be separated by combustion with chlorine.

If an experiment of this kind could be made without the production of any carbonic acid, or the consumption of any hydrogene, the volume of the gasses would be exactly doubled, and they would consist of equal parts of carbonic oxide and hydrogene.

It is evident from all these experiments, that olefiant gas may be considered as constituted by two proportions of carbon 22.8 and 4, of hydrogene 4, and the number representing it is 26.8: and supposing a double volume of gaseous carbon in olefiant gas, its specific gravity will be found to be the same as from the data presented by carbonic oxide.

7. Most of the gasses that form carbonic acid in burning were noticed by Dr. Priestley, who confounded them under the general name of heavy inflammable air. Olefiant gas was first described as a specific substance, in 1794, by Bondt, Deiman, and a society of Dutch chemists. Mr. Berthollet and Mr. Murray suppose that there is a great variety of gasses which consist of oxygene, hydrogene, and carbon, in different proportions; but the experiments of Mr. Dalton, Dr. Henry, and Dr. Thomson, are entirely opposed to these views; and the researches which I have made in conjunction with my brother, Mr. John Davy, have convinced me of the correctness of Dr. Henry's opinion, that what have been called different *oxicarburetted hydrogene gasses* are merely mixtures of olefiant gas,

carburetted hydrogene, carbonic oxide, and hydrogene gasses. We used chlorine for separating olefiant gas at common temperatures, and the same substance for separating hydrogene by explosion, or the action of light; and sulphur for decomposing the carburetted hydrogene: and in these modes of analysis our results were unequivocal.

8. Carbon and azote have no known action on each other.

9. I have already referred to the alcohol of sulphur. This substance was supposed by M. M. Clement and Desormes to be a compound of carbon and sulphur; there can be no doubt, from what has been stated, that this idea of its composition is incorrect: I have found it, however, sometimes to contain a minute quantity of charcoal; and there may possibly be a triple compound of carbon, sulphur, and hydrogene. Sulphur is very soluble in oils and other compounds which consist principally of hydrogene and carbon. The charcoal used for making the alcohol of sulphur always produces sulphureous acid by burning, though previously exposed to a strong red heat, and affords sulphur to a strong solution of alkali; but the quantity is very minute, and it may be questioned whether the sulphur is not in combination with the earthy or alkaline matter the charcoal contains; and no certain definite compound of sulphur and carbon can be as yet admitted in the arrangements of the science.

10. Phosphorus has been supposed capable of uniting to carbon; but in cases when specimens of phosphorus afford charcoal it is most probably mixed with the substance, or in triple combination with oxygene and hydrogene; and no distinct action of the two bodies, and no definite compound of them has as yet been described.

11. A number of forms of carbon are found in nature; one of the most interesting of them is the *diamond;* the properties of this stone are well known, it is the hardest of the gems, and is usually crystallized, often in the form of a six-sided prism terminated by a six-sided pyramid: its specific gravity is about 3.5; it does not conduct electricity. Of all known bodies it has the greatest power of refracting light. When the diamond is strongly heated in air, it consumes away; and if it be exposed to oxygene continuously ignited by a burning glass, or by other means, it acts upon the oxygene nearly in the same manner as charcoal. The volume of the oxygene

is not perceptibly changed, and it is found converted into carbonic acid. M. Lavoisier first determined that carbonic acid was formed from diamond; and Messrs. Tennant, Allen, and Pepys, have demonstrated by some refined experiments, that it produces about the same quantity as an equal weight of charcoal. Hence it has been concluded, that the diamond is pure carbon, differing from charcoal merely in the arrangement of its parts. When it is considered, however, that charcoal is a conductor and diamond a nonconductor of electricity, and that their physical properties differ entirely, it is impossible to receive this conclusion without doubt. I found that diamond powder heated strongly with potassium became blackened; and an effect was produced on the metal similar to that which the absorption of a minute quantity of oxygene would occasion; this would lead to the suspicion that there may be a little oxygene in diamond; but new experiments are wanting to prove this, and the quantity, if any, must be very minute, which does not harmonise with the doctrine of definite proportions. If it should be ultimately found that the diamond is merely pure carbon, it will be an argument in favour of the varieties of elementary forms being produced by different aggregations or arrangements of particles of the same matter; for it is scarcely possible to fix upon bodies less analogous than lamp black, and the most perfect and beautiful of the gems.

12. Plumbago or black lead, and anthracite or stone coal, are both tolerably pure forms of the carbonaceous element. In plumbago the carbon is united either chemically or mechanically to about $\frac{1}{23}$ of iron; in anthracite with small quantities of earthy matter. In the anthracite of Kilkenny in Ireland, the texture is often fibrous, and the substance has all the characters of well-burned charcoal. In flaming coal the carbonaceous element is united to bitumen.

13. Few substances are more important in civilized life than the different forms of carbon; in their various uses they are essential to the comforts and well being of society, and are necessary in almost all the useful arts and manufactures.

The inflammable gasses procured by the distillation of pit-coal have already been successfully used in manufactories for the purpose of affording light, and the application is at once safe and œconomical.

In nature the carbonaceous element is constantly active in an important series of operations; it is evolved in fermentation and combustion, in carbonic acid; it is separated from oxygene in the organs of plants, is a principal element in animal structures, and is found in different forms in almost all the products of organized beings.

VI. *Of Boron**, *or the Boracic basis.*

1. There is a white crystalline substance found native in volcanic districts called boracic acid. It may be procured artificially from borax by heating it in oil of vitriol diluted with eight times its weight of water: it is difficultly soluble in water, and may be separated by a filtre of cloth or paper. When this substance, slightly moistened, is exposed between two surfaces of platina, electrified by a Voltaic battery of not less than 100 double plates, a dark-coloured substance separates on the plate negatively electrified. This substance is *boron*, or the basis of the boracic acid. In this way it can be procured only in very minute quantities, and to obtain it for the purposes of experiment, boracic acid that has been long exposed to a red heat, is powdered and strongly ignited with an equal weight of potassium, in a tube of iron or copper. The result is exposed to diluted muriatic acid, and washed with it till nothing remains but a dark powder, which, when dried at a red heat, is the substance in question.

2. I first procured boron in October, 1807, by the electrical decomposition of boracic acid, and by potassium in March, 1808; but not in sufficient quantities to examine its properties, or to ascertain its nature. M. M. Gay Lussac and Thenard, in June, 1808, made the experiment of heating boracic acid and potassium together, but they did not describe the properties of boron till the middle of No-

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* In my first paper on this substance I named it boracium, for I supposed that in its pure form it would be found to be metallic; subsequent experiments have not justified this conjecture. It is more analogous to carbon than to any other substance; and I venture to propose Boron as a more unexceptionable name; the termination in um having been long used as characteristic of a metal. M. M. Gay Lussac and Thenard have proposed to call it Bore, a word that cannot with propriety be adopted in our language, though short and appropriate in the French nomenclature.

vember; and in the beginning of the same month I had procured sufficient quantities of the substance to ascertain its chemical relations. M. M. Gay Lussac and Thenard, I believe, recomposed the boracic acid before me, and our experiments were independent of each other; but in my first paper on potassium and sodium, read at the Royal Society, in November, 1807, at a time when the French chemists had no idea of the existence of the alkaline metals, I pointed out the probable application of these bodies to the decomposition of the acids not decompounded.

3. Boron is an opaque, dark olive-coloured powder, infusible, and not volatile at any temperature to which it has as yet been exposed. When heated strongly in contact with air, it burns, and forms dry boracic acid. In oxygene gas, it throws off bright scintillations, becomes coated with boracic acid, and the portion not converted into acid is found darker coloured than before. When gently heated in chlorine, it emits white fumes, but has no energetic action on the gas. It is a nonconductor of electricity, and insoluble in water.

4. That boron combines with oxygene is shewn by the phænomena of its combustion. *Boracic acid* is the only well-known result of their combination: the preparation of boron proves that the boracic acid consists of this body united to oxygene, for oxygene is added to the potassium in the process. It is very difficult to ascertain the proportions of boron and oxygene in boracic acid, for the boracic acid formed in combustion prevents the process from going on; and the black substance, which is probably an oxide of boron, is burnt only with great difficulty. From comparing the quantity of potassium required to decompose a given quantity of boracic acid, with the quantity of oxygene absorbed in the production of the acid, I am inclined to believe that boracic acid cannot contain much less than $\frac{2}{3}$ of its weight of oxygene: I have made a number of experiments on this subject, but have never gained perfectly satisfactory results. M. M. Gay Lussac and Thenard conceive that boracic acid contains only $\frac{1}{3}$ of its weight of oxygene; but their conclusions were drawn from the action of boron on solution of nitric acid, and the evaporation of the products; and boracic acid forms volatile compounds both with water and nitric acid; for I find that dry nitre and boracic acid afford, by distillation, a fluid containing a considerable quantity

of boracic acid. From the quantity of ammonia required to neutralize boracic acid, it appears that the number representing it is about 160; and to destroy the alkaline properties of 90 parts of potassa requires twice 160 of boracic acid, so that its acid powers are extremely feeble.

Boracic acid, in its common form, is in combination with water; it then appears as a series of thin white hexagonal scales; its taste is very slightly acid; it reddens vegetable blues. By a long continued white heat the water is driven off from it, and a part of the acid sublimes; the remaining acid is a transparent fixed glass, which rapidly attracts moisture from the air. The compound of boracic acid and water appears to contain, from my experiments, about 57 parts of acid to 43 of water. The specific gravity of the hydrat of boracic acid, as it may be called, is 1.479, that of the dry acid 1.803.

Boracic acid is very little soluble in water; even when boiling, that fluid does not take up $\frac{1}{50}$ of its weight. It dissolves in alcohol, and gives it the power of burning with a green flame.

5. Much still remains to be known respecting the nature and properties of boron, and its combinations. Probably a combination of it with chlorine may be formed. It seems to exert no action on any of the inflammable bodies except sulphur, which dissolves a little of it by a long-continued heat, and gives a green tint.

It has hitherto been obtained in quantities too small to ascertain whether it will have any applications to the arts.

DIVISION V.

OF METALS; THEIR PRIMARY COMBINATIONS WITH OTHER UNDECOMPOUNDED BODIES, AND WITH EACH OTHER.

1. *General Observations.*

1. THE metals form a numerous and most important class of natural bodies; they are connected with each other by close analogies, and by remote analogies to the inflammable solids described in the preceding pages: the number of metals known, or the existence of which may be presumed, amounts to 38. The characteristic properties of the metals are a high degree of lustre, opacity, combustibility, and the power of conducting electricity. A considerable degree of specific gravity was formerly considered as an essential character of metallic substances; but I have discovered bodies lighter even than water, which agree in all other essential qualities with metals, and which consequently must be arranged with them. In the order of classification to be adopted in the following pages, the most inflammable metals will be the first considered: though of recent discovery, they are the most important as agents of analytical chemistry, and have offered the means of reducing other substances to the metallic form. The most inflammable metals produce alkalies, alkaline earths, and earths in combustion. Other metals afford the substances called oxides, which are analogous to earths; and a few are converted into acids. The metals that produce alkalies are potassium and sodium; the alkaline earths are formed from metals, which have been called barium, strontium, calcium, and magnesium. The metals supposed to be contained in common earths are silicium, alumium, zirconium, ittrium, and glucium. The metals that produce oxides are manganese, zinc, tin, iron, lead, antimony, bis-

muth, tellurium, cobalt, copper, nickel, uranium, osmium, tungsten, titanium, columbium, cerium, palladium, iridium, rhodium, mercury, silver, gold, and platina. The metals that produce acids are arsenic, molybdenum, and chromium.

2. The metals differ considerably in their mechanical properties, in degrees of hardness, ductility, and tenacity; all of them that are fusible by common means assume regular crystalline forms by slow cooling, and these forms are usually cubical or octoedral. The common metals, in consequence of their fusibility, malleability, hardness, and durability, have been the most important instrument of the arts; the uses of them have been essential to the progress of civilization; and most of the comforts, and many of the luxuries and refinements of social life are connected with their applications.

2. *Of Potassium.*

1. There is a body usually called potash or the vegetable alkali, which may be thus procured: quick lime is mixed with solution of wood ashes, and boiled for some time with it. The liquor so obtained, after being passed through bibulous paper, is evaporated till a solid matter remains; this solid matter is heated with alcohol or pure spirit; the spirit is separated by distillation in a vessel of silver; a fusible solid mass is produced, which is the substance in question.

To form *potassium*, this substance in a thin piece, is placed between two discs of platina connected with the extremities of a Voltaic apparatus of 200 double plates; it will soon undergo fusion, oxygene will separate at the positive surface, and small metallic globules will appear at the negative surface, which consist of potassium. I discovered this metal in the beginning of October, 1807.

2. It may be procured by chemical means without electricity. If iron turnings be heated to whiteness in a curved gun-barrel, and potash be melted and made slowly to come in contact with the turnings, air being excluded*, potassium will be formed, and may be collected in a cool part of the tube; this method of procuring it was discovered by M. M. Gay Lussac and Thenard, in 1808. It may

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* See Plate VI. fig. 26.

likewise be produced by igniting potash with charcoal, as M. Curaudau shewed in the same year.

3. Potassium is possessed of very extraordinary properties; it is lighter than water, its specific gravity is between 8 and 9, water being 10. It is a solid at common temperatures; it is very soft, and easily moulded by the fingers. It fuses at about 150° Fahrenheit, and rises in vapour, in a heat a little below that of redness. It is perfectly opaque. Its colour is white, like that of silver when it is newly cut, but it rapidly tarnishes in the air; and to be preserved from change must be kept under naphtha. It is a conductor of electricity. When thrown upon water it acts with great violence, swims upon the surface, and burns with a beautiful light, which is white mixed with red and violet; the water in which it burns is found alkaline, and contains a solution of potassa. It inflames when gently heated in the air, burns with a red light, and throws off fumes, which are alkaline. It burns spontaneously in chlorine with intense brilliancy.

It acts upon all fluid bodies containing water, or much oxygene, or chlorine; and in its general powers of chemical combination may be compared and to when the alkahest, or universal solvent imagined by the alchemists. and w

4. Potassium combines with oxygene in different proportions. When potassium is gently heated in common air or in oxygene, the result of its combustion is an orange-coloured fusible substance; and for every grain of potassium consumed, about a cubical inch and $\frac{7}{10}$ of oxygene disappear. To make the experiment accurately the metal should be burnt in a tray of platina covered with a coating of the salt called, in the French nomenclature, muriate of potash, a substance immediately to be described, which may be easily done by fusing it in contact with the platina. This salt is one of the few substances that has no action on potassium or its oxides.

The substance procured by the combustion of potassium at a low temperature, I had observed in October, 1807, but I supposed it to be the oxide of potassium containing the smallest quantity of oxygene, for it effervesced in water; M. M. Gay Lussac and Thenard, in 1810, first demonstrated its real nature, and shewed that it was the combination of oxygene and potassium containing the largest quantity of oxygene.

The gas produced by its effervescence with water is oxygene. When it is fused and brought in contact with combustible bodies, they burn with vividness. When it is heated in carbonic acid, oxygene gas is expelled, and it is converted into the compound called subcarbonate of potash.

When it is heated very strongly upon platina, oxygene gas is expelled from it, and there remains a difficultly fusible substance of a gray colour, vitreous in its fracture, and which dissolves in water without effervescence, but with much heat, and renders the water alkaline. This substance is pure potash or *potassa*, which was unknown in its uncombined state till I discovered potassium, but which has long been familiar to chemists combined with water in the substance which has been called pure potash; but which ought to be called the *hydrat of potassa*.

That the potash obtained by alcohol in the manner described in the beginning of this section is a compound of potassa and water, is shewn by many experiments. If it be made to act upon iron turnings at a dull red heat, the iron becomes combined with oxygene, hydrogene is given off in abundance, and the alkali loses its easy fusibility, becomes harder, more opaque, and of greater specific gravity. In producing potassium in the experiment of acting upon white hot iron turnings by common potash, hydrogene is disengaged in abundance from the decomposition of the water in the potash; and I have procured this water by heating together the potash prepared by alcohol and boracic acid; 100 parts of potash treated in this way gave between 17 and 18 parts of pure water.

Potassa entirely free from water may be procured by other means besides the decomposition of the orange oxide of potassium, or the action of iron on common potash: for instance, by acting on potassium by a small quantity of water, or by heating potassium with common potash. The proportion of oxygene in potassa is learned by the action of potassium upon water: 8 grains of potassium produce from water about 9 cubical inches and a half of hydrogene; and for these there must be added to the metal four cubical inches and three quarters of oxygene.

5. It has been mentioned, page 64, that the number representing potassium is 75: and it appears from the experiments that the orange oxide of potassium must consist of 1 proportion of potassium 75, and 3 of oxygene 45; and the number representing it is 120. Potassa must consist of one proportion 75, and one of oxygene 15, and the number representing it is 90. Hydrat of potassa, or the potash prepared by alcohol, must contain one proportion of potassa 90, and one of water 17*.

6. When potassium is heated strongly in a small quantity of common air, the oxygene of which is not sufficient for its conversion into potassa, a substance is formed of a grayish colour, which, when thrown into water, effervesces without inflaming. This substance is likewise generated in experiments on the production of potassium by iron and hydrate of potassa, when a little common air is admitted into the barrel. It is doubtful whether it be a mixture of potassa and potassium, or a combination of potassium with a smaller quantity of oxygene than exists in potassa, that is, a protoxide of potassium. If a protoxide of potassium, it probably contains two proportions of potassium and one of oxygene.

7. I have already referred to the action of potassium and chlorine; the inflammation produced when thin pieces of potassium are introduced into chlorine is very vivid: potassium separates chlorine from hydrogene and phosphorus with inflammation; and when potassium is made to act upon sulphurane there is a violent explosion. The attraction of chlorine for potassium is much stronger than the attraction of oxygene; potassa, and the orange oxide of potassium, are immediately decomposed by chlorine, the chlorine combines with the metal, and the oxygene is set free.

The combination of chlorine and potassium is the substance which has been improperly called muriate of potash, and which, in common

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* In the few experiments that I have made on hydrat of potassa, there has been rather more water indicated, between 17 and 19 per cent.; but the potash I used was, I doubt not, adulterated with a little soda, as no particular care was taken to purify it, and hydrat of soda contains more water in proportion: and there is great reason to believe that 90 and 17 are the true estimation. M. M. Gay Lussac and Thenard allow about $\frac{1}{5}$ of water in potash.

cases, is formed by causing muriatic acid and solution of potassa to act upon each other, and by heating the mixture to redness; in which case the hydrogene of the acid, and the oxygene of the alkali are set free as water; and the metal of the alkali and the chlorine of the acid combine. From various analytical experiments it appears that muriate of potash, which may be called *potassane*, consists of 75 of potassium and 67 of chlorine, and the number representing it is 140. Potassane is the only known combination of potassium and chlorine.

8. There appears to be a gaseous combination of potassium and hydrogene; for I found that when potassium is heated strongly in hydrogene the gas contracts in volume, and becomes spontaneously inflammable, and gives alkaline fumes in its combustion. M. M. Gay Lussac and Thenard state that there is a solid compound of hydrogene and potassium, which may be obtained by heating the metal for a long while in the gas, at a temperature just below that of ignition. They describe it as a grayish solid, and state that it gives off its hydrogene by the action of mercury. As yet no experiments have been made on the proportions in which hydrogene and potassium combine.

9. Potassium and sulphur combine with great energy when they are heated together, producing much light and heat, even when the experiment is made out of the contact of air. The *sulphuret of potassium* is of a dark gray colour; acts with great energy upon water, producing sulphuretted hydrogene, and burns brilliantly when heated in the air, becoming the salt called sulphate of potash. From my experiments there is every reason to believe that this compound consists of one proportion of sulphur 30. and one of potassium 75, and the number representing it will be 105. Potassium has so strong an attraction for sulphur that it rapidly separates it from hydrogene; and potassium heated in sulphuretted hydrogene takes fire and burns with great brilliancy, and sulphuret of potassium is formed, and hydrogene set free.

10. Potassium and phosphorus enter into union producing light; but they act on each other with less energy than potassium and sulphur. The *phosphuret of potassium* in its common form is a substance of a dark chocolate colour; but when heated with potassium in great excess it becomes of a deep gray colour, and of considerable

lustre, so that it is likely that phosphorus and potassium are capable of combining in two proportions; probably the chocolate-coloured substance contains one proportion of each, and the dark gray substance two proportions of the metal.

The phosphuret of potassium burns with great brilliancy when exposed to air, and when thrown into water produces an explosion in consequence of the immediate disengagement of phosphuretted hydrogene.

11. When charcoal is present during the production of potassium, it usually contains a small quantity of carbonaceous matter; and charcoal that has been heated strongly in contact with potassium effervesces in water, and renders it alkaline, though previously exposed to a temperature at which potassium rises in vapour. These circumstances shew that there is an attraction, though feeble, between potassium and carbon; but as yet no compound of the two bodies of which the proportions can be assigned has been obtained.

12. Potassium like other metals has resisted all attempts to resolve it into other forms of matter. Since I first discovered it, and announced it as an undecompounded substance, there has been much discussion respecting its nature. M. M. Gay Lussac, Thenard, Ritter, and Dalton, supposed that it was a compound of hydrogene and potassa; but the first two chemists have allowed that the phænomena are incompatible with such an hypothesis; in this case potassium should form hydrat of potassa, or substances containing water in combustion, which is not the case; nor has hydrogene been in any instance obtained in experiments on potassium except when substances known to contain hydrogene were present; and it would not be more absurd to say that phosphorus is a compound of hydrogene and phosphoric acid, than to say that potassium is a compound of hydrogene and potassa.

13. Potassium, of all known substances, is that which has the strongest attraction for oxygene; and it produces such a condensation of it that the oxides of potassium are heavier than the metal itself. Potassium may be used as a general agent for detecting the presence of oxygene in bodies; and a number of substances undecomposable by other chemical agents are readily decomposed by this substance.

The compounds of potassium are of great use in the arts; potassa enters into the composition of soft soap, and the salts having a basis of potassa are many of them used in medicine.

3. *Sodium.*

1. *Sodium* may be procured exactly in the same manner as potassium, by electrical or chemical decomposition, the mineral alkali, or the alkali from the ashes of marine plants being used instead of pearl ashes. Rather a higher degree of heat is necessary for its production by the action of iron.

I discovered sodium a few days after I discovered potassium, in the year 1807.

2. In many of its characters it resembles potassium; it is as white as silver, has great lustre, and is a conductor of electricity. It enters into fusion at about 200° Fahrenheit, and rises in vapour at a strong red heat. Its specific gravity is between 9 and 10. When heated strongly in oxygene or chlorine, it burns with great brilliancy. When thrown upon water it effervesces violently, but does not inflame, swims on the surface, gradually diminishes with great agitation, and renders the water a solution of soda. It acts upon most substances in a manner similar to potassium, but with less energy. It tarnishes in the air, but more slowly, and like potassium it is best preserved under naphtha.

3. Sodium forms two distinct definite combinations with oxygene: one is pure soda, which has long been known, combined with water, in the substance which has been called by chemists *Soda*, but which was not examined in its uncombined state, till I formed it from the metal; the other is the orange oxide of sodium, which I observed in 1807; but of which the true nature was pointed out in 1810 by M. M. Gay Lussac and Thenard.

Pure soda may be made by burning sodium in a quantity of air containing no more oxygene than is sufficient for its conversion into the alkali, i. e. the metal must be in excess: a strong degree of heat must be applied.

Pure soda is of a gray colour, it is a nonconductor of electricity, of a vitreous fracture, and requiring a strong red heat for its fusion.

When a little water is added to it, there is a violent action between the two bodies; the soda becomes white, crystalline in its appearance, and much more fusible and volatile, and is then the substance which has been long known under the name of soda, but which may, with more propriety, be called *hydrat of soda*.

The *oxide of sodium* may be formed by burning sodium in oxygene gas in excess. It is of a deep orange colour, very fusible, and a non-conductor of electricity; when acted upon by water, it gives off oxygene gas, and the water becomes a solution of soda; it deflagrates when strongly heated with combustible bodies.

The proportions of oxygene in soda, and the orange oxide or peroxide of sodium, are easily learnt by the action of sodium on water, and on oxygene. If a given weight of sodium, in a little glass tube, be thrown, by means of the finger, under a graduated inverted jar filled with water, the quantity of hydrogene evolved will indicate the quantity of oxygene combined with the metal, to form soda; and when sodium is burnt slowly in a tray of platina, lined with dry common salt in oxygene in great excess; from the quantity of oxygene absorbed, the composition of the peroxide may be learnt. From experiments that I have made on this subject, compared with those made by M. M. Gay Lussac and Thenard, it appears that the number representing sodium is 88, and that soda consists of one proportion of sodium, and two of oxygene, 88 and 30: the oxide of sodium, of one proportion of sodium, and 3 of oxygene, 88 and 45: and hydrate of soda (soda prepared by alcohol) contains one proportion of sodium, two of oxygene, and two of water, and the number representing it is 152.

When sodium is kept for some time in a small quantity of moist air, or when sodium in excess is heated with hydrat of soda, a dark grayish substance is formed, more inflammable than sodium, and which affords hydrogene by its action upon water. It is probable that this is sodium in its first degree of oxygenation, or the *protoxide of sodium;* but as yet no experiments have been made on its constitution. If the protoxide, it is likely that it consists of one proportion of sodium, and one of oxygene.

4. Only one combination of sodium and chlorine is known: it is the important substance *common salt*. It may be formed directly

by combustion, or by decomposing any compound of chlorine by sodium. Its properties are well known; it is a non-conductor of electricity, is fusible at a strong red heat, is volatile at a white heat, and crystallizes in cubes. Sodium has a much stronger attraction for chlorine than oxygene; and soda or hydrate of soda is decomposed by chlorine, oxygene being expelled from the first, and oxygene and water from the second.

Potassium has a stronger attraction for chlorine than sodium has; and one mode of procuring sodium easily, is by heating together to redness common salt and potassium. The compound of sodium and chlorine has been called muriate of soda, in the French nomenclature; for it was falsely supposed to be composed of muriatic acid gas, and soda; and it is a curious circumstance, that the progress of discovery should have shewn that it is a less compounded body than hydrate of soda, which six years ago was considered as a simple substance, and one of its elements. According to the nomenclature which I have ventured to propose, the chemical name for common salt will be *sodane*.

Common salt consists of one proportion of sodium, 88, and two of chlorine, 134; and the number representing it is 222: when the proper corrections are made, the most accurate analyses, particularly those of Dr. Marcet, are found to agree with this number.

5. There is no known action between sodium and hydrogene, or azote.

6. Sodium combines readily with sulphur, and with phosphorus, presenting similar phænomena to those presented by potassium. The sulphurets and phosphurets of sodium agree in their general properties with those of potassium, except that they are rather less inflammable. They form by burning, compounds of sulphuric and phosphoric acid and soda, and therefore must contain two proportions of the inflammable substances, to one of sodium.

7. Sodium, when made from substances containing charcoal, usually affords charcoal by combustion; but as yet no definite combination of the two bodies has been obtained. No experiments have been made on the action of sodium on boron.

8. Potassium and sodium combine with great facility, and form peculiar compounds, which differ in their properties according to the

proportions of their ingredients. By a small quantity of sodium, potassium is rendered fluid at common temperatures, and its specific gravity considerably diminished. Eight parts of potassium, and one of sodium, form a compound that swims in naphtha, and that is fluid at the common temperature of the air. Three parts of sodium, and one of potassium, make a compound, fluid at common temperatures. A little potassium destroys the ductility of sodium, and renders it very brittle, and very soft.

9. The compounds of sodium are of great importance in the common arts, and are subservient to many of the wants of life. Soda is the most important ingredient in the different species of glass, and in hard soaps. The glasses are composed of soda united to earths and oxides; the soaps consist of soda, united to oily substances. Common salt is found abundantly in nature; it exists in small quantities in almost all waters and all soils. It diminishes the tendency of animal or vegetable substances to decompose, and probably preserves the ocean in a state fitted for the purposes of animal life. It is a part of the nourishment of animals, and though taken in very small quantities, seems to perform an important part in their œconomy.

10. The compounds formed by potassium and sodium, like the metals themselves, are possessed of strong resemblances; they may however be chemically distinguished by a very simple test; the diluted aqueous solutions of the compounds of potassium, render cloudy the nitro-muriatic solution of platina, which is not the case with similar solutions of the compounds of sodium. Most of the compounds of sodium differ from those of potassium, in containing double proportions of the other elements. Potassa contains one proportion of oxygene only; soda contains two, and the salts having potassa for their basis, contain only one proportion of acid, whilst those having soda for their basis, contain two. The attractions of potassium for all substances that have been examined, are stronger than those of sodium; and when sodium is procured from compounds, by the agency of potassium, 150 parts in weight of potassium, or two proportions, are required to produce 88 parts of sodium, or one proportion.

3. *Barium.*

1. There is a mineral substance found in Cumberland, Yorkshire, and other parts of Britain, called Witherite, or carbonate of baryta. By dissolving this substance in dilute solution of nitric acid, evaporating the solution to dryness, and heating the salt obtained to whiteness, a light fawn-coloured powder is procured, which is baryta or barium combined with oxygene. To obtain *barium*, a quantity of this substance is made into a paste, with water, and placed on a plate of platina; a cavity is made in the paste to receive a globule of mercury; the mercury is rendered negative, the platina positive, by means of a Voltaic battery, containing about 100 double plates.

In a short time an amalgam will be formed, consisting of mercury and barium. This amalgam must be introduced into a little tube made of glass free from lead, which must be bent in the form of a retort, filled with the vapour of naphtha, and hermetically sealed. Heat must be applied to the end of the tube containing the amalgam, till all the mercury has been driven off; there will remain a solid difficultly fusible metal, which is barium.

2. I first gained indications of the decomposition of baryta, in the end of October 1807, and I obtained an alloy of it with iron, in March 1808. The process of electrifying mercury, in contact with the earth, was pointed out to me in the course of my enquiries, by M. M. Berzelius and Pontin of Stockholm, in May 1808; and in the beginning of June in the same year, I obtained *the metal.*

3. Barium, as procured by heating the amalgam, appeared of a dark gray colour, with a lustre inferior to that of cast iron. It was considerably heavier than sulphuric acid, for though surrounded by globules of gas, it sunk immediately in that fluid. It instantly became covered with a crust of baryta, when exposed to air, and burnt with a deep red light, when gently heated. When thrown into water it effervesced violently, disappeared, and the water was found to be a solution of baryta.

Barium as yet has been obtained only in very minute quantities. I have never possessed enough of it to ascertain its general chemical and physical characters, and no experiments upon it have been published by any other person.

4. From some results that I have obtained, it seems probable that barium may be procured by chemical, as well as electrical decomposition. When baryta, or the salt improperly called muriate of baryta, ignited to whiteness, was exposed to the agency of potassium, that metal being sent through it in vapour, a dark gray substance appeared, diffused through the baryta, or the muriate, not volatile, that effervesces copiously in water, and that lost its metallic appearance by exposure to air:—the potassium in this process was converted into potassa.

5. The only well known combination of barium, with oxygene, is *baryta* or *baria*. It is of a pale grayish green colour. Its specific gravity is about 4, that of water being 1. This substance is a non-conductor of electricity, has a strong caustic taste, reddens turmeric, and renders green, vegetable blues. When acted upon by a small quantity of water, it heats violently, becomes white, unites to a proportion of water, and becomes a hydrate. The pure alkaline earth is infusible, except by an intense heat; the hydrate fuses at a strong red heat; a considerable part of its water is expelled by a still higher temperature. Baryta is soluble at 60°, in about 20 parts of water, and at 212° in about 2 parts. That baryta is composed of barium and oxygene, is proved by the combustion of barium in oxygene; in which, as I have found, oxygene is absorbed, and no product but baryta formed. It is likewise proved synthetically by the action of barium upon water, in which case hydrogene is evolved; and analytically it appears from the action of potassium on the earth. From indirect experiments, I am inclined to consider baryta as composed of 89.7 of barium, and 10.3 of oxygene: and supposing the earth to consist of one proportion of metal and one of oxygene, the number representing barium will be 130, and that representing the alkaline earth will be 145.

Barium, as would appear from the experiments of M. M. Gay Lussac and Thenard, is capable of combining with more oxygene than exists in baryta. These able chemists state, that when baryta is gently heated by a spirit lamp, in a glass tube filled with oxygene gas, an absorption of the gas takes place. As yet no experiments have been made on the properties of this *oxide of barium*, or on the quantity of oxygene it contains: probably baryta may be easily combined with oxygene, by heating it with hyper-oxymuriate of baryta. *The hydrat of baryta*, if its composition be estimated from M. Berthollet's experiments, consists of one proportion of baryta and one of water.

6. One combination only of barium and chlorine is known: it may be formed by heating baryta in muriatic acid gas, or in chlorine. In the first case, the oxygene of the baryta produces water by combining with the hydrogene of the acid; in the second it is expelled: and in an experiment made on purpose, I found that for every part in volume of chlorine absorbed, half a part of oxygene was given off from the alkaline earth. Hence it may be concluded that the compound of barium and chlorine contains one proportion of metal 130 and one of chlorine 67. This substance is fusible by a very strong heat, is very soluble in water; its taste is bitter, its colour white, it is crystalline and transparent. It is improperly called in the French nomenclature, muriate of baryta. According to the principles of nomenclature which I have proposed, its name will be *barane*.

8. No other combinations of barium, except those with oxygene and chlorine, have been as yet examined; there can, however, be little doubt that its powers of combination will be, in many respects, analogous to those of potassium and sodium, as of all metallic substances, it is the nearest related to these bodies.

9. The compounds of barium have as yet been applied to the arts in very few cases. Baryta is employed in small quantities, in the manufacture of certain kinds of porcelain; most of the salts containing baryta as a basis, are poisonous. The combination of baryta and carbonic acid, made artificially by pouring a solution of carbonate of ammonia, into a solution of nitrate of baryta, forms a pigment of a very pure white colour.

4. *Strontium.*

1. *Strontium* may be procured precisely in the same manner as barium; carbonate of strontia, or strontianite, a mineral found at Strontian in Scotland, being used instead of witherite. I first pro-

cured this metal in 1808, but in quantities too small to make an accurate examination of its properties. It seemed very analogous to barium, had not a very high lustre, appeared fixed, difficultly fusible, and not volatile. It became converted into strontia by exposure to air, and when thrown into water, decomposed it with great violence, producing hydrogene gas, and making the water a solution of strontia.

2 One combination of strontium with oxygene only is at present known; it is *strontia*, or strontites, the substance procured by burning strontium. It may be produced in large quantities by igniting strontianite intensely with charcoal powder, or by heating to whiteness the salt formed from this fossile, by the action of nitric acid. It appears of a light fawn colour, and agrees, in many of its characters, with baryta. It is fusible only by an intense heat. Its specific gravity is between three and four, water being one. It is soluble in about 200 parts of water, at common temperatures, and is much more soluble in hot than cold water; its taste is acrid and alkaline, it reddens paper tinged with turmeric. When acted upon by a small quantity of water, it becomes hot, its colour changes to white, and it is converted into a hydrate, and then becomes fusible at a white heat. From indirect experiments, I am disposed to regard it as composed of about 86 of strontium and 14 oxygene; and supposing it to contain one proportion of metal and one of oxygene, the number representing strontium will be 90, and that representing the earth 105.

3. No experiments have as yet been made on the direct combination of strontium and chlorine: but a substance which appears to consist of these two bodies, and no other elements, may be made, by heating strontia strongly in chlorine, or muriatic acid gas, or by igniting to whiteness the salt formed by the solution of strontianite in muriatic acid. By the action of chlorine on strontia, oxygene is expelled: by the action of muriatic acid gas upon it, water is formed. The compound of chlorine and strontium, or *strontane*, is a white substance, difficultly fusible, fixed in the fire, a non-conductor of electricity, and of a peculiar bitter taste; when brought in contact with the flame of wax, tallow, oil, or alcohol, it tinges it of a rose colour; and this is a distinctive character of the compounds of

strontium; the salts formed from it give this tint to flame, those of baryta give a yellow tint. From direct experiments I ascertained that 50 parts of strontane consisted of about 29 parts of metal and 21 of chlorine; so that it must be regarded as composed of one proportion of strontium, and one of gas, 90 and 67.

4. No experiments have as yet been made on the action of strontium on any of the other elementary substances.

5. None of the compounds of this body have as yet been applied to any of the purposes of the arts, and its combinations are rare in nature.

5. *Calcium.*

1. *Calcium* may be obtained by the same processes as barium and strontium. Mild calcareous earth, or chalk, being used instead of witherite and strontianite; or common well-burnt lime may be employed for making the paste, from which the mercurial amalgam is to be formed by Voltaic electricity.

I first procured calcium about the same time as barium and strontium, but only in very minute quantities, so that little can be said concerning its nature. It appeared brighter and whiter than these two metals, and burnt, when gently heated, producing dry lime. I have had no opportunity of examining its general physical and chemical qualities.

2. There is only one known combination of calcium and oxygene, which is the important substance, *lime* or *calcia*. The nature of this substance is proved by the phænomena of the combustion of calcium; the metal becomes converted into the earth, with the absorption of oxygene gas. When the amalgam of calcium is thrown into water, hydrogene gas is disengaged, and the water becomes a solution of lime; and from the quantity of hydrogene gas disengaged, compared with the quantity of lime formed in experiments of this kind, M. Berzelius has endeavoured to ascertain the proportion of oxygene in lime. The nature of lime may be also proved by analysis; when potassium in vapour is sent through the earth, ignited to whiteness, the potassium, I have found, becomes potassa, and a dark gray substance of metallic splendour, which is calcium either

wholly or partly deprived of oxygene, is found embedded in the potassa, and it effervesces violently, and forms a solution of lime, by the action of water.

Lime is obtained for common purposes, from marble of the whitest kind, such as the Parian or Carara marble, by long exposure to a strong heat. It is a white soft substance, of specific gravity 2.3. It requires a intense degree of heat for its fusion, and has not yet been rendered volatile. Its taste is analogous to, but milder than that of baryta and strontia. It is soluble in about 450 parts of water, and seems to be nearly as soluble in cold, as in hot water. It acts upon vegetable colours in a manner similar to the other alkaline earths. When water, in small quantities, is added to it, a considerable heat is produced, a portion of the water combines with the lime, and it becomes a hydrate; but water does not adhere to it with the same degree of energy, as to baria and strontia, for it may be expelled by a strong red heat. From the experiments of M. Berzelius, and those which I have made, it appears that lime consists of about 20 of metal to 7.5 of oxygene, and the number representing calcium is 40, and that representing lime 55; and the *hydrate of lime* must consist of 55 lime and 17 water, which estimation agrees with the experiments of M. Lavoisier and Mr. Dalton.

I have attempted to combine lime with more oxygene, but without success.

3. When lime is heated strongly in contact with chlorine, oxygene is expelled, and chlorine absorbed; and, as happens in all the decompositions of metallic oxides, of which the metals combine with only one proportion of oxygene and chlorine for every two in volume of chlorine absorbed, a volume of oxygene is expelled. The substance formed by the action of chlorine on lime, as the oxygene of the lime is expelled, must evidently consist of chlorine and calcium. It has been called dry muriate of lime; according to the true view of its composition, it may be called *calcane*. It is a semi-transparent crystalline substance, fusible at a strong red heat, a non-conductor of electricity, has a very bitter taste, rapidly absorbs water from the atmosphere, and is extremely soluble in water; by the evaporation of its solution at a low heat, crystals may be obtained, which consist of calcane, combined with more than a third their

weight of water. From my experiments, it appears that calcane consists of 31 chlorine and 19 of calcium, and hence it may be supposed to contain one proportion of the metal, and one of the gas, and the number representing it on this idea is 107; and it is evident, from the experiment on the action of chlorine on lime, that the proportion of oxygene in lime, and of chlorine in calcium, must be in the ratio of 15 to 67.

4. As yet no experiments have been made on the combinations of calcium with any of the inflammable, or acidiferous substances, or metals.

5. The compounds of calcium are found abundantly on the surface of the globe, and are of great importance in the œconomy of nature, and in the processes of art. Lime combined with carbonic acid is an essential part of fertile lands: a number of rocks are constituted by this substance. Gypsum or alabaster, is lime combined with sulphuric acid; and the earth of bones consists of lime united to phosphoric acid. There is no animal or vegetable substance that does not contain larger or smaller quantities of calcareous matter. The uses of lime in mortar are well known. Quicklime, employed as a manure, tends to decompose and dissolve inert vegetable matter, and renders it proper for the nourishment of plants; and in this operation the lime is united to carbonic acid, and becomes a permanent part of the soil. In the process of tanning, lime is employed to remove the hair from the skins of animals, and it is used in certain operations of bleaching, dyeing, and other useful arts.

6. *Magnesium.*

1. *Magnesium*[*] may be procured from the earth called magnesia, which is the same as the calcined magnesia of druggists, by processes similar to those referred to in the three preceding sections; but

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[*] In my first paper on the decomposition of the earths, published in 1808, I called the metal from magnesia, magnium, fearing lest, if called magnesium, it should be confounded with the name formerly applied to manganese. The candid criticisms of some philosophical friends have induced me to apply the termination in the usual manner.

a much longer time is required to produce an amalgam of magnesium and quicksilver, by electrical powers, than to produce amalgams of the metals of the other alkaline earths.

I succeeded in decomposing magnesia likewise, in the following manner: I passed potassium in vapour through magnesia, heated to intense whiteness, in a tube of platinum, out of the contact of air; I then introduced a small quantity of mercury, and heated it gently for some time in the tube. An amalgam was obtained, which by distillation, out of the contact of the atmosphere, afforded a dark gray metallic film, which was infusible at the point at which plate glass softened, and which, in the process of distillation of the mercury, rendered the glass black at its point of contact with it. This film burnt when heated strongly, with a red light, and became converted into a white powder, which had the character of magnesia: when a portion of the metal was thrown into water, it sunk to the bottom, and effervesced slowly, becoming covered with a white powder; by adding a little muriatic acid to the water, the effervescence was violent; the metal rapidly disappeared, and the solution was found to contain magnesia.

I have made several experiments with the hope of obtaining larger quantities of magnesium, such as might have enabled me to examine its chemical and physical properties; but without success. It is very difficult to procure a pure amalgam of magnesium by potassium and mercury; the heat must be intense; and at a high temperature, potassium acts with great energy upon platina, so that unless the tube is very solid, it is destroyed in the process, and when the heat is not very great, potassium remains in the tube, which is found afterwards in the amalgam. The potassium may however be separated by the action of water; which, even in the amalgam, rapidly converts it into potassa, but which has a much feebler action on magnesium. When the amalgam contains potassium, it likewise usually contains platinum, which is very soluble in the compound of potassium and quicksilver.

2. There is only one known compound of magnesium and oxygene, which is the substance from which the metal is procured, *Magnesia*. That magnesia consists of magnesium and oxygene, is proved both by analysis and synthesis. In the production of mag-

nesium by potassium, the potassium is found converted into potassa, and therefore must have gained oxygene from the magnesia; and in the formation of magnesia from magnesium, oxygene is absorbed. No experiments have as yet been made to determine the proportions of the elements in magnesia; but from experiments which I have made on the combinations of this substance with acids, assuming that they are single proportions, I am inclined to adopt 53 as the number representing it; and if it be supposed to be constituted by one proportion of metal, and one of oxygene, the number representing the metal will be 38.

Magnesia appears in its common form, as a white soft powder; its specific gravity is between 2 and 3. It is found in nature in the crystalline form; specimens have been brought from North America, which nearly resemble talc in their external characters. Magnesia has scarcely any taste, no smell; it reddens turmeric. It is infusible, except by the intense heat produced by the combustion of hydrogene gas in oxygene, or that generated by Voltaic electricity. It is scarcely soluble in water, but produces heat when water is mixed with it, and it absorbs a considerable portion of the fluid. When it is procured by the decomposition of a solution in which it is combined with an acid, by means of solution of potassa or soda, it falls down in union with water, as a hydrat; but the water adheres to it with a very feeble attraction only, and is expelled entirely at a red heat. *Hydrat of magnesia*, when dried at 212°, appears in coherent semitransparent masses, very brittle and soft; it contains about $\frac{1}{4}$ of its weight of water.

3. When magnesia is strongly heated in contact with chlorine, chlorine is absorbed, and oxygene expelled, and in the usual proportions as to volume. Hence it is evident that there exists a combination of magnesium and chlorine; though this body, which may be called *magnesane*, has never been examined in a separate state. The salt called muriate of magnesia, is a compound of magnesane and water, and when it is acted on by a strong red heat, by far the greatest part of the chlorine unites to the hydrogene of the water, and rises in the form of muriatic acid gas, and the oxygene of the decomposed water combines with the magnesium to form magnesia; some

magnesane is, however, found mixed with the magnesia, which affords crystals of muriate of magnesia by the action of water.

4. No experiments have as yet been made on the action of magnesium upon any of the inflammable or metallic substances.

5. The compounds of magnesium occur extensively diffused in nature. Magnesia exists in certain limestones which are found in different parts of Great Britain and Ireland, and which are less fitted for the general purposes of manure than common limestone. Magnesia, in its uncombined state, as appears from the experiments of Mr. Tennant, is injurious to plants, but united to carbonic acid, it seems to form an useful part of the soil: the magnesian limestones are distinguished by their slow solution in acids; and they render weak solutions of nitric acid turbid by their action upon them. Magnesia, and some of its saline combinations, are used in medicine; its application in bleaching has been referred to in an early part of this work.

7. *Aluminum.*

1. When a solution of ammonia or of potassa, not in excess, is thrown into a solution of alum, a substance falls down, which when well washed, and dried at a red heat, is alumina. This substance appears to contain a peculiar metal, but as yet aluminum has not been obtained in a perfectly free state, though alloys of it with other metalline substances have been procured sufficiently distinct to indicate the probable nature of alumina. Alumina cannot be decomposed by the electrization of mercury in contact with it, in the same manner as the alkaline earths. The first experiment by which I obtained evidences of its composition, was made in 1808, by fusing iron negatively electrified in contact with it; the earth was moist in this process, and a very high Voltaic power was applied. The globule of metal obtained was whiter than pure iron; effervesced slowly in water, becoming covered with a white powder, and the solution in muriatic acid decomposed by an alkali, afforded alumina and oxide of iron.

By passing potassium in vapour, through alumina heated to whiteness, the greatest part of the potassium became converted into potassa, which formed a coherent mass with that part of the alumina not decompounded, and in this mass there were numerous gray particles, having the metallic lustre, and which became white when heated in the air, and which slowly effervesced in water. In a case in which a similar experiment was made, a strong red heat only being applied to the alumina, a mass was obtained, which took fire spontaneously by exposure to air, and which effervesced violently in water, and which probably contained the basis of alumina united to potassium.

2. That oxygene exists in alumina, cannot be doubted, when the conversion of potassium into potassa by its action upon it, is considered; and that it contains an inflammable substance united to oxygene, seems likewise evident; and that this is metalline in its nature appears extremely likely, both from the facts detailed, and from analogy; but this point cannot as yet be considered as demonstrated.

Alumina, in the form in which it is usually obtained, has no taste nor smell, adheres strongly to the tongue, has no action upon vegetable colours, is insoluble in water, is soluble in all the mineral acids and in hot solutions of fixed alkalies. When the precipitate from solutions of alum has been dried only at the temperature of the atmosphere, it is found combined with nearly an equal weight of water, and then appears as a white powder or a gelatinous substance. There is a native *hydrat of alumina* found in different parts of the world, crystallized and transparent, and which has been called wavellite: from Mr. Gregor's experiments, and my own, it appears that this substance contains about 28 per cent. of water.

No direct researches have been made on the quantity of oxygene in alumina; but from some experiments that I made on the quantity of ammonia required to decompose saturated solutions of alumina in acids, it would appear that the number representing alumina is about 48, and supposing it to consist of one proportion of aluminum, and one of oxygene, 33 will be the number representing aluminum.

3. No substance is known that can be regarded as a compound of chlorine and aluminum. Alumina is soluble in solution of muriatic acid; but by heating the salt obtained, muriatic acid gas rises, and alumina remains behind.

4. The compounds of alumina are found abundantly in the mineral kingdom, and many of them are of great importance in the common arts. Alumina forms a part of the greater number of rocks, and is found in larger or smaller quantities, in almost all soils. In its crystallized form coloured by small quantities of iron, it constitutes a beautiful class of gems, distinguished by the name telesia, including the ruby, the sapphire, the oriental topaz, and other hard and brilliant stones.

Alumina combined with silica and other substances, forms the varieties of porcelain and china-ware. Its acid combinations are used to a great extent in dyeing and calico printing for fixing colours on stuffs.

8. *Glucinum.*

1. There is an earth which was discovered by Vauquelin in 1798, called glucine, or glucina. It may be obtained from the beryl or the emerald, by the following process: the stone, in fine powder, must be ignited for half an hour in a crucible of silver or platina, with three times its weight of hydrat of potassa or soda. The mass must be dissolved in solution of muriatic acid, and the compound obtained exposed to heat till it is dry. Water is then added to it, and the aqueous solution obtained acted on by solution of carbonate of potassa; a white powder is obtained, which must be dissolved in diluted oil of vitriol not added in excess; a little of the salt called vitriolated tartar, or sulphate of potassa, must be mixed with the solution, and the whole evaporated till it begins to crystallize; crystals of alum will form. When no more can be obtained, the remaining liquor must be mixed with solution of carbonate of ammonia added in great excess; the mixed liquor must be passed through bibulous paper, evaporated to dryness, and the solid matter remaining heated to redness; it is then *glucina.*

2. There is great reason to believe that glucina is a compound of a peculiar metallic substance, which may be called *glucinum*, and oxygene. The evidence that such is its composition, I have obtained, by heating it with potassium in the same manner as alumina; the potassium was for the most part converted into potassa, and dark co-

loured particles having a metallic appearance were found diffused through the mass, which regained the earthy character by being heated in the air, and by the action of water, and in this last case hydrogene was slowly disengaged.

3. Glucina in its pure form appears as a white powder without taste or smell ; it requires an intense degree of heat for its fusion ; it is not soluble in water in any perceptible degree ; it does not alter the colour of vegetable blues or yellows. When it is thrown down from an acid solution, by an alkali, it exists in combination with water, as a hydrat. It forms sweet-tasted salts soluble in water, with the acids, and hence it gained its name, from γλυκυς, sweet. From experiments on the quantity of ammonia necessary to decompose the muriate of glucina, I am inclined to adopt 54 as the number representing the earth, and supposing it a protoxide, 39 as the number representing the metal.

4. No compounds have been as yet examined in which glucinum can be supposed to exist, uncombined with oxygene. Glucina has not as yet been applied to any of the purposes of the arts, and its combinations in nature are very rare.

9. *Zirconum.*

1. There is a peculiar earth, which was discovered by M. Klaproth, in 1793, and which may be procured from a stone found in Ceylon, and called the jargon, or zircon, and likewise from the hyacinth, by the following process. The powder of those stones must be ignited for a long while with hydrat of potassa ; the substance which is not dissolved by the hydrate of potassa, is principally zircon. The soluble matters must be separated by water, and the insoluble matter boiled in muriatic acid, and the solution so obtained, evaporated to dryness, and heated to the temperature of 212°. An aqueous solution of zircona in muriatic acid, is obtained by the action of water on the solid mass; and pure zircona is procured by decomposing this solution by solution of ammonia, and heating the powder obtained to redness.

2. There is the same evidence for believing that *zircona* is a compound of a metal and oxygene, as that afforded by the action of potas-

sium on the other earths. The alkaline metal when brought into contact with zircona ignited to whiteness, is for the most part converted into potassa, and dark particles, which, when examined by a magnifying glass, appear metallic in some parts, of a chocolate brown in others, are found diffused through the potassa and the undecompounded earth.

3. Zircona appears as a harsh whitish powder without taste or smell; it possesses no action on vegetable colours, and is insoluble in water; its specific gravity is rather above 4. It is fusible at a lower temperature than any of the other earths; the heat of a good forge is sufficient to soften it. In a mass it is very hard, and scratches rock crystal. Zircona is insoluble in water, but when precipitated from its solution, and dried at a low temperature, is found in the state of a hydrat; and has an appearance like that of resin or glue, its particles adhere together; the hydrat contains more than $\frac{1}{3}$ of its weight of water. Zircona is soluble in the mineral acids and in solutions of alkaline carbonates. From experiments I have made on the comparative saturating powers of ammonia and zircona, I am disposed to give 85 as the number representing the earth, and 70 as the number representing the metal; supposing the earth to be a protoxide.

4. No substance has as yet been formed or examined, in which zirconum can be supposed to exist free from oxygene. It forms a crystallised muriate when dissolved in muriatic acid; but the muriatic acid is expelled by heat, without any apparent union of chlorine and the metal. Its combinations therefore must be objects of future enquiry.

Zircona has not yet been found in sufficient quantities, to be applied to any of the purposes of the arts. It combines with the other earths, and forms compounds analogous to porcelain.

10. *Silicum.*

1. Pure transparent quartz, or rock crystal, consists almost entirely of a peculiar earth called silex or silica: this earth may be procured from that stone or from common flints by igniting them in powder, with three or four times their weight of hydrat of potassa,

or soda, in a silver crucible, making an aqueous solution of the substance so obtained, and adding to it any acid in quantities barely sufficient to neutralize the alkali; a gelatinous substance separates, which is silica combined with water; and the pure earth may be obtained by washing this substance well, and then igniting it to whiteness.

2. That *silica* consists of oxygene united to a peculiar inflammable basis, which is probably metallic, is shewn by many experiments. When iron is negatively electrified, and fused by the Voltaic battery in contact with hydrat of silica, the metalline globule procured contains a matter which affords silex during its solution; and when potassium is brought in contact with silica ignited to whiteness, a compound is formed consisting of silica and potassa, and black particles not unlike plumbago are found diffused through the compound. From some experiments I made, I am inclined to believe that these particles are conductors of electricity; they have little action upon water, unless it contain an acid, when they slowly dissolve in it with effervescence; they burn when strongly heated, and become converted into a white substance having the characters of silica; so that there can be little doubt, both from analysis and synthesis, of the nature of silica; but no direct experiments have as yet been made upon the proportion of oxygene it contains.

3. Silica is a white powder, very analogous in its physical characters to the other earths; in its state of hydrate it is soluble in alkaline lixivia, and likewise in acids. It is separated from the common mineral acids by a very gentle heat, they rise from it in vapour, but it forms permanent compounds with boracic, phosphoric, and fluoric acids; its compound with phosphoric and boracic acids is a white powder, that with fluoric acid a permanent gas. From some experiments I have made on the quantity of ammonia necessary to decompose the saturated solution of silica in muriatic acid, and from the composition of its gaseous fluoric combination, as ascertained by my brother Mr. John Davy, I estimate the number representing silica as 61; and as it seems to combine with double proportions of acids, I am inclined to regard it as a deutoxide, composed of 31 basis, and 30 oxygene.

4. No compound of silicum and chlorine is known; and as this

substance has never been procured in masses, or even in an insulated state, its action upon the other undecompounded substances has not been examined.

5. Silica is one of the earths most generally diffused in nature. It forms perhaps the largest part of the solid surface of the globe. It is of great use in many of the arts; it is the basis of glass and porcelain, and the art of manufacturing these substances depends upon the attraction of silica for other metallic oxides.

11. *Ittrium.*

1. There is a mineral substance called Gadolinite, found at Itterby in Roslagen in Sweden, in which a peculiar earth was discovered in 1794, by Mr. Gadolin, and to which the name of *ittria* has been given. To procure this earth, the pulverized fossile must be digested for a considerable time in solution of muriatic acid. The solution obtained must be evaporated to dryness, redissolved in distilled water, and precipitated by caustic ammonia; the precipitate obtained must be digested with solution of hydrat of potassa; the remaining substance must be redissolved in solution of muriatic acid not used in excess, succinate of soda must be poured into this solution till all precipitation is complete; the filtered liquor must be decomposed by carbonate of soda, a white powder will fall down, which, when ignited strongly, is pure *ittria.*

2. When ittria is treated with potassium in the same manner as the other earths, similar results are obtained; the potassium becomes potassa, and the earth gains appearances of metallization, so that it is scarcely to be doubted that ittria consists of inflammable matter, metallic in its nature, combined with oxygene.

3. Ittria appears as a white powder, without taste, smell, or power of action on vegetable colours; it requires an intense degree of heat for its fusion; it is not soluble in water. No experiments have been made to ascertain whether it forms a hydrat with water, but this is most probably the case; its specific gravity is greater than that of any of the other earths, being more than 4.5. It combines with the acids, and forms sweet-tasted salts with those in which it is soluble. With acetic and sulphuric acids it forms crystals of an amethyst co-

lour. It is not acted upon by solutions of caustic alkalies; it is slightly soluble in solution of carbonate of ammonia.

4. It is probable that a compound of chlorine and ittria may be obtained; but as yet no experiments have been made on any compounds of this substance, except such as contain oxygene; the proportion of oxygene in ittria cannot be determined from any experiments hitherto published. According to Klaproth, 55 parts of ittria combine with 18 parts of carbonic acid; consequently, if it be supposed that the carbonate of ittria consists of one proportion of acid, and one of earth, the number representing ittria will be 126; and on the hypothesis that ittria consists of one proportion of metal, and one of oxygene, which is probable from all analogy, the number representing ittrium will be 111.

5. The compounds of ittria are very rare in nature, and as yet no application of this substance has been made to any of the purposes of the arts.

12. *Manganesum.*

1. The mineral called manganese has been referred to, page 128; it consists of a peculiar metal, *manganesum*, united to oxygene. To procure the pure metal, solution of muriatic acid must be distilled from manganese in fine powder, the mixture strongly heated, and the process repeated till the washings in pure water give only a white precipitate with a solution of the salt called prussiate of potassa and iron; an aqueous solution of potassa is then added to the mixture, so as to render it alkaline; the whole is then poured on a filtre, and the solid matter obtained well washed, dried, mixed with charcoal powder and oil, and intensely heated for half an hour in an infusible earthen crucible lined with charcoal powder; a number of small metallic globules will be obtained, which are globules of manganesum.

2. *Manganesum* was first procured in its pure form by Kaim and Gahn, between 1770 and 1775. It is of a grayish white colour, it has not much lustre; its hardness is nearly that of iron; the specific gravity is about 6.850. It is very brittle. It requires a higher degree of heat than iron for its fusion. It immediately tarnishes in the

air, and becomes gray, brown, and at last black; when strongly heated in contact with oxygene, it burns with great brilliancy, throwing off vivid sparks; when heated in chlorine, it takes fire and burns. It dissolves with effervescence in the mineral acids.

3. There are two definite combinations of manganesum and oxygene, one dark olive, and one brownish black. The first, or *olive oxide*, may be obtained by dissolving common manganese in nitrous acid, adding a little sugar, and precipitating by solution of potassa; a white powder is obtained, which must be heated to redness out of the contact of air; it is then the substance in question. The same body may be formed by precipitating the muriatic or sulphuric solutions of manganese by potassa, and treating the precipitate by heat; the white powder, when exposed to air, rapidly changes its colour to yellow, then puce colour, and lastly red brown: to be preserved, it should be washed in *boiling* water, which contains little air, and the water driven off from it in a retort filled with hydrogene gas.

The *dark olive oxide of manganesum* in its pure form, when examined in large quantities, appears almost black; but when spread upon white paper, its olive tint is apparent. It takes fire when gently heated, increases in weight, and gains a browner tint. It slowly absorbs oxygene from the air, even at common temperatures. It is the only known oxide of manganesum which dissolves in the acids without effervescence. The white powder produced by the action of acids on solutions of this oxide is a compound of the oxide and water, or the *hydrated oxide of manganesum;* and the different tints that it assumes by exposure to air, seem to depend upon the formation of smaller or larger quantities of the dark brown oxide, which probably retains the water contained in the white hydrat, and in this state is deep puce coloured; and when the water is expelled from it, it becomes dark brown, and then appears to be the same substance as the native oxide of manganesum, which may be called the *peroxide of manganesum*. The specific gravity of the peroxide is about 4; it is not capable of being combined with any of the acids; it gives off oxygene gas by a strong heat, as has been already stated, and by intense ignition it is partly or wholly converted into the first or olive oxide of manganesum. From some experiments that I have made on the two oxides of manganese, I conclude that the olive oxide consists of about 21 of oxygene to 79 of metal, and that the dark brown oxide contains nearly ten per cent. more of oxygene. According to these estimations, supposing the olive oxide a deutoxide, or an oxide containing two proportions of oxygene, the number representing manganesum will be 113; and the olive oxide will be represented by 143; and the dark brown oxide by 158, that is, it must be a tritoxide, or an oxide containing three proportions of oxygene. The white hydrated oxide of manganesum appears from my experiments to contain about 24 per cent. of water. Hence it may be regarded as consisting of one proportion of olive oxide of manganesum 143, and 34 of water, and the number representing it is 177. This hydrat is erroneously described in chemical books as the oxide of manganesum containing the smallest quantity of oxygene; and there are many other cases in which hydrats have been confounded with oxides.

It has been supposed that there is a peculiar oxide of manganese, which may be procured by alkalies from the sulphuric solution; but when this solution is concentrated, the precipitate is the pale hydrat, having a very slight tint only of puce colour, apparently from the formation of a little of the other oxide in consequence of the absorption of oxygene from the air dissolved in the alkaline solution used for its precipitation. It has been likewise conceived that there is a green oxide of manganesum; the olive oxide becomes green by the action of potassa; but in this case a combination takes place between the alkali and the oxide. I have made many experiments on the native dark oxide by exposing it at different intervals for several hours to intense heat: in these cases it passed through different shades of brown and olive brown, and finally became dark olive. Colour is too indefinite a property to found a definite species upon; a mere change of temperature, without any evident change in composition, alters the colours of many bodies; and it is very probable that the different shades of colour of different precipitates from solutions of manganesum depend upon mixtures of the white hydrat with the puce-coloured hydrat formed at the time of precipitation by the absorption of oxygene from the air in the fluid, and the white hydrat seems to be always the result of the action of alkali on solutions, in cases when there can be no interference from the influence of free or loosely combined oxygene.

4. A compound of chlorine and manganesum may be obtained by combustion of the metal in chlorine, or by heating strongly the substance obtained by the solution of manganese in muriatic acid. When made in this last way, it appears as a pale pink-coloured substance, and semitransparent, and in brilliant scales. This compound has been described by Mr. J. Davy as consisting of chlorine and manganese, and from his experiments may be considered as consisting of one proportion of the metal 113, and two of chlorine 134. It is probable that another compound consisting of one proportion of the metal and two of chlorine may be formed.

5. Hydrogene, azote, sulphur, and charcoal, have no distinct chemical action on manganesum.

6. Phosphorus has been combined with manganesum by Pelletier; the *phosphuret* is a substance possessing metallic lustre and very combustible; its constitution has not yet been ascertained.

7. The action of boron, and the metals of the alkalies, and earths, on manganesum has not yet been tried.

8. Manganesum in its oxidated form is of considerable use in certain arts. Its application for the production of chlorine has been already described. It is employed in glass-making, for depriving glass of colour: when in its state of full oxidation it gives a purple tint to glass, which is destroyed by thrusting a piece of wood into the melted glass, the inflammable matter of which seizes upon a part of its oxygene.

It is in some cases used to give colours to enamels in the manufacture of porcelain. The changes of colour of glass containing oxide of manganesum, according to its different states of oxidation, are easily exemplified by adding a little dark oxide to powdered glass mixed with borax, and fusing them by the blow pipe: as long as the globule is preserved within the blue flame, where there is combustible matter, it remains colourless; but when it is exposed to air at the extreme point of the flame it becomes purple. I am inclined to believe that the deutoxide is the only oxide which enters into combination with vitrifiable substances; and that the peroxide when formed is mechanically diffused through the glass, and being produced only in very minute quantities is transparent and coloured. There is great reason to believe that the colouring matters of many gems are merely oxides finely divided in a state of mechanical diffusion through their substance.

13. *Zinc or Zincum.*

1. Zinc is procured for the purposes of commerce from various ores known by the names of calamine and blende or black jack. To obtain the metal from calamine, which is a combination of zinc with oxygene and carbonic acid, the ore is strongly ignited with charcoal or carbonaceous substances; the zinc, which is volatile, rises at a strong red heat, and becomes condensed in the cool part of the furnace or retort in which the process is carried on. Zinc is procured from blende by a similar operation, but the blende must be previously roasted, that is, exposed for a long while to a dull red heat in a state of minute division. The zinc of commerce is seldom quite pure; to obtain it in this state white vitriol or sulphate of zinc is dissolved in pure water and exposed to the action of a plate of common zinc; this will separate any volatile metals that may happen to exist in the solution, which is then to be precipitated by subcarbonate of potassa: the white precipitate ignited with charcoal powder affords the metal.

2. Zinc is of a bluish white colour. Its hardness is nearly equal to that of copper. Its specific gravity varies from 6.8 to rather more than 7. When hammered it is 7.2. Its fusing point is 680° Fahrenheit; at a red heat in close vessels it volatilizes; and at this temperature in the atmosphere it burns with a brilliant bluish white flame. It has a certain degree of ductility, and when heated a little above 212° Fahrenheit, it is malleable, and when annealed it may be passed through rollers, and obtained in small thin sheets or leaves; it may be drawn into wire, the tenacity of which, according to Muschenbroek, is such, that a wire of $\frac{1}{10}$ of an inch in diameter will support a weight of about 26lbs. Its capacity for heat, according to Wilcke, is 0.102.

The atmosphere has but little effect on zinc at common temperatures; by exposure to the air for some time it acquires a grayish colour on the surface, which is owing to a partial oxidation. Zinc filings very slowly decompose water, hydrogene gas is evolved, and oxygene combines with the metal. The effect is rapidly produced when steam is passed over zinc at elevated temperatures. Zinc in thin leaves introduced into chlorine takes fire, and burns with a white light; even when in thick wire it may be made to burn in this gas by a gentle heat.

3. There is one well-known combination of zinc with oxygene; it is obtained by the combustion of zinc in the atmosphere, or by the precipitation of solutions of zinc in acids by alkalies and subsequent ignition. When examined in a state of minute division, such as it appears when obtained by combustion, it is white, and similar to cotton in its appearance; but when examined in mass it has a tint of pale yellow. It becomes fluid at a white heat, and is capable of being volatilized by an intense white heat. It is soluble in most of the acids, and in aqueous solutions of the fixed alkalies; when precipitated from its acid solutions by alkalies, it is in the state of combination with water, and a strong red heat is required for the expulsion of the water with which it is combined. From my experiments, and those made by my brother Mr. John Davy, it appears that the *white oxide of zinc* contains about 82 parts of metal and 18 of oxygene. M. Proust gives 80 to 20, which is not a wide difference. On the estimation of 18 per cent., supposing that the oxide of zinc consists of one proportion of oxygene and one of metal; the number representing zinc is 66 taking away the fractional part; the oxide of zinc is represented by 81; and the hydrate, supposing it to contain one proportion of water, will be denoted by 17 added to 81; but as yet no experiments have been made to shew that this is the composition of the hydrate. It has been supposed that there is a gray oxide of zinc produced by keeping zinc melted in the open air; and a yellow oxide formed by fusing the white powder produced by precipitation from acids, both containing less oxygene than the oxide just described; but there are no facts to warrant the idea that these bodies are distinct compounds of zinc and oxygene. The gray powder formed upon the surface of melted zinc, I am inclined to consider as a mixture of the white oxide with small particles of un-

burnt zinc, and the yellow oxide the same as the oxide produced by combustion free from water.

4. When zinc is burned in chlorine a solid substance is formed of a whitish gray colour, and semitransparent. This is the only compound known of zinc and chlorine. It may likewise be made by heating together zinc filings and corrosive sublimate; it is as soft as wax, fuses at a temperature a little above 212°, and rises in the gaseous form at a heat much below the red heat. Its taste is intensely acrid, and it corrodes the skin; it acts upon water and dissolves in it, producing much heat, and its solution decomposed by an alkali affords the white hydrated oxide of zinc. The compound of zinc and chlorine has been called butter of zinc and muriate of zinc; following the nomenclature already proposed its name will be *zincane;* from the experiments of my brother, Mr. John Davy, it consists of nearly equal parts by weight of zinc and chlorine; consequently it contains one proportion of metal and one of gas 66 and 67, and the number representing it will be 133.

5. It is not easy to combine zinc and sulphur. When a solution of sulphuretted hydrogene and an alkali is dropped into an acid solution of zinc, a whitish powder falls down, which has been supposed to be a *sulphuret of zinc.* When zinc and sulphur are heated together in close vessels the sulphur rises in vapour without uniting to the zinc; but it is stated by Mr. E. Davy, that in some experiments made in the laboratory of the Royal Institution, in which sulphur in vapour was passed over melted zinc, they united, and formed a white crystalline substance, analogous to the substance found in nature, and called phosphorescent blende. The proportions of the elements in the blendes, or supposed sulphurets of zinc, have not yet been ascertained with accuracy; but if some experiments on record can be depended upon, they must contain two proportions of metal to one of sulphur.

6. Zinc combines with phosphorus, when the metal is fused and the phosphorus brought in contact with it. The *phosphoret of zinc* was discovered by Pelletier; it is possessed of metallic splendour, and is of a dull gray colour analogous to lead; when hammered or filed it emits the odour of phosphorus. From experiments made on its composition in the laboratory of the Royal Institution by Mr. E.

Davy, it is probable that it consists of one proportion of phosphorus and one of metal.

7. Zinc has not been combined with hydrogene, azote, or boron: zinc sometimes during its solution in acids leaves a residuum having the characters of carbonaceous matter: but no definite compound of zinc and carbon has as yet been described.

8. Zinc readily enters into union with the metals of the fixed alkalies; great heat is produced during the process, and metallic compounds or alloys are obtained, which rapidly decompose water, and tarnish in the atmosphere.

9. Zinc is applied to a number of important uses; it is particularly employed in the manufacture of brass and tombacs; which consist of this metal combined with different proportions of copper. It is used by the Chinese in various alloys: some of its combinations are employed in medicine.

14. *Tin or Stannum.*

1. Tin is procured from the native combinations of this metal with oxygene, known by the names of tin stones, or oxides of tin, by ignition with charcoal or carbonaceous substances. The metal obtained from these ores is not pure. To obtain it in a state of purity, metallic tin should be boiled for some time in solution of nitric acid, the white powder formed should be well washed in pure water, and heated strongly in contact with about $\frac{1}{4}$ of its weight of charcoal powder in a covered crucible for about half an hour; a button of pure tin will be found at the bottom of the crucible.

2. Tin has been known since the earliest periods of civilization; it was used in the time of Moses: it is mentioned by Homer, and was brought from Cornwall by the Phœnicians and Greeks, some centuries before the Christian era; it is called by Aristotle Κασσιτερον Κελτικον, or Celtic tin. The colour of tin is white, and resembles that of silver. Its hardness is greater than that of lead, and less than that of zinc. Its specific gravity is 7.291, and it is somewhat increased by hammering; it is very malleable, and may be extended into extremely thin leaves. Tin foil is about the $\frac{1}{1000}$ part of an inch thick; it has comparatively little ductility or tenacity. It is

flexible, and when bent produces a crackling noise. It has a slight taste, and when rubbed emits a peculiar smell. It fuses at 442° Fahrenheit, but requires an intense degree of heat for its evaporation. Its capacity for heat, according to Dalton, is .07. It acquires a slight tarnish by exposure to the atmosphere, but undergoes no further change. It is not affected by water at common temperatures, but when steam is passed over red hot tin it is decomposed, oxide of tin is formed, and hydrogene gas is evolved. When heated strongly in air, it takes fire and burns with a pale white light; when burnt upon charcoal by a stream of oxygene gas, the colour of the flame is white, edged with violet. Tin foil burns when very gently heated in chlorine.

3. There are two definite combinations of tin and oxygene: the first, which may be called the *protoxide*, is gray; the second, which may be called the *peroxide*, is white; the first is formed by heating tin in the air, or by dissolving tin in muriatic acid, and precipitating the solution whilst recent, and before it has been exposed to air by solution of hydrat of potassa, not added in excess. This substance, after being heated to whiteness, is the protoxide of tin; and it is converted into the peroxide by being boiled with diluted nitric acid, dried by evaporation, and heated to redness. From experiments which I have made, it appears that the protoxide of tin contains about 13.5 per cent. of oxygene, and from experiments made by Mr. John Davy, the peroxide is composed of about 24 of oxygene and 76 of metal. These oxides are difficultly fusible bodies, insoluble in water, soluble in diluted oil of vitriol, and in fixed alkaline solutions. Computing from their composition, and supposing one to consist of one proportion of tin and one of oxygene, and the other of one of tin and two of oxygene, the number representing tin will be 110, and the number standing for the protoxide will be 125, and that standing for the deutoxide, or white oxide, 140. Both these oxides appear capable of combining with water to form hydrats; and when precipitated from their acid solutions, they always contain water, but experiments are wanting to determine the quantity: both are insoluble in water.

4. As there are two combinations of tin with oxygene, so there are two which it forms with chlorine. When tin is burnt in chlorine

a very volatile clear liquor is formed, a nonconductor of electricity, and which, when mixed with a little water, becomes a solid crystalline substance, a true muriate of tin containing the peroxide of tin. This liquor, which has been called Libavius's liquor, from its discoverer Libavius, may be likewise procured by heating together tin filings and corrosive sublimate, or an amalgam of tin and corrosive sublimate. It consists, according to the analysis of Mr. J. Davy, of two proportions of chlorine 134, and one of tin 110; and according to the proposed principles of nomenclature, its name will be *stannanea.* The other compound of tin and chlorine is a gray semitransparent crystalline solid; it may be procured by heating together an amalgam of tin and calomel: it dissolves in water, and forms a solution which rapidly absorbs oxygene from the air, depositing oxide of tin. This compound of chlorine and stannane, it appears from the experiments of Mr. J. Davy, who first described it, consists of one proportion of tin 110, and one of chlorine 67; it may be called *stannane.*

5. There are two *sulphurets of tin:* one may be made by fusing tin and sulphur together; it is of a bluish colour and lamellated structure; and from the experiments of my brother, consists of one proportion of tin and one of sulphur, 110 and 30. The other sulphuret of tin, or the supersulphuret, is made by heating together the peroxide of tin and sulphur; it is of a beautiful gold colour, and appears in fine flakes; it was formerly called *aurum musivum.* It has been supposed by Pelletier and Proust to contain tin in an oxidated state; but Mr. John Davy has shewn that this is not the case, and that it consists merely of one proportion of metallic tin combined with two proportions of sulphur, 110 and 60; so that the number representing it is 170.

6. Tin combines with phosphorus when the two substances are heated together. As yet only one compound is known, which appears from my experiments to consist of 17 per cent. of phosphorus, and therefore may be regarded as composed of one proportion of tin and one of phosphorus, 110 and 20. The *phosphoret of tin* has a metallic appearance, is so soft that it may be cut with a knife; the phosphorus burns when it is gently heated in the air.

7. Tin has not been combined with hydrogene, azote, carbon, or boron: it readily unites to the metals of the fixed alkalies, and forms

alloys which speedily tarnish in the air, and which effervesce in water. It unites with zinc by fusion; the alloy is harder than zinc and stronger than tin.

8. Tin is a metal of great use, and of various application; it is an important ingredient in pewter, bell-metal, and bronze; it is employed to cover culinary vessels, as tin plate; some of its acid compounds are used in dyeing. Tin is almost always found in nature in the oxidated state, and in the crystalline form; and it appears from the analysis of Klaproth that the native oxide or tin stone of Cornwall must contain one proportion of tin and two of oxygene. All the well-known combinations of this metal are such as they ought to be according to the theory of definite proportions, and its compounds with oxygene, sulphur, and chlorine, afford similar results, which correspond with the numbers gained from its simplest combination.

16. *Iron or Ferrum.*

1. The iron of commerce is obtained from various ores of that metal, in which it exists combined with oxygene, by intense ignition with carbonaceous substances: the purest iron is made from an ore called hæmatites by ignition with charcoal; and the metal is hammered whilst in a soft state, exposed to air, till it becomes ductile. Iron was known in the time of Moses, and used for the manufacture of swords, knives, and axes. It is referred to in the Iliad and the Odyssey of Homer. A ball of iron was one of the prizes offered by Achilles at the funeral rites of Patroclus; and the effect of the burning brand thrust by Ulysses and his companions into the eye of Polyphemus, is compared by the poet to that of the hot iron plunged into water by the smith. The soft iron employed in the useful arts is free from any alloy, and therefore may be used for the purposes of chemistry.

2. The colour of iron is well known, and its other sensible properties; its specific gravity is about 7.7. Its malleability, though considerable, is inferior to that of gold, silver, and copper. Its ductility and tenacity are, however, greater; it may be drawn into extremely fine wire, and a wire of 0.078 of an inch in diameter is capable of supporting 549.25 lbs. It requires the highest heat of a wind

furnace for its perfect fusion: it is attracted by the magnet and is capable of acquiring magnetism, though in its unalloyed state it retains it only for a very short time. When iron is exposed to the atmosphere it slowly combines with oxygene and carbonic acid, and its surface becomes covered with a yellowish substance well known by the name of *rust*. It burns with great splendour in oxygene gas, as has been stated, page 130. At common temperatures it slowly decomposes water. Hydrogene gas is evolved, and oxygene combines with the metal. The effect is rapidly produced when the vapour of water is passed over red hot iron. When gently heated in chlorine it takes fire and burns with a deep red light.

3. The combinations of iron and oxygene have been referred to, page 61. The *black* and the *red-brown oxides* are the only oxides of this metal known; these substances, which have been considered as green and white oxides, are in fact hydrated oxides. The black oxide of iron, which may be regarded as a deutoxide, as containing two proportions of oxygene, is formed by the rapid combustion of iron in oxygene. The red-brown oxide, which must be considered as a tritoxide, may be produced from the black by keeping its powder red hot for a considerable time in contact with the atmosphere, often changing the surface. Reasoning on the composition of these oxides, 103 must be the number representing iron; and the black oxide, or the deutoxide, consists of one proportion of iron 103, and two of oxygene 30; and the brown-red oxide, or tritoxide, of 103 metal, and 45 oxygene. Both these oxides are soluble in the common acids. The black produces pale green solutions; the brown-red deep yellow solutions: the solutions of triple prussiate of potassa, precipitate the solutions of the black oxide white; those of the red bright blue. When solutions of these oxides are acted upon by solutions of pure alkalies, a white precipitate, having a tint of green or olive, is thrown down from the solution containing the black oxide; and an orange-coloured precipitate from the solution containing the red-brown oxide; and both these precipitates, I find, are the oxides combined with water, or hydrates. The pale hydrate, when exposed to air, rapidly changes in colour, first becomes pale olive, then dark olive, then olive brown, and last of all orange; so that there is strong reason to conclude that the colours of different precipitates depend upon their be-

ing composed of mixtures of the two hydrates; and solutions of the black oxide cannot be exposed to air for a moment without being changed by the absorption of oxygene. I have made no experiments to ascertain the composition of the two hydrates; probably the white contains two proportions of water. It would seem from the experiments of Dr. Thomson that there is a black hydrate formed by passing steam over iron; and which probably consists of one proportion of iron, two of oxygene, and one of water. M. Daubuisson has described a native hydrated oxide of iron.

4. There are two compounds of iron and chlorine. The one containing the largest proportion of chlorine is formed by burning iron wire in the gas. It is a very beautiful substance of a bright yellowish brown colour. It has a high degree of splendour, and is very volatile, rising in the gaseous state at a temperature a little above that of boiling water, and crystallizing in small irridescent plates. It acts with violence upon water, and forms a solution of red muriate of iron. I have called it *ferranea*, and I find by analysis that it consists of one proportion of iron 103, and three proportions of chlorine 201.

The other compound of chlorine and iron has been formed and analyzed by my brother, Mr. John Davy; it contains proportions which agree nearly with one of iron 103, and two of chlorine 134. It is a dark gray opaque substance, fusible at a red heat, and not rising in vapour at the point of fusion of glass. It forms a solution of green muriate of iron by its action upon water; it may be named *ferrane*.

5. No combinations of iron with hydrogene or azote are known; but this metal readily combines with sulphur. There are two well-known sulphurets of iron; one is formed by heating iron filings and sulphur together out of the contact of air; they combine with great energy, producing the effect of ignition. The *sulphuret of iron* formed in this way is of metallic splendour, and a dull yellow colour. This compound is found in nature, and has been analyzed by Mr. Hatchett. It is magnetic, and has been called magnetic pyrites. The other sulphuret of iron, which may be called the *supersulphuret*, has not yet been made artificially, but it is found abundantly in metallic veins: it is of a bright yellow colour, and of-

ten crystallized in cubes. According to Hatchett and Proust, the sulphuret of iron consists of about 63 of iron to 37 sulphur, and the supersulphuret of about 46 to 54; so that the quantity of iron remaining the same, the last sulphuret contains nearly double as much sulphur as the first; and iron being represented by 103, the proportions are not very remote from two of sulphur 60 in the sulphuret, and four of sulphur 120 in the hypersulphuret.

6. Iron is capable of combining with phosphorus; but the proportions of the elements of *phosphoret of iron* have not been ascertained; nor is it known whether more than one compound of this exists. The phosphoret may be made by passing phosphorus in vapour over ignited iron. It is very brittle, of a dark steel gray colour, and of the specific gravity of 6.7. This substance, which was first found in the peculiar iron called cold short iron, because it is brittle when cold, was once supposed by Bergman and Meyer to be a peculiar metal; but Klaproth discovered its real nature. It may be formed likewise by heating together phosphoric acid, iron, and charcoal

7. Iron is capable of combining with carbon; and *steel*, perhaps the most important substance employed in the useful arts, is one of the results of their combination. Steel is usually made by a process called cementation, which consists in keeping bars of iron in contact with powdered charcoal in a state of ignition for ten or twelve days, in earthen troughs, or crucibles, the mouths of which are closed with clay. Cemented steel is made into the substance called *cast steel* by being fused in a close crucible with a mixture of powdered glass and charcoal. Steel is possessed of the power of receiving very different degrees of hardness by different applications of heat or cold. When it is heated to redness and suffered to cool slowly, it is found very soft; but if plunged into cold mercury or water, it acquires extreme hardness; and by heating hard steel to different degrees, it receives different degrees of temper, from that which renders it proper for files, to that which fits it for watch springs. In the process of tempering, the steel changes colour even though plunged under oil. Between 430° and 450° Fahrenheit, according to Mr. Stoddart, it assumes a pale yellowish tinge; at 460° the colour is a straw yellow, and the metal is of the temper necessary for penknives, razors, and fine-edged tools. The colour gra-

dually deepens as the temperature rises higher, and it passes through brown, red, and purple, to 580, when it becomes of an uniform deep blue. These changes of colour seem to depend upon some change in the arrangement of the exterior layer of particles of the metal; they cannot depend on oxidation, as they take place under mercury. Steel is of greater specific gravity than iron; when the metal is hammered it is about 7.8. When it is acted upon by an acid, such as diluted nitric acid, a black spot appears upon it from the separation of the carbonaceous matter. Steel is attracted by the magnet, and is capable of receiving permanent magnetism. It is not easy to determine the exact quantity of carbon in steel, but it consists of several proportions of iron to one of carbonaceous matter. Different specimens of steel are said, on the authority of Bergman, Vauquelin, and Mushet, to contain only from $\frac{1}{140}$ to $\frac{1}{60}$ of carbon.

Iron has been converted into steel by cementation with diamond by Morveau and Sir George Mackenzie.

Plumbago, or *black lead*, as has been mentioned page 177, is a compound of carbon, with $\frac{1}{20}$ its weight of iron. There is a substance formed in iron foundries called *kish*, of a brilliant appearance, usually in thin scales, analogous to plates of polished steel. It consists chiefly of carbonaceous matter united to iron, and a little manganesum.

8. When iron and charcoal are strongly ignited with boracic acid, the iron produces, during its solution, boracic acid, as M. Descotils has shewn. Hence it is probable, as M. M. Gay Lussac and Thenard have supposed, that iron is capable of combining with boron.

9. Iron is capable of combining with potassium and sodium; these alloys are more fusible and whiter than iron, and effervesce copiously in water. There is great reason to believe that alloys may be formed of iron and the metals of the earth. *Cast iron*, which is produced by fusing iron ores with pitcoal, during its conversion into malleable iron affords about one fourth of its weight of a glass, which consists of silex, alumine, lime, oxide of iron, and oxide of manganesum. In the process for reducing cast iron into malleable iron called *blooming*, the iron, after being fused in a forge by a fire of charcoal, is hammered, whilst in a soft state, on an anvil by a large hammer worked by water; a vivid combustion, which seems

to be connected with the formation of the glass and the oxides takes place on the surface of the mass; that the earths are formed by the oxidation of metals combined in the cast iron seems probable from the circumstance of the combustion; and the idea is confirmed by the distinct metallic character of cast iron: it is white, crystallized, and has all the appearances of a perfect alloy. Specimens of cast iron usually contain likewise sulphur and carbon.

10. Manganesum forms very readily binary combinations with iron; the alloys have a white colour, and are very brittle. Iron likewise combines with tin. By fusing the two metals together, Bergman obtained two alloys: the first containing 21 parts of tin, and one part of iron; the second two parts of iron and one of tin. The first was very malleable, harder than tin, and not so brilliant; the second scarcely malleable, and very hard. The formation of *tin plate* depends upon the chemical attraction between the two metals. Tin plate is formed by dipping thin plates of iron into melted tin; the iron must be very clean. It is usual to add $\frac{1}{10}$ of copper to the tin, to prevent it from forming too thick a coat.

11. To describe the uses of iron would require volumes; as it is the most generally diffused metal, so it is likewise the most important in its applications to the purposes of society. By means of it the earth has been cultivated and subdued. Without iron, houses, cities, and ships could not be built. It is subservient both to the common and the refined arts; it forms the machinery by which the most important mechanical powers are generated and applied. Its uses have awakened human industry, and made it more efficacious, and have offered an infinite variety of resources to ingenuity and talent.

17. *Lead or Plumbum.*

1. The lead of commerce is chiefly procured from certain ores, in which it is combined with sulphur. The sulphur is expelled or burnt by a long-continued heat in a reverberatory furnace, and the metal is obtained by fusion. To procure pure lead a solution of the lead of commerce in nitric acid, largely diluted with water, may be precipitated by zinc; or a solution of acetite of lead, i. e. sugar of

lead, may be used. The arborescent brilliant metallic substance produced from solution of sugar of lead by zinc is generally *pure lead.*

2. Lead was known in a very early age of the world. It is often mentioned by Moses; and is described by Homer as in common use at the period of the Trojan war.

Lead is of a bluish white colour, but soon tarnishes by exposure to the air. It is the softest of the common metals. Its specific gravity is 11.352, and is not increased by hammering. It is very malleable, but not very ductile. Its tenacity is such that a wire of $\frac{1}{12.6}$ of an inch in diameter, supports only 18.4 pounds. Its point of fusion is 612°, but an intense degree of heat is required for its evaporation. It combines with oxygene slowly, at the temperature of its fusion, and burns when strongly ignited in the atmosphere; when a current of oxygene gas is thrown upon it in this state, the flame it emits is of a brilliant whiteness, and it sends off a dense smoke. When heated in chlorine it unites to it, but does not inflame.

3. Lead combines with oxygene in different proportions; and three of its combinations with this substance appear to be well-defined and distinct bodies. Two of the oxides of lead may be formed by heat with accession of air; the one is *massicot,* the other is *minium,* or red lead. When lead is heated in contact with the atmosphere, it soon becomes of a dirty yellow, or yellowish green colour, and at length of a pure yellow colour. This oxide is massicot, and is the oxide existing in the different salts of lead; when precipitated from these salts by caustic alkalies, it falls down in combination with water, and appears as a white *hydrated oxide of lead;* the water may be expelled from it by a strong red heat. From the experiments of Vauquelin and Klaproth, it may be concluded that this oxide of lead contains about 7 per cent. of oxygene. Litharge is this oxide of lead, according to Dr. Thomson, mixed with a little carbonate of lead: litharge is formed during the extraction of silver from lead by the calcination of the lead, and the carbonic acid is acquired from the carbonaceous matter burnt in the flame of the furnace.

Massicot is fusible at a strong red heat, and appears, when fused, as a yellow glass, insoluble in water, without taste or smell, and of great specific gravity.

The first oxide of lead, by being heated moderately in contact with air, for a considerable time, combines with an additional quantity of oxygene, and then becomes of a beautiful red colour, in which state it is called minium, or red lead. 100 parts of lead carefully and slowly converted into minium become between 110 and 111 parts; so that there is strong reason to believe that the quantity of lead being the same, the oxygene in minium is to that in massicot, as 3 to 2. Minium exposed to a strong red heat gives off from 3 to 4 per cent. of oxygene gas, and becomes massicot.

When nitric acid is digested upon minium, a part is dissolved, but a puce-coloured powder remains, which contains more oxygene than minium, and the formation of which seems to be owing to the circumstance that the oxide, which dissolves during its solution, becomes massicot, and affords oxygene to the undissolved portion, so as to convert it into a new substance. The *puce-coloured oxide of lead*, long dried at 212°, loses from 6 to 7 parts per cent. during its conversion into massicot by fusion; so that it may be considered as containing twice as much oxygene as that oxide, the proportion of lead being considered as the same. On these views massicot will be a deutoxide of lead, minium a tritoxide, and the puce-coloured oxide a tetroxide; and the number representing lead will be 398; and the oxides will be composed respectively of 398 of metal, and 30, 45, and 60, of oxygene.

4. One combination only of lead with chlorine is known; it may be obtained directly by heating lead in chlorine, or by decomposing the oxides of lead by chlorine, in which case oxygene is expelled, or by acting on oxides of lead by muriatic acid gas, when water is formed. The combination of chlorine and lead is a dull whitish semitransparent substance, fusible at a heat below redness, and volatile at an intense heat. This substance has a sweetish taste, and is soluble in 22 parts of cold water. It was called horn lead by the old chemists, and improperly muriate of lead by modern chemists. The name proposed for it is *plumbane*. According to my experiments made on the absorption of chlorine by lead, it contains 401 of

lead to 131 of chlorine, which agrees very nearly indeed with one proportion of metal, and two of chlorine; and this compound decomposed by alkalies affords the oxide containing two proportions of oxygene.

5. Sulphur is easily made to unite with lead by a gentle heat. One combination only of these bodies is certainly known, and it is the same as the substance found in nature, referred to in the beginning of this section, and called *galena*. It is very brittle, brilliant, and of a deep bluish gray colour. It is less fusible than lead, and crystallizes in cubes. 100 parts of lead in becoming the sulphuret unite to about 15 parts of sulphur; which gives the *sulphuret*, as consisting of one proportion of metal and two proportions of sulphur.

6. A compound of lead with phosphorus may be formed by fusing together equal parts of filings of lead and phosphoric acid. It is of a silver white colour with a shade of blue; may be cut with a knife, but is brittle under the hammer. The same substance may be formed by bringing phosphorus in contact with melted lead. According to Pelletier it consists of 88 parts lead and 12 of phosphorus, whic gives nearly 3 proportions of phosphorus 60, to one of lead 398.

7. There are no known combinations of lead with hydrogene, azote, carbon, or boron.

8. Lead unites by fusion with the metals of the fixed alkalies, and forms compounds which tarnish in the air, and are readily decomposed by the agency of water.

9. Lead combines with zinc, tin, and iron. Its alloy with iron is made with great difficulty, and has not been accurately examined. The alloys of zinc and lead may be easily made by fusion. These alloys are harder than zinc, and ductile. In whatever proportions the metals are melted together, the mass, on cooling, is found to contain them in a state of chemical union or intimate mixture. Lead and tin combine in a similar manner; this alloy is harder and more tenacious than tin. It is said by Muschenbroeck that these qualities exist in the highest degree in the alloy, when it is composed of 3 parts of tin, and one of lead; which quantities nearly correspond with single proportions of each of the two metals. This mixture is often employed to cover copper vessels; and, as appears from the

experiments of M. Proust, is difficultly acted upon by vegetable acids, and when acted upon, the tin is dissolved, and not the lead; so that such vessels may be safely employed for culinary purposes.

10. Lead is very extensively used both in the common and refined arts. Its oxides, and some of its saline combinations, are extensively applied in painting; white lead is the deutoxide combined with carbonic acid. Both massicot and minium are common pigments. The deutoxide combined with chromic acid forms the most beautiful and permanent deep yellow known. Lead is used as an ingredient in various solders; it is applied for covering houses and churches. It will be unnecessary to dwell upon its still more familiar applications. Its oxide forms an important part of flint glass, and is used in various enamels and pastes.

18. *Antimony or Antimonium.*

1. The ancients were acquainted with certain ores of antimony; the most common of them, the sulphuret of antimony, was employed by the ladies of the oriental countries to tinge the extremity of the eyelid black for the purpose of giving greater brilliancy of effect to the pupil. Basil Valentine is the first chemist who has described the process of extracting antimony from the sulphuret, though it does not appear that he was the inventor of this process. He published his Currus Triumphalis Antimonii towards the end of the fifteenth century.

To procure antimony, the common antimony sold by druggists, which appears as a series of crystals, like needles, possessing the metallic brilliancy, and which are composed of the metal and sulphur, are ignited with half their weight of iron filings, and a quarter of their weight of nitre added when they are in fusion; the antimony will be found in the bottom of the vessel in which the experiment is made. To obtain it quite pure, it may be dissolved in aqua regia; water is added to the solution, a white powder will fall down; this is to be ignited for about 20 minutes, with twice its weight of tartar, when the metal will be produced.

2. Antimony is of a brilliant white colour with a shade of blue; its hardness is equal to that of zinc. Its specific gravity is about

6.8. It is very brittle, and may be easily pulverized. It has little tenacity. It fuses at about 810° Fahrenheit. On cooling it crystallizes, and its laminated structure is owing to the new arrangement of its parts. It is but little affected by exposure to the air or water at common temperatures; but when the vapour of water is passed over red hot antimony, it acts so powerfully upon the water, as to decompose it with explosions.

3. Two combinations of antimony with oxygene are known; one, the *fusible oxide*, is obtained by dissolving antimony in muriatic acid by heat, and adding water to the concentrated solution; a white powder falls down, which, when washed with a solution of subcarbonate of potassa, and afterwards with distilled water, is a combination of the fusible oxide with water, and by fusion at a red heat it becomes the pure oxide. This substance is of a dirty yellowish white colour. It crystallizes by slow cooling after fusion. By being strongly heated in contact with the atmosphere it combines with more oxygene, rises in the volatile form, and condenses in white crystals of a silvery lustre; and this substance is the *peroxide* or antimony saturated with oxygene. This oxide is much less fusible, yet more volatile than the other, and is more difficultly combined with acids. The fusible oxide, in its combination with water, was for a long while called the powder of Algaroth, from its discoverer Algarotti. Antimony burns, when heated strongly in the air, with a faint white light, and produces the second or the volatile oxide, which rises from it in the form of a dense white smoke. From experiments made on these two oxides, by Mr. John Davy and myself, it appears that the fusible oxide contains $\frac{2}{3}$ as much oxygene as the volatile oxide, supposing the metal to be the same in both; and calculating from his experiments on the fusible oxide, the number representing antimony is 170; the fusible oxide may be considered as consisting of 170 metal, and 30 of oxygene, and the peroxide of 170 metal, and 45 oxygene.

4. Antimony burns spontaneously when powdered and thrown into chlorine. In this way the only known compound of antimony and chlorine, *antimonane*, or butter of antimony, is formed. It is a soft semitransparent substance, of a yellowish white colour, very fusible, volatile at a moderate degree of heat. It crystallizes in paral-

lelopipeds. It is a very caustic and corrosive substance; it acts with great energy upon water: with a small quantity of water it heats violently, and forms a solution; a large quantity precipitates the fusible oxide of antimony, and muriatic acid is found in the solution. Antimonane may be likewise formed by the distillation of a mixture of powdered corrosive sublimate and antimony. From the experiments of Mr. John Davy, it appears to contain 44 per cent. of chlorine, and therefore may be regarded as consisting of one proportion of metal and two of chlorine.

5. Sulphur and antimony are readily combined by fusing them together, when they form a compound of metallic appearance, similar to the natural sulphuret, and which is much more fusible than antimony: according to Proust it contains about 25 per cent. of sulphur, and may therefore be considered as consisting of one proportion of metal, and two proportions of sulphur, 170 and 60.

6. Antimony has not yet been combined with hydrogene, azote, carbon, or boron.

7. Antimony combines with phosphorus by fusion. According to the experiments of M. Pelletier, *the phosphuret* is white, brittle, and has the metallic lustre; its composition has not been determined.

8. Potassium and sodium may be combined with antimony by fusion; they form alloys very similar to those they form with lead and tin in their obvious properties. Antimony may be combined with all the other metals which have been described. The alloy of tin and antimony is employed in the arts, particularly for making music plates. Antimony very much impairs the magnetic properties of iron. The alloy of lead and antimony is used for printers' types; and for this purpose it is formed of 16 parts of lead and one of antimony. The oxides of antimony are used for giving a yellow colour to glass. Various combinations of antimony are employed in medicine.

19. *Bismuth or Bismuthium.*

1. The bismuth of commerce is procured from ores which usually contain it in the metallic state, or combined with sulphur, by roasting, and ignition with charcoal. The metal may be obtained in a state of purity by dissolving the ore in strong nitric acid, and adding

water to the solution, a white precipitate will appear, it is to be washed, dried, and heated to a dull red for about 20 minutes, with a little oil, and some black flux, a substance made by heating together nitre and tartar; a globule of metal will thus be procured.

2. The ores of bismuth were first described by Agricola before 1530; the properties of the pure metal were not known before the middle of the last century. The colour of bismuth is white with a slight tint of red. It is nearly of the same hardness as copper. Its specific gravity is 9.822, and it is increased by hammering. It is brittle, it cannot be drawn into wire. Its tenacity is such, that a rod $\frac{1}{10}$ of an inch in diameter sustains a weight of about 29 lbs. It fuses at about 476° Fahrenheit, and, if slowly cooled, crystallizes in cubes: if it is exposed to a strong heat in close vessels, it sublimes unaltered. Bismuth acquires a superficial tarnish by exposure to the air; it is not affected by water.

3. One combination only of bismuth and oxygene is certainly known. When bismuth is kept at a dull red heat in open vessels, its surface soon becomes tarnished; and, by exposing surfaces, the whole may be converted into an oxide. When heated more intensely in the atmosphere, or in oxygene gas, it burns with a bluish flame, and a yellow oxide is formed, which fuses at an elevated temperature. The oxides formed by slow or rapid combustion are of the same kind. When in powder, they are yellow; when fused, they form a yellowish green vitreous mass. The oxide of bismuth requires an intense degree of heat for its volatilization. When this oxide is precipitated from its solutions in acids by water or alkalies, it appears as a white powder, which probably is a compound of the oxide and water. Klaproth has shewn that 100 parts of bismuth, by treatment with nitric acid and water, produce about 123 parts of the white powder. This powder has been called magistery of bismuth. Geoffroy found 100 parts of bismuth become 110 parts by exposure to heat and air; but, in his experiments, probably some of the metal escaped oxidation. Mr. J. Davy has found the yellow oxide to contain, in 100 parts, 90 parts of metal, and 10 of oxygene, and this estimation is very near that of Bucholz; and supposing the oxide to consist of one proportion of metal, and one of oxygene, the number representing bismuth will be 135.

4. Bismuth, when thrown in fine powder into chlorine, takes fire, and burns with a pale blue light; in this case, the only known compound, bismuth and chlorine, is formed. It has been called *butter of bismuth.* It may be called *bismuthane.* It is an easily fusible substance, volatile at a moderate heat; its colour is greyish. It corrodes the skin, and is readily decomposed by water; the bismuth combines with the oxygene of the water; the chlorine with its hydrogene. From the experiments of Mr. J. Davy, it appears that bismuthane contains 33.6 per cent. of chlorine, and therefore may be considered as consisting of one proportion of metal, and one of the gas, 135 and 67.

5. There are no known combinations of bismuth with hydrogene, azote, carbon, or boron.

6. Bismuth combines with sulphur when they are fused together; the *sulphuret* is of a bluish grey colour, and has metallic lustre. According to Mr. J. Davy's experiments, it contains about 18 per cent. of sulphur. By this estimation, the sulphuret of bismuth must contain about one proportion of metal to one of sulphur.

7. Bismuth appears to have little affinity for phosphorus; the attempts hitherto made to form this compound have been unsuccessful.

8. The action of the metals of the fixed alkalies on bismuth is similar to that which they exert on other easily fusible metals.

9. Bismuth forms alloys with all the metals which have been described, except zinc; these alloys have been little examined. It sometimes enters into the composition of pewter; and it forms a principal part of Newton's fusible metal. This alloy is composed of 8 parts of bismuth, 5 of lead, and 3 of tin, and melts at a temperature below that at which water boils.

10. Bismuth is not of much use in the arts. The white hydrat is employed as a pigment, but is not very permanent, becoming yellow by the action of light. It is probable that the Roman ladies used the oxide of bismuth for whitening the skin; for Martial, in speaking of a lady who made too free a use of cosmetics, describes her as afraid of the sun.

This metal is sometimes employed in alloys to make easily fusible solders. The white hydrat has been lately employed in medicine, as a remedy in spasmodic affections of the stomach.

20. *Tellurium.*

1. Tellurium was discovered by Klaproth, in 1798, and was procured by him from an ore found near Zalethna, in Transylvania, in which it exists, in alloy with gold, lead, and silver. The process for obtaining the metal is very simple: the ore is dissolved in aqua regia made of a mixture of 1 part strong nitric acid and two parts muriatic acid. When the solution is saturated, water is to be added, a white powder falls down, which, when dried, and heated in a retort of glass, with $\frac{1}{10}$ of its weight of charcoal powder, will afford pure *tellurium.*

2. Tellurium is of a colour nearly the same as that of antimony. It easily fuses, and rises in vapour at a strong red heat. It burns, when heated in the air, with a vivid bluish green flame, sending off a dense white smoke. Its powder takes fire in chlorine. Its specific gravity is 6.115.

3. One *oxide of tellurium* only is known, the substance formed by combustion of the metal; it is white, with a tint of yellow, when examined in the mass. It fuses by a strong heat, and requires a very high temperature for its volatilization. When precipitated from its acid solutions, it is found in union with water, as a white hydrat. According to Klaproth, 178 grains of oxide of tellurium afford 148 grains of metal: supposing the oxide to consist of one proportion of oxygene, and one of metal, the number representing tellurium will be 74.

4. When tellurium is burnt in chlorine, an easily fusible substance is formed, which rises in vapour at a strong heat, and crystallizes. Its colour is white; it is semitransparent; when decomposed by water, it affords the white hydrated oxide. From my own experiments, it appears this compound, or *tellurane*, consists of 2 in weight of metal to 1.83 of chlorine; it may therefore be regarded as composed of one proportion of metal 74, and of chlorine 67.

5. Tellurium and hydrogene are capable of being combined. To make this combination, hydrat of potassa and oxide of tellurium are ignited with charcoal, and the mixture acted upon, by diluted sulphuric acid, in a retort connected with a mercurial pneumatic apparatus; an elastic fluid will be generated, which consists of hydrogene holding tellurium in solution. It is possessed of very singular properties. It is soluble in water, and forms a claret-coloured solution. It combines with the alkalies. It burns with a blueish flame, depositing oxide of tellurium. Its smell is very strong and peculiar, not unlike that of sulphuretted hydrogene. I discovered this elastic fluid in August, 1809. When tellurium is made the electrical negative surface in water in the Voltaic circuit, a brown powder is formed, which appears to be a solid combination of hydrogene and tellurium, and which was first observed by M. Ritter, in 1808: a claret-coloured solution of the gas is likewise formed when the water is free from air. The composition of *telluretted hydrogene* gas, and of the solid *hydruret of tellurium* has not been yet ascertained.

6. Tellurium has not been combined with azote, carbon, or boron. No experiments are on record as to its action on phosphorus.

7. It unites to nearly its own weight of sulphur by fusion; the result is a lead-coloured striated mass. It seems probable that the sulphuret contains two proportions of sulphur.

8. Very few experiments have been made upon the alloys of tellurium. It combines readily by fusion with potassium and sodium, producing heat and light; and forms with them difficultly fusible alloys, which, when thrown into water, produce purple solutions consisting of the alkalies united to telluretted hydrogene.

Tellurium has as yet been found in quantities too small to render it applicable to any of the purposes of the common arts.

21. *Cobalt or Cobaltum.*

1. Cobalt is procured from its ores, which are for the most part combinations of this substance with other metals; or of its oxide with arsenic or sulphuric acids. It is difficult to obtain the metal in a state of complete purity. The pure oxide may be procured by dissolving the ore known by the name of *arsenical cobalt* in nitric

acid. The sulphur either remains on the surface, or is acidified with the arsenic, when both are to be separated by nitrate of lead. The excess of lead is to be removed by a little sulphuric acid, and the copper, if any, precipitated, by a bar of iron. The clear solution is to be precipitated by carbonate of potassa, and the precipitate digested with solution of ammonia. The ammoniuret is to be evaporated till it does not tinge turmeric, and then acted on by solution of potassa: the precipitate, if any, is to be separated, and the clear fluid evaporated to dryness. The solid matter obtained by evaporation will afford *cobalt* when mixed with a little very fine charcoal powder, and exposed to an intense heat for about half an hour in a covered Hessian crucible.

Metallic cobalt was first procured by Brandt in 1733.

2. Cobalt is of a light gray colour, with a tint of red; its hardness appears to be greater than that of copper; its specific gravity is about 7.7. It is rather brittle; its fusing point is very high, not much inferior to that of iron, on the scale of Wedgwood as 130 to 158; it suffers little change from being exposed to air or water at common temperatures. Like iron, it is attracted by the magnet, and is capable of being rendered permanently magnetic. When fused on charcoal, and acted on by a stream of oxygene gas, it burns brilliantly, throwing off bright sparks.

3. Cobalt combines with oxygene; when kept red hot for some time it becomes covered with a dark powder, and by being long exposed to air in a state of intense ignition, it is entirely oxidated, and in this process, according to Klaproth, 100 grains of the metal became 118 grains of oxide. This oxide, though it appears black, is in fact deep blue, and gives this tint to glass. It seems to be cobalt in its first state of oxygenation, and when dissolved by acids and thrown down by fixed alkalies, forms the basis of *a hydrat* of a bright blue colour. By heating the *hydrat gently in the air*, it gradually becomes black, loses its water, and absorbs oxygene. This black powder has the property of decomposing muriatic acid; its excess of oxygene combines with the hydrogene, and the chlorine is set free. From a rude experiment I am inclined to conclude, that the oxygene in the black powder from cobalt is to that in the blue oxide as 2 to 3. If Klaproth's experiments be made the ground-

work of calculation, and the blue oxide be considered as a deutoxide, then the number representing cobalt will be 166, and the blue oxide will consist of 166 of cobalt and 30 of oxygene; and the black oxide of 166 and 45. Mr. Thenard states that there is an olive oxide of cobalt, produced by exposing the blue powder, which must be regarded as a hydrat, to air at common temperatures. And Mr. Proust has stated that there is a red hydrated oxide of cobalt; it is probable that this last is a compound of the black oxide and water; and the substance supposed by Mr. Thenard to be an olive oxide, a mixture of the two hydrates.

4. Cobalt combines with chlorine: the compound may be obtained by introducing chlorine into an exhausted retort containing the metal in fine powder and gently heating it; a combustion takes place, but the results of this combustion have not yet been accurately examined.

5. Cobalt is not known to enter into combination with hydrogene, azote, carbon, or boron.

6. Cobalt combines with sulphur and phosphorus, but with considerable difficulty. The sulphuret is formed by acting on oxide of cobalt in a state of ignition by sulphur, and, according to Proust, it consists of 71.5 parts cobalt and 28.5 of sulphur; which indicate nearly one proportion of metal 166, and two of sulphur 60. The *phosphuret* is made by dropping phosphorus upon ignited cobalt; it has not been minutely examined, nor its composition ascertained.

7. The action of the metals of the alkalies and earths on cobalt has not been examined.

8. There are no accurate experiments on the combinations of pure cobalt with the common metals. Lead unites with it, as Gmelin has shewn, and forms an alloy less malleable in proportion as it contains more cobalt.

9. Cobalt in its metallic state is not employed in the useful arts. in its state of combination with oxygene, it is used to give glass, porcelain, &c. a rich blue colour. One grain of the pure oxide will give a deep tint of blue to 240 grains of glass. The solution of the oxide of cobalt in muriatic acid, forms one of the most beautiful of the symphathetic inks. This solution when concentrated is pale rose-coloured in the cold, but becomes blue green when heated; let

ters or figures traced by it upon paper are invisible in the cold, but become blue green when held before the fire.

22. *Copper, Cuprum.*

1. The copper of commerce is procured from the native combinations of this metal with sulphur, oxygene, and certain acids, by roasting and fusion either alone or with lime and carbonaceous substances; it is not however quite pure. To obtain it in a state of purity, dissolve copper in strong muriatic acid, dilute the solution with water, and put into it a polished plate of iron, the copper will be precipitated in its metallic state: it should be washed in dilute muriatic acid, and then with pure water.

2. Copper is of a red colour; it is a little harder than silver; its specific gravity is about 8.89. When rubbed it emits an unpleasant smell, and it has a disagreeable taste. It is very malleable, has considerable ductility, and in tenacity is superior to all the metals except iron; it fuses at a low white heat. By exposure to the air copper becomes tarnished, and after some time is coated with a green crust, which consists of the metal in union with oxygene and carbonic acid. Copper is not affected by being kept in water, nor does it decompose this fluid at any temperature.—It burns with a red flame edged with green, when fused and acted upon by oxygene, when in thin leaves it inflames spontaneously in chlorine.

3. Two compounds are known, consisting of oxygene and copper. One is found native, and is the *ruby copper ore.* It occurs in octaedrons of a considerable lustre; its powder is dull orange red. According to Mr. Chenevix it contains 11.5 per cent. of oxygene; according Mr. J. Davy about 11 per cent. It is soluble in solution of muriatic acid; and when this solution is precipitated, a pale orange-coloured powder falls downs, which is this oxide united to water. The other oxide of copper is formed in the combustion of copper, or by heating the precipitate from a nitrous solution of copper by potassa to redness. It is a black powder, and appears, from various experiments, to contain about 20 per cent. of oxygene; when it is precipitated from acids by potassa it is in combination with water, and is then pale *blue;* and as I have found, contains 10

per cent. of water. If the red oxide of copper be considered as a protoxide and the black a deutoxide, the number representing copper will be 120, and this number will be found to correspond accurately with that gained from the analysis of the other combinations of the metal. The number representing the protoxide is 135, and that representing the deutoxide 150, and that representing the blue hydrat 167.

4. As there are two combinations of copper and oxygene, so there are likewise two combinations of this metal with chlorine; both are produced by the same time, by the combustion of the metal in chlorine; one is a fixed, easily fusible substance, like rosin in its exterior characters, the other is a yellowish sublimate. The first of these, as appears from the analysis of Mr. John Davy, consists of 36 chlorine, and 64 copper; and the second of 53 chlorine and 47 copper; the first may be called *cuprane*, the second *cupranea*. Cuprane may be formed likewise by heating strongly together a mixture of one part of copper filings, and two parts of corrosive sublimate; and it was in this way first produced by Boyle, who appears to have been its discoverer. Cuprane is converted into cupranea by being heated in chlorine. Cuprane may be regarded as consisting of one proportion of copper 120, and one of chlorine 67; and cupranea of one of copper 120, and two of chlorine 134. Cuprane is not soluble in water, but slowly becomes green by the action of the atmosphere; when introduced into the flame of a candle, it produces a most beautiful light possessing almost all the prismatic colours. *Cupranea* dissolves in water and gives it a greenish colour; it is decomposed by a strong heat, and converted into cuprane by the expulsion of oxygene.

5. Copper readily combines with sulphur, producing ignition when they are fused together; and they form together a substance more fusible than copper, brittle, and of a deep gray colour. This substance is likewise found native, and, according to the analysis of Mr. Chenevix, contains about 19 per cent. of sulphur. The artificial *sulphuret*, in some synthetical experiments which I made upon it, appeared to contain from 21 to 19 per cent. It may therefore be regarded as composed of one proportion of copper 120, and one of sulphur 30. It is probable that a supersulphuret of copper may exist:

some of the golden-coloured copper pyrites, which contain as much as 41 per cent. of copper, afford from 35 to 45 of sulphur: but they likewise contain iron. No *supersulphuret* has as yet been made artificially.

6. Copper combines with phosphorus, by fusion. The *phosphuret* is of a white colour and very brittle, its specific gravity is 7.1220. It was first formed by Margraaf. According to Pelletier it contains 20 per cent. of phosphorus; and allowing this estimation it must be composed of two proportions of metal, and three of phosphorus, 240 and 60.

7. Copper has not yet been combined with hydrogene, azote, carbon, or boron.

8. It unites to the fixed alkaline metals, and to all the common metals that have been described. Some of its alloys with the common metals are well known. Copper is rendered yellowish white by alloy with a small quantity of manganesum. United to zinc, copper produces brass, Dutch gold, Rupert's metal, and pinchbeck: from a third to a twelfth of zinc is used; the paler the alloy required, the larger the quantity of zinc.

Copper with a fourth of its weight of lead, forms pot metal. Copper alloyed with from $\frac{1}{12}$ to $\frac{1}{3}$ of tin forms the different species of bronze and bell-metal. The best composition for the mirrors of reflecting telescopes is a combination of 32 parts copper, 15 parts tin, 1 part brass, 1 silver, and 1 of arsenic. Tutenag, according to Keir, is a white alloy of copper, zinc, and iron.

9. The account of the alloys of copper proves its importance in the arts. It is used unalloyed likewise for various important purposes, such as sheathing of ships, forming vessels when united with other metals, for culinary purposes, &c. In early ages the alloys of copper formed the principal arms offensive and defensive. I have examined an ancient Attican helmet which consisted of an alloy of copper and tin. The swords and spear-heads of the early inhabitants of Greece and Italy seem to have been composed of the same materials.

All the saline combinations of copper are poisonous.

23. *Nickel or Nickolum.*

Nickel was discovered by Cronstedt in 1751, and examined in its pure state by Bergman, in 1775. Nickel exists in an ore called kupfernickel combined chiefly with sulphur, or in nickel ochre, in which it is united to oxygene. The metal may be obtained from these ores by roasting and ignition with charcoal; but in this case it is far from being pure. *Pure nickel*, or at least nickel free from any other metallic substance, may be procured by nearly the same process as cobalt. The precipitate from the ammoniacal solution by solution of potassa, contains the nickel, and this precipitate must be intensely heated with charcoal powder.

2. Nickel is of a white colour, and possesses considerable lustre; its hardness is little inferior to that of iron: its specific gravity is about 8.38, but when forged it increases to 8.82. It is ductile and malleable. It requires a stronger heat for its fusion than iron—like that metal it is attracted by the magnet. When in fusion it burns like iron under a stream of oxygene gas.

5. Nickel when intensely ignited, exposed to air, becomes a dark brown powder, which is still attractable by the magnet. Its solution in nitric acid decomposed by potassa affords a pale grass green hydrated oxide, which contains more than a fourth of its weight of water, and which when heated to dull redness becomes an oxide of a pale ash gray colour, and which, according to Tupputi, is composed of 21.2 parts of oxygene, and 78.8 of metal; this oxide by strong ignition becomes darker coloured, but when pure cannot be reduced to the metallic state by heat alone. Another oxide of nickel has been described by M. Thenard containing more oxygene. It may be procured by acting on the hydrat of nickel by the salts called hyperoxymuriates; it is of a black colour; its composition has not been accurately ascertained. From the nature of the compounds of nickel and sulphur, to be discussed immediately, it seems probable that the gray oxide is a deutoxide; and if this be allowed, the number representing nickel will be 111, and the gray oxide will be represented by two proportions of oxygene 30, added to one proportion of metal.

4. Nickel, when strongly heated in chlorine, smokes, and produces an olive-coloured substance; but the composition of this substance has not been ascertained, nor its properties examined. When muriate of nickel is decomposed by heat some white brilliant scales are formed, which, as appears from experiments made by Mr. E. Davy, consist of nickel and chlorine; but their composition has not been exactly ascertained.

5. Sulphur combines with nickel by fusion, and forms a bright gray sulphuret, possessing metallic lustre. From experiments made on this *sulphuret* by Mr. E. Davy, it appears to contain about 34 per cent. of sulphur, which gives proportions corresponding nearly to one proportion of metal 111, and two of sulphur 60, and harmonizes with the supposition that the olive oxide is a deutoxide. The same enquirer states that there is a supersulphuret, which may be formed by heating the gray oxide with sulphur, and which contains about 56.5 of nickel to 43.5 of sulphur, and which agrees nearly with one proportion of metal to three of sulphur.

6. *Phosphuret of nickel* may be formed by causing phosphorus in vapour to act on metallic nickel in ignition; the phosphuret is almost black, and has metallic lustre. Its composition has not as yet been accurately determined.

7. Some specimens of nickel afford carbon during their solution in acids; but no definite compound of carbon and the metal has been obtained. Nickel has not yet been combined with hydrogene, azote, or boron, nor have any accurate experiments been made on its action on the metals of the fixed alkalies.

8. It forms alloys with some of the common metals; but few of these compounds have been examined with attention: with tin it produces a white brilliant compound. Its alloy with copper is less ductile than pure copper, and is slightly magnetic. Its combination with iron is the most interesting of these compounds; these metals seem to unite in all proportions; the colour of the alloy approaches nearer to that of silver in proportion as the nickel prevails, and the iron retains its malleability. In all the meteoric stones that have been examined, it is remarkable that the iron is alloyed by from 1.5 to 17 per cent. of nickel. The masses of iron found in Siberia and South America contain nickel, and there is the strongest probability

that they are likewise of meteoric origin. The alloy of iron and nickel is much less liable to rust than common iron, and it is likely may be advantageously applied in the useful arts. The oxide of nickel is employed to give colours to enamels and porcelain; in different mixtures it produces brown red, and grass green tints.

24. *Uranium.*

1. *Uranium* was discovered by Klaproth, in 1789. It may be procured from the ores called Pechblende, and Uranochre, by the following process. Let the ores be boiled in moderately diluted nitric acid, and solution of sulphate of soda added, and the precipitate, if any, separated. The clear solution is to be acted on by solution of potassa, the precipitate digested in ammonia, and the residuum heated with strong nitric acid, and evaporated to dryness. The clear solution obtained from the mass by pure water when precipitated by solution of potassa will afford a yellow powder, and this made into a ball with wax, and intensely ignited in a crucible of charcoal, affords metallic *uranium.*

2. Uranium is of an iron gray colour and has considerable lustre; it is hard and brittle. Its specific gravity, according to Klaproth, is 8.1; its fusing point is higher than that of manganesum. It undergoes no change by exposure to air, but when heated strongly, burns, combines with oxygene, and assumes a blackish colour.

3. Two compounds of uranium and oxygene have been examined by Klaproth; the precipitate thrown down from the solution of uranium in nitric acid, when heated to dull redness, is still yellow, and this treated with oil, and incinerated slightly, so as to burn off the oil, becomes a *black oxide.* It appears probable from Bucholz's experiments, that the oxygene in the black oxide is to that in the yellow as 1 to 3, and that the yellow oxide contains about 80 of metal and 20 of oxygene. I found that 8 parts of potassa precipitated 8.2 parts of yellow oxide of uranium from the saturated nitrous solution; and from this experiment, if potassa and the yellow oxide of uranium be supposed analogous in composition, 76.8 will be the number for the metal, and the black oxide must be a compound of three proportions of metal with one of oxygene. The substance that has been called

the native oxide, and which is crystallized in quadrangular plates, is, I find, a *hydrated oxide*. Bucholz supposes that there are several different oxides of uranium; but he founds his opinion upon the different colours of precipitates, which may be mixtures of hydrates of the two oxides.

4. No experiments have as yet been made on the action of uranium on chlorine, hydrogene, azote, boron, the metals of the fixed alkalies, or the common metals.

5. A sulphuret of uranium may be procured by igniting the oxide with sulphur. It is a black heavy powder: its composition has not been ascertained.

6. Uranium has been hitherto found in quantities too small to render it applicable to the purposes of the arts. Its oxides give bright colours to glass, which according to the proportions are brown, apple green, or emerald green.

25. *Osmium.*

1. This metallic substance was discovered by Mr. Tennant in 1804. It may be obtained from crude platina, by dissolving all the soluble parts in aqua regia, and distilling the black powder that remains with nitre, at a heat under redness; a sublimate rises, which is soluble in water. When mercury is shaken with the solution, an amalgam is formed, and by distilling off the mercury, pure osmium is obtained.

2. This metal has been procured only in very minute quantities; it is of a dark blue colour, has not been fused, nor does it undergo any change at the most intense heat unless in contact with air, when it is converted into a volatile oxide.

3. The composition of the *oxide of osmium* has not been ascertained; it is a solid semitransparent substance, having a sweet taste and a strong smell: it is soluble in water, combines with potassa, and makes with it an orange solution in water. It tinges the skin of a dark colour; and produces a purple with solution of galls.

4. No combinations of osmium with any of the undecompounded substances described in the foregoing sections except that with oxygene have been examined. The metal is not soluble in any of the acids; but when fused with the hydrat of potassa becomes oxidated

and combines with the potassa. It is a metal very easily reduced, being precipitated from the aqueous solution of the oxide by ether or alcohol.

26. *Tungsten or Tungstenum.*

1. Tungstenum is obtained from a mineral known by the name of *wolfram;* it contains the oxides of tungsten, iron, and manganese, with earthy matter. To procure the metal pure, boil finely pulverised wolfram in strong muriatic acid for some time; separate the solution; the residuum contains a yellow powder; it is to be washed, dissolved in ammonia, evaporated to dryness, then mixed with a little fine charcoal powder, and exposed to a very intense heat for about 20 minutes in a covered Hessian crucible. Small grains of pure tungstenum will be found at the bottom of the crucible.

Tungstenum in its metallic form was first procured by Messrs. D'Elhuyars, in 1782.

2. *Tungstenum* is of a grayish white colour, and has considerable lustre. It is hard and rather brittle. Its specific gravity is about 17.3. It requires the strongest heat of a forge for its fusion. It is scarcely affected by exposure to air at common temperatures. At a temperature below redness its surface exhibits iridescent colours like iron.

3. Tungstenum combines with oxygene. When the metal in fine powder is heated to redness, it soon acquires a yellow colour, and is gradually converted into a *yellow oxide,* which is not soluble in water. Its specific gravity is 612, water being 100. It is very difficultly fusible. According to Messrs. D'Elhuyars 100 grains of metal by calcination form 124 grains of yellow oxide. Supposing the oxide a deutoxide, this result would give the number representing tungstenum as 125, and the number representing the yellow oxide as 155. Taking Klaproth's analysis of the combination of tungstic acid and lime* as the basis of calculation, and supposing double proportions of the oxide to one proportion of lime, the number representing the yellow oxide will be 124. From this it is probable

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* 17 of lime, 77 of tungstic oxide.

that in D'Elhuyars' experiments the metal was not entirely converted into oxide; and that the number is about 94; but new experiments are wanting to elucidate this point. When the yellow oxide of tungstenum is digested with solution of tin in muriatic acid, it becomes blue from losing oxygene. It is probable that in this state it is a protoxide, but no accurate researches have been made on this blue substance.

4. Tungstenum, I have found, burns with a deep red light when heated in chlorine, and forms an orange-coloured volatile substance, which affords the yellow oxide of tungstenum, and muriatic acid, when decomposed by water. I have made no experiments, nor are any, I believe, on record on the composition of *tungstenane*.

5. Sulphur and phosphorus are both capable of being combined with tungstenum by being made to act upon it in a state of ignition; but the properties of the *sulphuret* and *phosphuret* have not been examined accurately.

6. This substance has not been combined with hydrogene, azote, carbon, boron, or the metals of the fixed alkalies. From the experiments of Messrs. D'Elhuyars, it appears to unite with most of the common metals; but its alloys have been only rudely examined.

7. Tungstenum and its oxides have as yet been applied to no uses: it was stated by Guyton de Morveau that the yellow oxide formed a mordant useful in dyeing; that the red juices of fruits were fixed by it, so as to make permanent and beautiful lakes. The dyers who have tried the experiments in this country have not, however, given a favourable report of the results.

27. *Titanium.*

1. Titanium is obtained from a mineral long known by the name of *red schorl*, or titanite. The mineral in powder is to be fused with five or six times its weight of subcarbonate of potassa; the mass is to be fully exposed to the action of water, and the solid matter remaining digested and boiled with muriatic acid. The white powder not dissolved, when mixed with oil, and intensely heated in a crucible of charcoal, affords titanium. The oxide of titanium was discovered by Mr. Gregor, in 1781, in an ore found in the valley of Menachan

in Cornwall ; but metallic titanium was not produced till 1796, by Vauquelin and Hecht.

2. Little is known concerning the physical and chemical properties of *titanium ;* it has only been procured in minute quantities, and in an imperfectly reduced state. Its colour resembles that of copper. It has much lustre. It is brittle. It tarnishes by exposure to air ; and requires the most intense heat of a forge even for its imperfect fusion.

3. Titanium combines with oxygene when it is exposed to heat in the atmosphere, and acquires a blue colour. The *red oxide*, which contains a larger proportion of oxygene, is found in the mineral kingdom. There is a powder of a white colour procured by fusing the red oxide with potash. This has been supposed to be a peroxide, but is probably a hydrated oxide ; no precise experiments have been made on the composition of these bodies. This white powder is insoluble in acid and alkaline solutions ; and becomes yellow by being heated.

4. The combination of titanium with chlorine has not yet been made.

5. Titanium is not known to combine with hydrogene, azote, carbon, or boron.

6. Titanium has not yet been combined with sulphur. It enters into union with phosphorus. The phosphuret is brittle, and has metallic lustre. Its composition has not been determined.

7. The agency of the metals of the alkalies on titanium has not been examined. It has not been combined with any of the common metals except iron ; and this alloy is not characterised by any remarkable properties.

8. Titanium has not been employed in the arts except for one purpose ; its oxide has been used at Sevres in the manufacture of porcelain, to impart a brown colour.

28. *Columbium.*

1. Columbium exists in an ore brought from North America, of a black colour ; and likewise in two substances found in Sweden, called tantalite and ittrotantalite. The metal may be procured by ignit-

ing the ores with hydrated fixed alkali; and saturating the alkali with nitric acid, a white powder falls down. This powder was first obtained by Mr. Hatchett from the American specimen, in 1802: and soon after the same substance was procured by Ekeberg from the Swedish mineral, and considered by him as a new substance. Dr. Wollaston, in 1810, demonstrated the identity of the two bodies.

2. The white powder combines with alkalies and metallic oxides, and reddens litmus paper. Hence Mr. Hatchett named it *columbic acid.* Attempts were made to reduce it by ignition with charcoal, in the same manner as the oxide of titanium, but without success; it became black, but did not acquire the metallic lustre. By passing potassium in vapour through the white powder, heated to redness, I found that the potassium became converted into potassa, and a dark-coloured brilliant powder, like plumbago, was produced. This is probably the metallic basis of the substance, or pure columbium.

3. No experiments have been made upon the combinations of this substance. The white powder is soluble in boiling sulphuric acid; and it is precipitated from its solution of an olive colour by triple prussiate of potash, and of a bright orange by solution of galls.

29. *Cerium.*

1. There is a mineral found at Ridderhytta in Sweden, very like tungsten, of a reddish colour, and which has been called cerite. From this substance, Hissinger and Berzelius, in 1804, extracted a brown powder, having the characters of a metallic oxide, and which they named *oxide of cerium.* To procure this powder, the ore is digested with solution of nitromuriatic acid; and the solution obtained evaporated to dryness, and heated with a little muriatic acid; the solution so procured is to be precipitated by solution of ammonia, the precipitate redissolved in muriatic acid, and acted upon by solution of hydrosulphuret of potassa; the clear liquor, precipitated by solution of carbonate of potassa in excess, affords a white powder, which, when heated to redness, affords the *brown oxide of cerium.*

2. *Cerium* had not been obtained in the metallic form till I succeeded in reducing some oxide sent me by M. Berzelius, by means

of potassium; potassa was formed, and a deep gray metallic powder, which became brown by oxidation.

3. When the brown oxide of cerium is digested in the mineral acids, it becomes dissolved; and is thrown down from those solutions by alkalies, as a white powder: it is supposed that this powder contains less oxygene than the brown oxide; but it is probably a *hydrat*. As yet, no experiments have been made either on the composition of the brown oxide, or the white powder.

4. No researches have as yet been made on the combinations of cerium with the other undecompounded bodies. The solutions of cerium are not precipitated by solutions of galls; they give a white precipitate with the triple prussiate of potassa.

30. *Palladium.*

1. *Palladium* was discovered by Dr. Wollaston, in 1803. It exists in the ores of platinum, both those from Peru and the Brazils. It may be procured by dissolving crude platina in aqua regia, and precipitating the saturated solution by solution of prussiate of mercury. The precipitate, washed, dried, and exposed to a strong heat, is converted into palladium.

2. The colour of palladium is white, resembling that of platinum. Its hardness is rather greater than that of bar iron. Its specific gravity varies from 11.3 to 11.8. It is very malleable, but has little ductility. It fuses at a high temperature; but the precise point has not been determined. It is not affected by air or water at common temperatures. When it is heated strongly, its surface acquires a blue colour.

3. Palladium combines with oxygene and chlorine by heat; but neither its oxides nor its combinations with chlorine have as yet been examined. Dissolved in nitric acid it forms a beautiful red solution, from which the alkalies throw down an orange-coloured powder, which probably is a *hydrated oxide*.

4. Palladium readily combines with sulphur when they are heated together in a glass tube. The *sulphuret* is rather paler than the metal, and very brittle: in an experiment that I made, 6.7 grains of palladium gained 1.5 grains, by being converted into the sulphuret;

and supposing the sulphuret to consist of one proportion of metal, and one of sulphur, the number representing palladium will be 134.

5. Palladium seems to have no action on hydrogene, azote, or carbon. Its relations of attraction to boron, and the metals of the fixed alkalies, have not yet been examined. It forms alloys with most of the common metals; but the properties of these compounds have not been examined with attention.

Palladium has not as yet been found in sufficient quantities to be applied to the purposes of the arts.

31. *Iridium.*

1. Iridium was discovered, in 1803, by Mr. Tennant; before Mr. Tennant had published his experiments, it was likewise discovered by M. Descotils.

Iridium exists in minute quantity in the crude ore of platina. To obtain it, the black powder (remaining after the solution of the ore of platina in nitro-muriatic acid) is to be mixed with about five times its weight of pure soda, and heated to redness in a silver crucible for about 30 minutes. The dry mass is to be dissolved in diluted muriatic acid, and the undissolved residuum is to be alternately treated with alkali and acid; by which means it will be all taken up. The solution, containing an excess of muriatic acid, is to be evaporated to dryness, redissolved in pure water, and slowly evaporated, so long as any octohedral crystals form. These crystals are muriate of iridium, and are reduced to the metallic state by exposing them for a short time to an elevated temperature in a platinum crucible.

2. Little is known concerning the properties of this metal. Iridium is of a white colour. It is brittle; and requires for its fusion a most intense heat: it is probable that its specific gravity is higher than that of platinum. It is not acted upon by oxygene even when heated to whiteness. From its relations to muriatic acid, which dissolves it, it seems that it is capable of uniting to chlorine.

3. Iridium has not been combined with hydrogene, azote, sulphur, phosphorus, carbon, or boron, or the metals of the alkalies. It unites to lead, and forms a malleable alloy with copper. Dr. Wollaston

has found amongst the grains of crude platina small white particles of specific gravity 19.25; which consist of iridium alloyed with osmium, and no other metallic substance. The osmium may be oxidated by the water in hydrat of potassa, and united with the potassa; and the iridium combined with chlorine by treatment with muriatic acid, and thus dissolved.

32. *Rhodium.*

1. Rhodium was obtained by Dr. Wollaston, in 1804, from the ore of platina, by the following process. The ore is dissolved in dilute aqua regia; a solution of sal-ammoniac is added; the clear liquor, separated from the precipitate, is acted on by a rod of zinc. By the zinc, a black powder is thrown down, which is washed with very diluted nitric acid. This black powder is re-dissolved in dilute aqua regia; to this solution some common salt is added; the whole is then evaporated to dryness, and washed by alcohol, till it has dissolved all the soluble matter; there remains behind a deep red substance, which, when dissolved in water, and acted on by a rod of zinc, affords a metallic powder, which, intensely ignited with borax, gives a metallic button of rhodium.

2. The specific gravity of rhodium exceeds 11. Its colour approaches to that of silver, with a tint of yellow. It is not acted upon by nitric or sulphuric acids. It is not known whether it combines with oxygene; but solution of potassa throws down a yellow-coloured powder from the red crystals, obtained by dissolving in water the powder left after the washing by alcohol, and evaporating, so as to permit crystallization. From the action of nitro-muriatic acid on rhodium, it is probable that it combines with chlorine.

3. Rhodium unites with sulphur, and is rendered easily fusible by it. It likewise combines with lead, copper, and bismuth; and its alloys are easily soluble in nitro-muriatic acid.

33. *Mercury*, or *Mercurium*.

1. Mercury has been known from the earliest ages of the world. It is found native in the mines of Idria, Spain, and Peru; and likewise combined with sulphur in cinnabar, from which it is separated by distillation with quicklime.

2. Mercury is of the specific gravity 13.56. Its colour is a brilliant white. It is fluid at the common temperature of the air; and becomes a solid at 39° below 0 of Fahrenheit's scale; at about 660° it boils. It is capable of being burnt when the Voltaic flame is made to act upon it, and it produces a brilliant greenish light; its capacity for heat has been referred to, page 43.

3. There are two well-known compounds of mercury and oxygene, one black and the other red; the first may be made by keeping mercury long in agitation, as, for instance, by fastening it in a bottle containing much air, to a mill wheel. The second is produced by keeping it heated in the atmosphere for a long while, nearly at its boiling point. The black oxide of mercury may be likewise made by acting on calomel by solution of potassa; and the red oxide by acting on corrosive sublimate by the same substance, and gently heating the precipitates after they are washed. The black oxide changes when gently heated in the air, and becomes the red oxide. Both the black and the red oxides of mercury are decomposed by a strong heat; the mercury revived, and oxygene liberated. From experiments on their decomposition, I ascertained that the quantity of mercury being the same, the red oxide contained exactly twice as much oxygene as the black; and my results give the number representing mercury about 380, the protoxide or black oxide as composed of 380 mercury and 15 oxygene, and the red oxide or deutoxide as constituted by 380 metal and 30 oxygene. It has not yet been ascertained whether these oxides can be combined with water, so as to form hydrates.

4. Mercury combines with chlorine: when the metal is heated in the gas, it burns with a pale red flame, and the substance called *corrosive sublimate* is formed. When corrosive sublimate is long rubbed with mercury till they are incorporated together, and

the mass sublimed, the substance called calomel is formed. I have found, by a minute analysis, that the quantity of chlorine in *calomel* is to that in corrosive sublimate as 1 to 2, the quantity of mercury being the same in both. Calomel is tasteless, corrosive sublimate has an acrid, burning taste; calomel is insoluble, corrosive sublimate soluble in water. Calomel, according to my analysis, consists of one proportion of mercury 380, and one proportion of chlorine 67. Corrosive sublimate of 380 metal, and 134 chlorine. The names *mercurane* and *mercurana*, which may be adopted to signify the relations of their composition, are too similar to each other to be safely used as familiar appellations for the two substances, as corrosive sublimate is a powerful poison, calomel an excellent medicine.

5. Sulphur and mercury readily combine by fusion; three parts of mercury and one of sulphur melted together, heated to redness, and then sublimed out of the contact of air, afford a cake of a fine red colour, called *cinnabar*, and known in commerce under the name of *vermillion*. It seems, from the experiments made on this substance, that it contains one proportion of mercury, and two of sulphur. When sulphur and mercury are heated strongly together, but not to sublimation, a black mass is obtained, which has been called *Ethiops mineral*. It is probable that this substance contains a larger quantity of sulphur than cinnabar, but its composition has never been ascertained, and it is always converted into cinnabar by sublimation. The specific gravity of cinnabar is about 10, that of Ethiops is less: both these substances are easily decomposed by any metal having a stronger affinity for sulphur; when heated with iron filings, for instance, the sulphur combines with the iron, the mercury rises in vapour and condenses.

6. I have made a combination of phosphorus and mercury, by strongly heating together phosphorus and calomel. It is of a chocolate colour, and not fusible at the boiling point of mercury. I have made no experiments on its composition.

7. No combinations have as yet been effected of mercury with hydrogene, azote, charcoal, or boron.

8. Mercury unites readily with potassium and sodium, and forms solid alloys; the combination is attended with much heat. One part of potassium renders solid at common temperatures 70 parts of mer-

cury. These *amalgams*, for so the metallic combinations of mercury are called, are of the colour of silver; the mercury rises from them at a heat below redness. The alkaline metals are rapidly separated from the mercury by the oxygene of air or water.

9. Mercury combines with most of the common metals described in the preceding pages, and forms *amalgams* with them. It unites most readily with the easily fusible metals, but few researches have been made on its union with the difficultly fusible metals, as its volatility renders it difficult to make the experiments under favourable circumstances.

10. Mercury is a very important and useful metal. It is employed for extracting gold and silver from their ores. It is used in amalgamation with tin for covering mirrors. The sulphuret forms the most perfect red pigment as yet discovered. Its oxides and combinations with chlorine constitute some of the most important substances employed in pharmacy.

34. *Silver, or Argentum.*

1. Silver is found native, or is procured from ores, which are principally combinations of silver with other metals or with sulphur, but the silver of commerce is not pure. To obtain it pure: the metal must be dissolved in nitric acid, and the solution mixed with solution of common salt until no further precipitate takes place. The precipitate must be washed and ignited strongly with about three times it weight of subcarbonate of potassa, mixed with a little charcoal in powder, for half an hour; a button of pure silver will be procured.

2. Silver is of a brilliant white colour. It has no taste or smell; it has great lustre. Its hardness is inferior to that of copper: its specific gravity is about 10.40, and it is slightly increased by being hammered. It yields to none of the metals except gold in malleability. It is very ductile, and may be readily drawn out into extremely fine wire. Its tenacity is considerable. A wire of 0.078 of an inch in diameter will support 187.13 lbs. weight. Its fusing point is about 1000° Fahrenheit. It tarnishes slowly in the air; and this tarnish is owing to the presence of fumes containing sulphur.

3. Silver enters into combination with oxygene; it absorbs this gaseous principle when kept intensely ignited in an open vessel for some time, and is converted into an olive-coloured glass. It burns with a fine green flame, and is converted into an oxide when acted upon by a powerful Voltaic instrument.

The olive oxide of silver is likewise obtained by dissolving the metal in nitrous acid, precipitating by aqueous solution of baryta, and heating the precipitate to dull redness. From my experiments I conclude that 100 of silver absorb about 7.3 parts of oxygene to become the brown oxide; and supposing this oxide to be composed of one proportion of metal and one of oxygene, the number representing silver will be 205. No other oxide of silver except the brown is certainly known.

4. Silver combines with chlorine when the metal is heated in contact with the gas. The compound, which may be called *argentane*, has been long known by the name of *hornsilver*. It is a whitish semitransparent substance, cuts like horn, is fusible at a red heat, and is insoluble in water. It contains about 24.5 per cent. of chlorine, and may be considered as consisting of one proportion of silver 205, and one of chlorine 67.

5. Silver is not known to combine with hydrogene, azote, carbon, or boron.

6. Silver and sulphur combine. This combination is effected, according to M. Proust, when silver is exposed for a considerable time to the atmosphere; it is readily formed by heating to redness thin plates of silver and sulphur. It is of a black colour, is brittle, and has the metallic lustre. According to the experiments of Wenzel, 100 parts of silver by fusion combine with 14.7 parts of sulphur. The sulphuret of silver may therefore be regarded as constituted by one proportion of silver 205, and one of sulphur 30.

7. Silver combines with phosphorus. This compound may be made, according to M. Pelletier, by heating to redness a mixture of silver, phosphoric glass, and charcoal powder. It is a white brittle substance; its composition has not been determined with precision.

8. Silver has not yet been combined with hydrogene, azote, carbon, or boron.

9. The action of the metals of the alkalies and earths on silver has not been examined. Silver forms alloys with most of the other metals, but the greater number of them have not been examined with much attention, or been applied to the purposes of the arts.

The alloy of silver and copper is employed in coins. It is harder than pure silver, and better adapted to receive a fine impression.

10. Silver is employed for a great variety of purposes in the useful and ornamental arts. It is largely used for silvering copper, brass, and sometimes iron. In the common form in which it is applied, it is alloyed with $\frac{1}{12}$ of copper, which gives to it hardness, without impairing its colour or its lustre.

35. *Gold, or Aurum.*

1. Gold is found native, alloyed with copper or silver. To obtain it in a state of purity, gold is dissolved in nitro-muriatic acid; the silver will remain an insoluble muriate, and must be separated; to the clear solution a solution of green sulphate of iron must be added; the gold will be precipitated in the state of a fine powder, and after being well washed in diluted muriatic acid, and then in distilled water, may be fused into a mass.

2. Gold is of a fine light yellow colour; its hardness is scarcely superior to that of tin. Its specific gravity is about 19.277, and it is somewhat increased by hammering. In malleability and ductility it is superior to all the other metals. It has a considerable degree of tenacity; a wire of 0.078 inch in diameter will support a weight of 150lbs. It fuses at about 1300° Fahrenheit. It is not altered by exposure to air or water.

3. There are no accurate experiments recorded on the combinations of gold with oxygene. A purple oxide is formed when gold leaf is burnt by electricity, or gold wires by the Voltaic battery, but its composition has not been ascertained. No dependance can be put on the statements of chemists relative to pure oxides of gold, said to be obtained by treating solution of gold, with potassa, lime, and other substances, for in these instances, as far as my experience has gone, triple compounds always appear to be formed.

4. Gold combines with chlorine when the metal, in a minute state of division, is heated in chlorine, or when the nitro-muriate of gold is partially decomposed by heat, treated with muriatic acid, and evaporated to dryness. It is a brown substance, is very deliquescent, and readily decomposes the water in the atmosphere, forming a muriate of gold. It has not been examined with precision.

5. There are no known combinations of gold with hydrogene, azote, carbon, or boron.

6. There has been no distinct combination made of gold and sulphur.

7. Gold combines with phosphorus: this compound has been recently made in the laboratory of the Royal Institution by Mr. E. Davy, by heating gold, in a minute state of division, with phosphorus in an exhausted tube. It is of a gray colour, and has the metallic lustre. It is readily decomposed by the heat of a spirit lamp; and contains about 14 per cent. of phosphorus.

8. The metals of the alkalies combine with gold; but the alloys have not been minutely examined.

9. Gold forms alloys with the other metals; many of them are brittle, as those of bismuth, antimony, and lead. Others are malleable, as those of silver, copper, and platina. The alloy of gold and copper is employed in coin.

The applications of gold to the useful and ornamental arts, &c. are too well known to need particular detail. The purple oxide of gold is employed for colouring glass and porcelain.

36. *Platinum.*

1. The ores of *platinum* are very rare; they have been found only in South America and in Spain. The ores from South America consist of small roundish flattened grains. The ore found in Spain is in a vein principally consisting of silver. The only places in South America in which grains of the ore of platina have been discovered are at Choco in Peru, Santa Fe near Carthagena, and a district in the Brazils.

Platinum is procured from the South American ore by dissolving it in aqua regia, and dropping into it a solution of sal-ammoniac; a yellow powder falls down, which must be redissolved in nitro-muriatic acid, and again be precipitated by sal-ammoniac; and after this second process, when ignited to whiteness, it is pure platinum. The particles may be made to unite into one mass by hammering them in a state of ignition.

2. Platinum was first described as a peculiar metal by Dr. Lewis, in 1754.

Platinum is of a white colour, but much less brilliant than silver; it is not quite so hard as malleable iron: its specific gravity after being hammered is 21.3, that of water being 1. It is very ductile and malleable; may be easily drawn into wires about the $\frac{1}{2000}$ of an inch in diameter, and hammered into very thin plates: its tenacity is such, that a wire 0.078 of an inch in diameter is capable of supporting a weight of 274.31 lbs. avoirdupois without breaking. It is not fusible by the heat of a forge; and requires either the intense heat of the concentrated solar rays, of Voltaic electricity, or of a flame produced by the agency of oxygene gas.

3. Platinum combines with oxygene only with great difficulty. When intensely ignited by Voltaic electricity it fuses, and throws off sparks, and a fume rises from it, which is probably the oxide of platinum.

When solutions of platinum are precipitated by alkalies, or alkaline earths, the precipitate always appears to be a compound of platinum, oxygene, and earth or alkali employed; yet Mr. Chenevix has stated, that by dissolving the precipitate from the nitro-muriatic solution by lime water in nitric acid, and driving off the acid by heat, a brown powder is formed, which is an oxide of platinum, and which contains 13 per cent. of oxygene. The same ingenious chemist states that there is another oxide of platinum of a green colour, made by heating the brown oxide, and which he believes contains 7 per cent. of oxygene. I have seen several experiments made by Mr. E. Davy, in which no precipitate was produced by the action of lime water on the nitro-muriatic solution: the lime water was used in various proportions, but without success.

When an alloy of potassium and platinum is heated, exposed to air, both metals burn, and a yellow powder is formed, which gives off oxygene gas by ignition: but this powder, after being long washed, reddens turmeric, so that it is not pure oxide of platinum.

4. A bright brown powder may be obtained by evaporating to dryness the nitro-muriatic solution of platinum. This powder, when heated to whiteness, is resolved into platinum and chlorine, and the chlorine gas may be collected in a proper apparatus. From some experiments made on this powder, at my request, by Mr. E. Davy, it appears to contain about 24 per cent. of chlorine; but this estimate can be considered only as an approximation, for there are many difficulties in gaining accurate results on a substance so easily decomposed.

5. Sulphur combines with platinum when they are heated together in exhausted tubes. The *sulphuret* is an infusible black powder, decomposable by a white heat. According to Mr. E. Davy, who first made it in the laboratory of the Royal Institution, it contains about 16 per cent. of sulphur. He supposes that there is another combination of sulphur and platina, which may be made by heating the precipitate from the nitro-muriatic solution by sal-ammoniac and sulphur together, and which contains 28 per cent. of sulphur.

6. Phosphorus and platinum combine with great energy, when the phosphorus is made to act in vapour, in exhausted tubes, on platina, heated to dull redness: the combination is so violent that the mass becomes vividly ignited. The *phosphoret* of platina is an infusible bluish gray powder with little lustre. According to Mr. E. Davy, it contains more than 17 per cent. of phosphorus. He believes that there is a *superphosphoret* of platina containing 30 per cent. of phosphorus, made by heating the yellow powder procured by sal-ammoniac with phosphorus; but new experiments are wanting on this result, as well as on the results of the action of sulphur on platinum. The quantities do not correspond with the theory of definite proportions; and as neither the metal nor the compounds made can be fused under the circumstances of the experiment, it is not possible to say that the combination is perfect; and as all such combinations are decomposable by a strong heat, part of the compound first formed may be decomposed before other parts of the mass enter into union.

7. From the experiments of M. Descotils it is probable that platinum is capable of combining with boron; it has never been united to hydrogene, azote, or carbon.

8. Platinum readily unites to potassium and sodium; their combination takes place with ignition, and a bright brittle mass is obtained, from which the alkaline metals are readily separated by the action of air or water. Platinum combines with most of the other metals; but the properties of its alloys have been very little studied. To the fusible metals it communicates difficult fusibility. It amalgamates with mercury when heated with that metal in a finely divided state. It combines with gold, and renders its colour pale; even $\frac{1}{16}$ of platinum can be detected in union in gold, from the colour.

9. Platinum is a most valuable metal; as it is not oxidable, nor fusible under common circumstances, and only difficultly combinable with sulphur, and not acted upon by common acids, it is admirably adapted for the uses of the philosophical chemist, and may be advantageously employed in all cases where gold is applied, unless the use is connected with the colour or malleability of the metal. The general application of platinum as a manufactured metal to the purposes of the laboratory is one of the many benefits which chemistry and the useful arts owe to Dr. Wollaston.

37. *Arsenic or Arsenicum.*

1. Arsenic may be easily procured by heating the substance known by the name of white arsenic in powder with charcoal, in a Florence flask, or a glass tube; before the mixture becomes red hot, a metal sublimes, and condenses in the upper part of the vessel, which is arsenic.

2. Arsenic is of a bluish white colour, not unlike that of steel. Its specific gravity is 8.31. It is very brittle: its point of fusion has not been ascertained; but it is the most volatile of all the metals, rising in vapour at about 356° of Fahrenheit's scale. When a part of it is suddenly ignited, it burns with a pale bluish light, sending off dense white fumes. It burns spontaneously in chlorine.

3. There are two known combinations of arsenic and oxygene; both of which are possessed of several of the properties of acids.

The first is the substance formed by combustion, and this contains the smallest quantity of oxygene ; the compound containing the largest quantity of oxygene may be formed by distilling nitrous acid, mixed with $\frac{1}{16}$ of its weight of muriatic acid from the other compound. The compound formed by combustion has been called *arsenious acid*, and likewise white oxide of arsenic. When procured by precipitation from acid solutions, it exists as a *hydrat:* it is fusible by a strong heat suddenly applied, but sublimes slowly at 383° Fahrenheit; after fusion it appears as a white vitreous substance, of specific gravity 5. It is soluble in 80 parts of water at 60°, and in 15 parts at 212°. Its taste is acrid, leaving an impression of sweetness. When heated its smell is like that of garlic. The compound of arsenic with the largest proportion of oxygene is called *arsenic acid.* It is much more fixed in the fire than arsenious acid, is very soluble in water, and has an intense sour taste. From experiments on the quantity of oxygene absorbed by arsenic during its conversion into these two compounds, made by Proust and by myself, I conclude that the arsenious acid consists of about 25 of oxygene and 75 of metal; and the arsenic acid of 33 of oxygene and 67 of metal. Hence it appears that the quantity of metal being the same, the oxygene in the arsenic acid is to that in the arsenious nearly as 3 to 2; and if the arsenious acid be supposed to contain two proportions of oxygene, the number representing arsenic will be 90; and those representing arsenious and arsenic acids will be 120 and 135.

4. The only compound of chlorine and arsenic known, is made by the combustion of the metal in chlorine, or by distilling a mixture of arsenic and corrosive sublimate together: it is a heavy limpid fluid, capable of being easily rendered gaseous, forming a liquid muriate of arsenic by the action of a small quantity of water, and affording a precipitate of arsenious nearly acid by the action of a large quantity. From my experiments it appears that the compound of chlorine and arsenic, which may be called *arsenicane*, consists of 40 metal to 60 of chlorine; therefore it may be regarded as composed of two proportions of chlorine, and one of metal.

5. Arsenic combines with hydrogene. The best known substance containing the two bodies is *arseniuretted hydrogene* gas. This elastic fluid, which was discovered by Scheele, may be procured by dis-

solving an alloy of 14 parts of tin and 1 of arsenic in muriatic acid. This substance has an extremely fetid smell; it burns when brought near an inflamed taper in the atmosphere; its flame is blue; and if the vessel in which it is burnt have a narrow neck, it deposits arsenic. It inflames spontaneously when acted upon by chlorine; it is soluble only to a very slight extent in water It is probable that the gas called *arseniuretted* hydrogene is always a mixture of a true gaseous compound of arsenic and hydrogene, with common hydrogene. Its specific gravity varies, as I have found, from 5 to 8, that of hydrogene being 1. When decomposed by attracting the arsenic from it, by the action of ignited metals, there is an expansion of volume. M. M. Gay Lussac and Thenard found 100 parts of it decomposed by tin become 140 parts. M. Stromeyer states that he analysed a gas consisting of 106 parts arsenic, and 2.19 hydrogene. This would agree with the idea that the pure gas is composed of 2 proportions of hydrogene, and one of metal; but such a gas must be more than twice as heavy as any specimen that has been weighed; and this circumstance leads me to doubt of the correctness of M. Stromeyer's results.

There is likewise a solid compound of hydrogene and arsenic: it may be procured by acting on water by an alloy of potassium and arsenic in great excess: it is a brown powder, which burns, when gently heated in the atmosphere, and which gives off arseniuretted hydrogene, when heated in close vessels. The same substance is procured when arsenic is made the negative surface in contact with water in Voltaic combinations. No experiments have as yet been made on the proportions of its elements.

6. Sulphur and arsenic readily unite by fusion, and form a red vitreous semitransparent mass. The same substance is found native in different parts of Europe, and is called realgar; it is often crytallized in transparent prisms: its specific gravity is 3.225. If Thenard's account of its composition be considered as accurate, it must consist of two proportions of arsenic, and three of sulphur, 180 and 90. If sulphuretted hydrogene gas be made to act upon a solution of arsenious acid in muriatic acid, a fine yellow powder falls to the bottom. This powder is usually called *orpiment*. It may be formed likewise by subliming arsenic and sulphur together in a heat not suf-

ficient to produce a fusion of the mass. It is composed of thin plates, which have a considerable degree of flexibility. According to Thenard it contains mure sulphur than realgar; but Mr. Proust states that by fusion it becomes realgar.

7. Arsenic readily combines with phosphorus, and they form together a black powder; the proportions of its elements have not yet been accurately ascertained.

8. Arsenic has not been combined with azote, boron, or carbon.

9. Arsenic combines with most metallic substances. It renders the metals of the fixed alkalies less fusible by uniting to them, but its alloys with the common metals are usually very fusible. It renders gold and platina brittle, and gives whiteness to copper: none of the alloys containing it in any considerable quantity are malleable.

10. Arsenic is not much used in the arts. Realgar and orpiment are employed as pigments. The solutions containing arsenious, or arsenic acids, are extremely poisonous. The arsenious acid, in very small doses, has been employed in medicine, particularly for the cure of intermittent fevers.

38. *Molybdenum.*

1. There is an ore found in different parts of Europe, particularly in Sweden, not unlike plumbago, from which Scheele, in 1778, procured a white powder; and from this powder Hielm, in 1782, obtained a metal, which he called *molybdenum.*

Pure molybdenum may be obtained either from the ore like plumbago, or from another ore found in Carinthia called the molybdat of lead; by digesting them in powder in nitric acid, and boiling the mass in sulphuric acid; by lixiviation with water a liquor is obtained, which when acted on by solution of ammonia passed through a filtre and mixed with nitric acid, deposits a white powder, and this powder intensely ignited in a charcoal crucible mixed with linseed oil affords the metal.

2. Molybdenum, according to the observations of Bucholz, is brittle; its specific gravity is 8.611. Its colour is white. It burns when placed on ignited charcoal and acted on by a current of oxygene gas, and gives off a white smoke which collects in small needle-formed crystals.

3. There are two well-defined combinations of molybdenum and oxygene. One is blue, the other is pale yellow; they both possess acid properties, and therefore may be distinguished by the names of *molybdous* and *molybdic* acids. The *molybdic acid* is easily obtained from the ores of the metal by treatment with acids and ammonia: the white powder described in the last page is this substance combined with water, and it may be procured pure by ignition. Its specific gravity is 3.4; its taste is sour; it is fusible in a strong heat, and volatilized by intense ignition: it is soluble in about 1000 times its weight of water.

The blue acid, or the *molybdous acid*, is formed by triturating together in boiling water, one part of molybdenum in powder, and two parts of molybdic acid. The solution is to be passed through a filtre, and evaporated in a temperature not exceeding 120°; the blue acid remains in the state of a fine powder. This acid is more soluble in water than the molybdic acid, and acts more intensely on vegetable blues, converting them to red. According to Bucholz the blue acid consists of 100 parts of metal to 34 of oxygene, and the yellow acid of 100 parts of metal to 50 of oxygene. On these data it seems probable that molybdous acid consists of 2 proportions of oxygene and one of metal; and molybdic acid of 3 proportions of oxygene and 1 of metal; and assuming the composition of the molybdous acid as the foundation of calculation, the number representing molybdenum will be 88.2. Mr. Bucholz supposes that there are *oxides* of molybdenum, containing smaller quantities of oxygene than the two acids. It is probable that there is a brown oxide containing a single proportion of oxygene, obtained by exposing the metal to a red heat; but what Bucholz considers as a violet brown oxide produced by heating the brown oxide, is probably only a mixture of the brown oxide and the blue acid.

4. No direct experiments have, I believe, been made on the action of chlorine on molybdenum; but when the molybdic acid is dissolved in muriatic acid, and the residue heated to redness, chlorine rises, and the blue acid remains behind; but a grayish sublimate is likewise formed, in which chlorine is indicated by the action of nitrat of silver.

5. Molybdenum combines readily with sulphur by fusion, or by

heating strongly together molybdic acid and sulphur. The sulphuret of molybdenum is a black shining powder, the same as the native mineral from which Scheele first procured the acid. According to Bucholz it contains 60 of metal and 40 of sulphur per cent. and therefore may be considered as consisting of one proportion of metal and two of sulphur.

6. Phosphorus combines with molybdenum; but the properties and constitution of the *phosphoret* have not been investigated.

7. Hydrogene, azote, carbon, and boron, have not been combined with molybdenum.

8. It unites to several of the metals; one of the most perfect of its alloys is with iron. With lead it forms an alloy somewhat malleable. Most of its other alloys break under the hammer; from the difficult fusibility of the metal it is not easy to make them uniform in their constitution.

Molybdenum has not yet been applied to any of the purposes of the arts.

39. *Chromium.*

1. There are two ores from which chromium may be procured; one is the red lead ore of Siberia, the chromat of lead, the other is the chromat of iron, which has been found in France and in North America.

Chromium was discovered by Vauquelin, in 1797. To obtain chromium, chromat of lead in fine powder is to be digested with moderately strong muriatic acid, till its power of action is exhausted. The fluid produced is to be passed through a filtre, and a little oxide of silver, such as is procured by precipitation from nitric acid by potassa, very gradually added to it till the whole solution becomes of a red tint. This liquor by slow evaporation deposits small ruby red crystals, which, when intensely ignited, mixed with a little charcoal powder, afford *chromium*. Chromat of lead may be procured from chromat of iron, by decomposing it by hydrat of potassa, making a solution in nitric acid, and adding solution of nitrate of lead; the chromat of lead falls down as a beautiful orange powder.

2. Chromium is a white brittle metal, requiring an intense heat for its fusion ; it is very difficultly acted on by acids. It does not readily enter into combustion. Its specific gravity is 5.9.

3. Very few experiments have been made on the combinations of chromium. The red crystals procured from chromate of lead by muriatic acid appear to be a *hydrated acid ;* they are soluble in water, have a sour taste, and combine with alkalies.

The red crystals strongly heated become a green powder, which is considered as an *oxide of chromium*. It is said that from 100 parts of the red crystals 67 parts of metal may be procured. The acid of chromium, when combined with alkalies, precipitates most of the metallic solutions. In solutions of mercury it produces a vermillion red precipitate ; in those of silver, a carmine red ; in those of tin, a green. The name chromium has been given to the metal from its remarkable colouring powers*.

4. The artificial chromate of lead forms a beautiful and permanent pigment. I have found the orange colour most pure when the nitrate of lead used for the precipitation contained an excess of acid. The oxide of chromium has been employed for giving an emerald green colour to glass and enamel. Chromic acid is the colouring matter of the spinelle ruby; and oxide of chromium gives its beautiful colour to the emerald. The oxide of chromium has been lately found in some meteoric stones.

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* From Χρωμα.

DIVISION VI.

OF SOME SUBSTANCES THE NATURE OF WHICH IS NOT YET CERTAINLY KNOWN.

1. *Preliminary Observations.*

THE bodies to be examined in this division have been arranged into a distinct class, because they present some extraordinary and anomalous results, and because as yet the knowledge obtained respecting their nature is imperfect; many of the facts ascertained respecting them harmonize with the general doctrines of the science, and some of them offer new views respecting the arrangements and properties of matter; they are therefore amongst the most interesting objects of chemical enquiry.

2. *Of the Fluoric Principle.*

1. There is a substance found abundantly in nature called *fluor spar;* it is usually either blue, green, yellow, or white, transparent, and crystallized in cubes. It is a common product of the mines in Derbyshire.

2. When this substance, in fine powder, is mixed with oil of vitriol and distilled in retorts of silver or lead, connected with receivers of the same metal artificially cooled, an intensely active fluid is produced. It has the appearance of sulphuric acid, but is much more volatile, and sends off white fumes when exposed to air. It must be examined with great caution, for when applied to the skin it instantly disorganizes it, and produces very painful wounds. When potassium is introduced into it, it acts with intense energy upon it, and produces hydrogene gas, and a neutral salt; when lime

is made to act upon it there is a violent heat produced, water is given off, and the same substance as fluor spar is produced. When it is dropped into water a hissing noise is produced with much heat, and an acid fluid not disagreeable to the taste is formed if the water be in sufficient quantity. It instantly corrodes and dissolves glass.

3. If, instead of being distilled in metallic vessels, the mixture of fluor spar and oil of vitriol be distilled in glass vessels, little of the corrosive liquid will be obtained; but the glass will be acted upon, and a peculiar gaseous substance will be produced, which must be collected over mercury. The best mode of procuring this gaseous body is to mix the fluor spar with powdered glass or powdered quartz, and in this case the retort may be preserved from corrosion, and the gas obtained in greater quantities. This gas, which is called *silicated fluoric gas*, is possessed of very extraordinary properties.

It is very heavy; 100 cubical inches of it weigh 110.77 grains, and hence its specific gravity is to that of hydrogene nearly as 48 to 1. When it is brought in contact with water it instantly deposits a white gelatinous substance, which is hydrat of silica, and the water becomes an acid solution of silica; it produces white fumes when suffered to pass into the atmosphere. It is not affected by any of the common combustible bodies, but when potassium is strongly heated in it, it takes fire and burns with a deep red light; the gas is absorbed, and a fawn-coloured substance is formed, which yields alkali to water with slight effervescence, and contains a combustible body, and the washings afford potassa and a salt, from which the strong acid fluid mentioned in the last section may be procured by sulphuric acid.

4. If instead of glass or silica the fluor spar be mixed with dry vitreous boracic acid, and distilled in a glass vessel with sulphuric acid, the proportions being one part boracic acid, two fluor spar, and 12 oil of vitriol, the gaseous substance formed is of a different kind, and is called *the fluoboric gas*. 100 cubical inches of it weigh 73.5 grains, so that its specific gravity is rather more than 32 times that of hydrogene. When a little of it is suffered to pass into the atmosphere it produces fumes much more dense than those produced by the gas described in the last section, and which appear white, and almost opaque. It is absorbed rapidly by water, and forms with

it a dense fluid like sulphuric acid in appearance and consistence; and when water is saturated with it at 50° Fahrenheit, it contains 700 times its volume of gas, and is of specific gravity 1.77. When potassium is heated in this gas, it takes fire, and burns with a red light; the gas is destroyed, if the metal be in sufficient quantity, and an olive-coloured substance is produced, which seems to be principally boron, and a neutral salt, which, by the action of oil of vitriol, affords the dense fluoric acid, and sulphat of soda.

5. It appears extremely probable, from all the facts known respecting the fluoric combinations, that fluor spar contains a peculiar acid matter; and that this acid matter is united to lime in the spar seems evident from the circumstance that gypsum, or sulphate of lime, is the residuum of the distillation of fluor spar and sulphuric acid: the results of experiments on the decomposition of fluor spar, have been differently stated by different chemists; the maximum of sulphate of lime obtained from 100 grains in some experiments made in the laboratory of the Royal Institution, was 174.2 grains, and from this result fluor spar may be supposed to consist of 55 lime, and about 20.7 fluoric acid, and this last number will represent the acid.

6. The dense acid fluid described in 2, must, on the same idea, be supposed to be a compound of an acid unknown in a separate state, and water; and may be called *hydrofluoric* acid; and supposing all the water in oil of vitriol transferred to it, it will consist of 20.7 fluoric acid, and 17 water.

7. The gas formed by the action of hydrosulphuric acid on a mixture containing silica and fluor spar, silicated fluoric gas, must be regarded as a kind of neutrosaline gaseous compound consisting of fluoric acid and silica, and it has been found to afford, when decomposed by solutions of ammonia, 61.4 per cent. of silica; it may therefore be supposed to consist of two proportions of acid 41.4, and one of silica 61. According to this view of its composition, the number representing it is about 102; 1 volume of it condenses two volumes of ammonia, and they form together a peculiar saline substance which is decomposed by water. The composition of this salt is easily reconciled to the numbers above given, as representing silica and fluoric acid, on the supposition that it contains one proportion of

ammonia, and one of silicated fluoric acid; and calculating the number of silicated fluoric acid on this supposition, it would be about 99.

There is great reason to believe that, when potassium burns in this gas, it is the acid matter which is decomposed, and that it consists of oxygene united to an inflammable basis; for if it were the silica alone which is decomposed, or if a mere combination were formed between the potassium and the acid gas, the same quantity of fluate of lime or fluor spar ought to be formed from equal quantities of silicated fluoric acid, acted upon by potassium, and afterwards exposed to solution of ammonia, and the other absorbed by water, and acted on by solution of ammonia; which I have found is not the case, for in the first instance there is considerably less produced. In the experiment, it seems likely that the potassium acquires oxygene principally from acid matter combined with the silica, and that the inflammable basis of the acid partly combines with the potassa, and partly with the silica, or with silicum; and forms with the first a compound that effervesces, and is partly decomposed by water; and with the second an insoluble substance, which affords silicated fluoric acid by absorption of oxygene.

8. It is extremely likely that fluoboric acid gas is composed of the peculiar acid which is supposed to consist of oxygene and an inflammable basis, and boracic acid; but it appears that in the combustion of potassium in this gas it is the boracic acid alone that is decomposed, and that the fluoric acid combines with the potassa formed.

9. It is a peculiar circumstance with respect to the fluoric principle, that silicated fluoric gas, and fluoboric gas combine with bodies without decomposition. Thus they both form peculiar compounds with the alkalies; and though silica is deposited by the action of silicated fluoric gas on water, and on other oxidated bodies, yet the new compound formed always appears to contain part of the earth, which is supposed to be a constituent of the gas. In general, silica and boracic acid can only be procured from the two gasses by the intervention of bodies that contain water or oxygene: this circumstance, if it were not opposed by the results of the experiments on the action of potassium on silicated fluoric gas, which, however, ought to be repeated, might lead to the suspicion, that the fluoric

gasses are compounds of a principle unknown in the separate state, but analogous to chlorine, with silicum and boron; that the hydrofluoric acid is a compound of the same principle with hydrogene and water, and fluor spar a compound of the same principle with calcium.

10. If 20.7 be really the number representing fluoric acid, it can be supposed to contain only one proportion of oxygene, and the fluoric basis will be represented by 5.7, and it will be the only known acid so constituted.

11. Silicated fluoric gas, when absorbed by water, affords an acid fluid, which, when acted upon by ammonia, deposits silica; and in glass vessels pure hydrofluoric acid cannot be obtained. Silicated fluoric gas seems to form only one combination with ammonia, which deposits silica by the action of water; but fluoboric gas forms three combinations with ammonia, one volume of it condenses 1.2 and 3 volumes of ammonia. The saline compound containing the least quantity of ammonia is solid, the other two compounds are fluids at the common temperature of the atmosphere.

12. The only use to which the fluoric combinations have as yet been applied is for etching on glass; for this purpose the hydrofluoric acid, or the fluate of ammonia, should be used; the gasses have no action on glass.

13. Silicated fluoric gas, and diluted hydrofluoric acid were discovered by Scheele, in 1771. Margraaf, three years before, had pointed out some of the results of the action of acids on fluor spar; concentrated hydrofluoric acid and fluoboric gas were made known by some elaborate researches of Gay Lussac and Thenard, in 1809. My brother, Mr. John Davy, in 1810 and 1811, extended the knowledge of the properties of these bodies, and the modes of procuring them pure, ascertained the specific gravity of fluoboric and silicated fluoric gasses, and the proportions in their ammoniacal combinations. The action of potassium on silicated fluoric gas and fluoboric gas was investigated by M. M. Gay Lussac and Thenard, in 1809; and I made a number of experiments on the same subject about the same time.

3. *Of the Amalgam procured from ammoniacal Compounds.*

1. When a globule of pure mercury is negatively electrified by a Voltaic apparatus of 100 pair of plates, it being in contact with solution of ammonia in a cavity made in a piece of muriate of ammonia, or any ammoniacal salt, moistened in such a manner, and so placed on a disc of platina, that the circuit is completed; the globule rapidly increases in volume, the quicksilver loses its fluidity, and at length becomes of the consistence of soft butter, and arborescent crystallizations shoot from it, which are quite solid. The amalgam so formed has perfectly metallic characters. It effervesces copiously when thrown into water, hydrogene gas is given off, and a solution of ammonia is found in the water. When exposed to the air it gradually loses its consistence; it emits a strong odour of ammonia, and reddens paper tinged with turmeric held above it; and at last is found merely quicksilver.

This curious experiment was made about the same time by Dr. Zeebeck of Jena, and by M. M. Hissinger and Berzelius of Stockholm, before the middle of the year 1808; and they were led to make it in consequence of my experiments on potassa and soda.

2. I found a still more easy mode of making the amalgam, by employing mercury combined with a minute quantity of potassium, sodium, or barium. When a compound of this kind is placed in contact with a solution of ammonia, or any moistened ammoniacal salt, it enlarges to eight or ten times its bulk, and becomes a soft solid, and may be preserved for a much longer time than the amalgam formed by electrical powers; it changes very slowly even under water.

3. Different opinions have been formed, and may still be formed, concerning the nature of this extraordinary substance. M. Berzelius supposes that ammonia consists of a peculiar metal combined with oxygene, and of which metal hydrogene and azote are both peculiar oxides; this idea was one that I started likewise soon after the discovery of the amalgam..

4. Another view of the subject is, that the amalgam consists of mercury united to azote and hydrogene, the hydrogene being in

larger proportion than in ammonia; and this view has been embraced and defended by M. M. Gay Lussac and Thenard; but the subject is still obscure and mysterious, and the true theory of the experiment can only be developed in consequence of new facts.

5. Soon after the discovery of the amalgam, I attempted to procure a peculiar metallic substance from it by distillation out of the contact of air, but without success; whether I used the amalgam formed by electricity, or that procured by the intervention of the alkaline metals; on the application of heat, hydrogene and ammonia were always evolved, and the mercury recovered its former state. On the idea of the basis of ammonia being a peculiar metal, of which azote and hydrogene are oxides, these results can only be explained by supposing that the amalgam being formed from moist substances, sufficient water adheres to it to afford oxygene, and to produce the gaseous matter; and the most perfect amalgam does not yield a quantity of gaseous matter equal to more than $\frac{1}{800}$ of its weight.

I procured ammonia and hydrogene by heating the amalgam, however, in cases in which it was carefully wiped with bibulous paper, and in which there was no appearance of adhering moisture; and similar results have been obtained by M. M. Gay Lussac and Thenard.

In the most accurate experiments, the proportions of ammonia and hydrogene were two to one in volume.

6. There is no instance known of mercury retaining its metallic characters in combination with any other substance than a metal; and it seems very probable that, if the matter existing in the amalgam from ammonia could be procured in its perfect form, and could be exhibited as a solid under pressure, and at a very low temperature, it would appear as an extremely light metallic substance. On the idea of its being a compound of azote and hydrogene, it will consist of one proportion of azote 26, and 8 of hydrogene 8; and the number representing it will be 34.

It is very difficult, but not however altogether impossible, to reconcile the idea of the substance in the amalgam being elementary, with analogies belonging to the general series of definite proportions. On such a supposition, azote must necessarily contain more than four times as much oxygene as hydrogene; and if 1 of basis to

5 of oxygene, be supposed in hydrogene, then there will be 1 to 25 in azote, and 1 to 40 in nitrous oxide, 1 to 55 in nitrous gas, 1 to 85 in nitrous acid, and 1 to 15 in ammonia ; and 5, 15, 25, 40, 55, and 85, form a series of numbers having definite relations to each other.

If the hypothesis of the elementary nature of the substance in the amalgam be adopted, water must be supposed to be constituted by 1 basis, and 50 of oxygene.

It is extremely unlikely that such proportions should exist, and the general tenor of our knowledge of chemistry, as well as the results of the experiments, render it much more probable that the amalgam is composed of quicksilver, azote, and hydrogene.

DIVISION VII.

ON THE ANALOGIES BETWEEN THE UNDECOMPOUNDED SUBSTANCES; SPECULATIONS RESPECTING THEIR NATURE; ON THE MODES OF SEPARATING THEM, AND ON THE RELATIONS OF THEIR COMPOUNDS.

1. *Of the Analogies between the undecompounded Substances; Ideas respecting their nature.*

1. THE undecompounded substances most analogous to each other are certainly to be found amongst the metals; some of these are so similar, that it requires refined observation, and sometimes experiment, to distinguish them. There is likewise a chain of gradations of resemblance which may be traced throughout the whole series of metallic bodies, at the same time that certain similar and characteristic properties are found to belong to metals in other respects most unlike each other.

Silver and palladium, antimony and tellurium, agree in a great number of qualities. Potassium and platinum, if we except their lustre, colour, and power of conducting electricity, are bodies extremely dissimilar; yet, by arranging the metals in the order of their natural resemblances, these two substances may be made parts of one chain of natural bodies: potassium, sodium, and barium are very like each other; barium approaches to manganesum, zinc, iron, tin, and antimony. Platinum is analogous to gold, silver, and palladium; and palladium is connected by distinct analogies with tin, zinc, iron, and manganesum. Arsenic and chromium, though amongst the most dissimilar of the metals in other respects, agree in the property of forming acid matter by combination with oxygene.

Amongst the inflammable bodies not metallic there are analogies, but not a similar series. Sulphur and phosphorus agree in many respects; carbon and boron are likewise analogous, and are connected by distinct relations with the metallic substances. Azote, whilst it agrees with the other combustible bodies that have been named in forming an acid by saturation with oxygene, is analogous to carbon in its incapacity of uniting to chlorine.

Chlorine and oxygene are separated from the inflammable bodies by a number of marked distinctions; yet sulphur agrees with chlorine in forming an acid by combining with hydrogene; and has a weak attraction for chlorine, and a strong attraction for metallic substances.

2. As far as our knowledge of the nature of compound bodies has extended, analogy of properties is connected with analogy of composition; if one of the inflammable solids or metals is proved to be compound, there would be strong evidence for supposing that the others were likewise compounded. It has been already mentioned that sulphur and phosphorus, when Voltaic electrical sparks are taken in them in a state of fusion, afford hydrogene gas. I found, likewise, that when an alloy of tellurium and potassium was acted upon by melted sulphur, telluretted and sulphuretted hydrogene equal to at least 80 times the volume of the sulphur were disengaged. I have made many experiments of this kind with similar results, the sulphur being recently sublimed in azote, and moisture being excluded with the greatest care. In the experiments of Voltaic electrization, it might be supposed that the hydrogene being only in very small quantity might belong to an accidental admixture in the sulphur and the phosphorus; but the proportion is too large in the experiments on the action of tellurium, potassium, and sulphur, to allow of a similar inference, and it seems more probable that it arises either from the decomposition of the sulphur, or of the metals, or all of these bodies.

3. We know nothing of the true elements belonging to nature; but as far as we can reason from the relations of the properties of matter, hydrogene is the substance which approaches nearest to what the elements may be supposed to be. It has energetic powers of combination, its parts are highly repulsive as to each other, and at-

tractive of the particles of other matter; it enters into combination in a quantity very much smaller than any other substance, and in this respect it is approached by no known body.

After hydrogene, oxygene partakes most of the elementary character; it has perhaps a greater energy of attraction, and next to hydrogene is the body that enters into combination in the smallest proportion.

4. I have already hinted at the idea that all inflammable matters may be similarly constituted, and may contain hydrogene. And on this supposition they may be conceived to owe their powers of combining both with oxygene and chlorine, to the attractive energies of their combined hydrogene.

On the most probable view of the nature of the amalgam from ammonia, as I have mentioned, it must be supposed to be composed of hydrogene, azote, and quicksilver; and it may be regarded as a kind of type of the composition of the metals; and by supposing them and the inflammable bodies different combinations of hydrogene with another principle as yet unknown in the separate form, all the phenomena may be easily accounted for, and will be found in harmony with the theory of definite proportions.

The metal of ammonia or *ammonium* must be supposed to be constituted by 8 of hydrogene, and 26 of azote; and as azote unites to five proportions five times 15 of oxygene, it may be supposed to contain ten proportions of hydrogene; and its constitution may be thus expressed, 10 proportions of hydrogene and 16 proportions of an unknown basis. Ammonium, on the same hypothesis, will consist of 16 unknown basis, and 18 hydrogene. Potassium, the number representing which is 75; as it combines with 3 proportions of oxygene, may be supposed to consist of 69 unknown basis, and 6 hydrogene. Sodium, which is represented by 88, and which likewise combines with three proportions of oxygene, may be considered as consisting of 82 basis, and 6 hydrogene. Tin, the number of which is 110, and which combines with two proportions of oxygene, may be supposed to be consituted by 106 of basis and 4 hydrogene; and silver, which is represented by 205, of 203 of basis, and 2 hydrogene. Amongst the acidifiable bodies, sulphur, which is represented by 30, may be supposed to consist of 6 hydrogene, and 24 basis;

phosphorus of 4 hydrogene, and 16 basis; and charcoal of 4 hydrogene and 7.4 basis. It will be unnecessary to supply any more of these estimations, the principles of which are obvious; and in an elementary book it would be improper to dwell upon matters of mere speculation; even these transient views have been developed merely for the sake of pointing out a promising path of enquiry.

5. In supposing the quantity of hydrogene in the inflammable solids and metals denoted by the quantity of oxygene or of chlorine they absorb, it is taken for granted that the hydrogene forms only water or muriatic acid in the new combination, but it is possible that hydrogene may combine with oxygene and chlorine in many different proportions, and that its union with a peculiar basis may modify its power of attraction; so that even allowing the general hypothesis, no confidence can be placed in the numerical expressions of the proportions of hydrogene and basis; they are offered merely as possible circumstances.

6. The probabilities that the metals and inflammable solids may be constituted by different and various proportions of hydrogene and an unknown basis, are however strengthened, by the fact, that the metals in which hydrogene is supposed to be attracted by the largest quantity of other matter are the least disposed to combine with oxygene and chlorine; and those that are supposed to contain the largest quantity of hydrogene to the smallest quantity of other matter, are the most combustible, and likewise those supposed to contain the largest and consequently the least attracted quantity of hydrogene, have the lowest specific gravity.

7. When the analogy of the oxides to many of the hydrats, and that of the combinations of chlorine to many of the neutral salts, is considered, bodies so much alike that till lately they have been confounded together; the view that the inflammable bodies contain hydrogene becomes still more likely. Water cannot be separated from the hydrats of potassa or soda by heat; and the hydrat of lime is extremely analogous to the pure earth; and supposing the oxides to be compounds of unknown bases and water, it might be expected that the water would adhere to them with great energy, and would only be separated in consequence of the bases entering into a new combination.

Common salt is very analogous to sulphat of potassa and other bodies known to consist of acid matter and alkaline matter; and if sodium consist of a basis combined with hydrogene, then common salt may be considered as composed of the same basis united to muriatic acid.

8. Chlorine and oxygene agree in many of their characters; but the weight of chlorine, its colour, its absorbability by water, are all in favour of its being a compound. The number representing chlorine is so high that it may include four proportions of oxygene; and if this body be supposed to consist of oxygene united to an unknown basis, the analogy of the combinations of chlorine, both to the oxides and the salts, might be easily explained. The evidences in favour of such an idea of the constitution of chlorine are, however, much inferior to those which render it probable that the inflammable solids contain hydrogene; and this speculation on the composition of chlorine must not be confounded with the notion that chlorine is a compound of oxygene and muriatic acid free from water; for supposing a basis to exist in chlorine, it does not follow that it will be acid in its nature. The characteristic acid belonging to the combinations of chlorine is formed by the union of that body with hydrogene; and sulphur likewise forms an acid by combining with hydrogene.

9. I have mentioned, page 96, that in the electrization of a globule of mercury in water, oxygene appears to be combined with the metal, and yet no hydrogene evolved. I have made a number of experiments on this subject, and have ascertained that, in the process described, oxide is formed, without any apparent compensation in the production of inflammable matter; nor was I able to detect any combination into which the hydrogene could have entered; so that these experiments, as they now stand, would induce the belief that water is the ponderable basis of both oxygene and hydrogene, and that these two forms of matter owe their peculiar properties either to the agency of imponderable substances, or to peculiar arrangements of the particles of the same matter; but such a formidable conclusion as this must not be hastily adopted, for in all other cases oxygene and hydrogene appear as perfectly inconvertible substances, and in no other instance can one be procured from water without the correspondent quantity of the other, or without some product in

which the other may be supposed to enter. In all cases in which the circuit appears to be interrupted, even this is the case. When the finger is plunged in a glass of water connected with a wire of platina positively electrified from the battery of 2000 double plates of the Royal Institution, oxygene is produced, and there is no appearance of hydrogene; but in this case the body is connected with a floor containing moisture, and at the extreme point of the moist surface, where it is in contact with a metallic body, hydrogene must be disengaged; and the same changes occur if a circuit be made through eight persons, their hands being in contact, the two forming the extremity of the chain having their fingers plunged in two glasses connected by wires of platinum with the two poles of the battery; hydrogene is produced from one wire, and oxygene from the other. Till I ascertain that even acids and alkalies could be attracted from a central vessel in the Voltaic circuit to the two extremities of the positive and negative metallic surfaces, it appeared very mysterious that oxygene and hydrogene should be separately produced in the Voltaic electrization of water; but if it be possible for lime to be attracted through sulphuric acid to the negative surface, it seems equally possible that hydrogene may be attracted through the moisture in a living body; or a series of decompositions and recompositions may be simultaneously produced throughout the whole extent of the moist surface, by which, whilst a particle of oxygene is produced at one extremity of the chain, a particle of hydrogene is evolved at the other.

10. There is, however, no impossibility in the supposition that the same ponderable matter in different electrical states, or in different arrangements, may constitute substances chemically different: there are parallel cases in the different states in which bodies are found, connected with their different relations to temperature. Thus steam, ice, and water, are the same ponderable matter; and certain quantities of ice and steam mixed together produce ice-cold water. Even if it should be ultimately found that oxygene and hydrogene are the same matter in different states of electricity, or that two or three elements in different proportions constitute all bodies, the great doctrines of chemistry, the theory of definite proportions, and the specific attractions of bodies must remain immutable; the causes

of the difference of form of the bodies supposed to be elementary, if such a step were made, must be ascertained, and the only change in the science would be, that those substances now considered as primary elements must be considered as secondary; but the numbers representing them would be the same, and they would probably be all found to be produced by the additions of multiples of some simple numbers or fractional parts.

11. That the forms of natural bodies may depend upon different arrangements of the same particles of matter has been a favourite hypothesis advanced in the earliest era of physical research, and often supported by the reasonings of the ablest philosophers. This sublime chemical speculation, sanctioned by the authority of Hooke, Newton, and Boscovich, must not be confounded with the ideas advanced by the alchemists concerning the convertibility of the elements into each other. The possible transmutation of metals has generally been reasoned upon, not as a philosophical research, but as an empirical process. Those who have asserted the actual production of the precious metals from other elements, or their decomposition, or who have defended the chimera of the philosopher's stone, have been either impostors, or men deluded by impostors. In this age of rational enquiry it will be useless to decry the practices of the adepts, or to caution the public against confounding the hypothetical views respecting the elements founded upon distinct analogies, with the dreams of alchemical visionaries, most of whom, as an author of the last century justly observed, professed an art without principles, the beginning of which was deceit, the progress delusion, and the end poverty.

II. *Of the Analogies between the Properties of the primary Compounds, and on their Chemical Relations.*

1. In those compounds, which contain the same element combined with bases that resemble each other, a very great degree of similarity might be expected; and it is found that a number of secondary combinations are still more analogous to each other than any of the undecompounded bodies. Ittria and glucina, baryta and strontia, potassa and soda are instances of bodies which, as to many

of their properties, might be mistaken for each other; and a chain of analogies may be traced through all the combinations of inflammable bodies and metals with chlorine, oxygene, and each other. All the acids, alkaline earths, alkalies, and combinations of chlorine in their pure states at common temperatures are nonconductors of electricity, by far the greater number possess a certain degree of transparency; in their combinations with each other they display analogous results; most of them form hydrats; they render solid a certain quantity of water, and are usually dissolved by a greater quantity; and even acids combine with each other in consequence of the intermedium of water, as is the case with the sulphureous and nitrous acid gasses.

Libavius's liquor, or stannanea, is a limpid fluid; if mixed with a certain proportion of water it becomes a solid crystalline body. The glacial oil of vitriol, and the hydrophosphorous acid are instances of oxidated bodies forming crystalline solids with water.

2. The earths and the oxides which are insoluble in water still condense a certain quantity of this fluid, and it gives a greater fusibility to those which retain it with sufficient energy to be submitted to a strong heat. All oxides and earths obtained by precipitation from aqueous solution, that I have examined, are hydrats, and such of them as I have carefully analyzed, I find contain the water in definite proportions. The combination of an earth, an alkali, or an oxide with water may be considered as amongst its weakest combinations, for the water is expelled by carbonic acid. The expulsion of water from the earths seems to be connected, as I stated in page 41, with the contraction of volume, which many of them undergo by ignition: the particles, when the water is driven off, approach nearer to each other, and a great contraction is the result, and probably sometimes a semi-fusion. This quality on which, as it has been stated, the pyrometer of Wedgwood is founded, is elegantly exemplified in an experiment I have lately made on the hydrat of zircona. When this body is heated, at the moment of the expulsion of the water, there is so great and rapid a contraction of the particles of the earth, that they become incandescent in the process; and, from its being as soft as resin, become sufficiently hard to scratch rock crystal.

3. In general those compounds of oxygene, the bases of which combine with most energy, likewise exert the greatest force of attraction on each other; such, for instance, are the metals of the fixed alkalies in their relations to sulphur, phosphorus, arsenic, and tellurium; and potassa and soda readily combine with the acids of sulphur, phosphorus, and arsenic, and with the oxide of tellurium.

4. No refined experiments have as yet been made on the mutual action of these compounds of chlorine and oxygene, which are capable of co-existing; but the salts called hyperoxymuriates are substances in which clorine and oxygene exist combined with metals; and the facility with which they are decomposed depends upon the tendency of the metal to unite to chlorine, so as to form a binary compound, a circumstance connected with the expulsion of the oxygene. The hyperoxymuriate of potassa, when it was first formed by Dr. Higgins, was supposed by him to be a species of nitre, from the similarity of its obvious properties: and it is remarkable that its composition is the same as that of nitre, except that in the first salt there is a proportion of chlorine, and in the second one of azote. Hyperoxymuriate of potassa consists of 1 proportion of potassium 75, 6 of oxygene 90, and 1 of chlorine 67. Nitre consists of 1 of potassium 75, 6 of oxygene 90, and 1 of azote 26. The combinations of ammonia with the compounds of chlorine, offer a class of curious bodies to the chemical enquirer, the properties of which have never been investigated: that formed by phosphorana, and referred to page 165, is a most extraordinary substance, and its elements are combined with a degree of energy which renders it analogous to a primary compound.

5. In the combinations of ammonia with acids and oxides, the hydrogene of the ammonia is always in some definite proportion to the oxygene of the acid or oxide, so that water may be formed by the decomposition of the compound; this is obvious from the decomposition of the fulminating ammoniacal metallic compounds. If a solution of ammonia be poured into a solution of gold, a brown powder falls down, which, when washed and dried, explodes by a gentle heat. I caused it to detonate in small quantities in exhausted glass retorts, and I found that the products were water, azote, and gold

Fulminating silver is a compound in which the elements seem to be in similar relations to each other; it was discovered by M. Berthollet, and may be made by dissolving the oxide of silver, procured from the nitrous solution by lime water in solution of ammonia at common temperatures, and exposing the mixture to spontaneous evaporation; black crystals form, which must be examined with great caution, and only in small quantities, as they explode by the mere contact of a soft body.

6. The extensive class of bodies called neutral salts are formed by the mutual action of acids, and oxides, alkalies, and earths; and in general those oxidated bodies that contain least oxygene, are such as most readily enter into combination with acids; thus the peroxides generally are either insoluble in acids, or require the abstraction of a portion of oxygene to become soluble; and in general two inflammable bodies in combining with oxygene, unite to less than the added sums of the quantity they would separately combine with to saturation. Many of the neutral salts may be considered either as combinations of peroxides with inflammable bases or as alkalies united to acids, or as peroxides united to oxides; for instance, the compound formed from sulphureous acid gas and potassa consists of potassium and sulphur, with three proportions of oxygene, and may be regarded as a compound of peroxide of potassium and sulphur. Sulphate of potassa contains four proportions of oxygene, and might be regarded as a compound of peroxide of potassium, and oxide of sulphur. They are in fact all compounds of oxygene with double bases; and when one fixed alkali, or earth, or oxide, separates another, it may be supposed that the basis only is changed: thus, where hydrat of potassa separates lime from its nitric solution, it may be conceived that the potassium only takes the place of calcium; and that the oxygene and water of the hydrat of potassa unite to this metal, and that the potassium unites to the oxygene, nitrous acid, and water of the solution.

7. It is very easy to estimate the composition of any of the combinations of alkalies, earths, or oxides with acids, by adding together the numbers representing their elements; thus sulphate of soda is composed of 60 sulphur, 90 oxygene, which make two proportions of sulphuric acid; and 88 of sodium, and 30 of oxygene, which

make one proportion of soda. Carbonate of lead is composed of two proportions of carbonic acid, equal to 82.8, two proportions of oxygene 30, and one of lead 398. Sulphate of lead is composed of two proportions of sulphuric acid 150, two of oxygene 30, and one of lead 398: sulphate of nickel of two proportions of sulphuric acid 150, and one of oxide of nickel 141; and these proportions agree almost precisely with the best analysis.

8. It appears that in the neutrosaline compounds in which there is a perfect harmony between the proportions of the elements, the result is neutralization; and in this case a crystalline compound, or an insoluble compound is usually formed. Thus in the instances above mentioned, in the sulphates of soda and lead; the sulphur is a binary proportion, and the oxygene a binary proportion, or a multiple of a binary proportion; and in the carbonate of lead, the carbon is a binary proportion, and the oxygene a multiple of a binary proportion; and to give another instance, in the sulphate of barytes the sulphur is a single proportion, and the oxygene a single proportion, or a multiple.

When, on the contrary, there is a want of harmony in the proportions, the excess either of acid or basis seems to be shewn in the properties of the result; and it is seldom a crystallized body. Thus in the soluble red sulphate of iron, the number of proportions of oxygene in the oxide are three, and those of the sulphur in the acid are four: and this body is strongly acid and uncrystallizable.

III. *On the relative Attractions of the undecomposed Substances for each other.*

1. The attractions of the undecompounded substances vary with the temperature, probably, chiefly in consequence of their different degrees of volatility; for although freedom of motion in the parts of bodies wonderfully promotes combination, yet the disposition in bodies to assume the aeriform state at high temperatures, enables decompositions to take place in an order which would not be expected from the known agencies of the substances under common circumstances.

2. The bodies that follow are arranged in the order of their attractions for oxygene, at the lowest temperature of visible ignition, after the results of my own observations. Potassium, sodium, barium, boron, carbon, manganesum, zinc, iron, tin, phosphorus, antimony, bismuth, lead, sulphur, arsenic, tungstenum, azote, palladium, mercury, silver, gold, platinum.

3. The attractions of bodies for chlorine follow an order very different, though with some exceptions; potassium, sodium, zinc, iron, lead, silver, antimony, bismuth, phosphorus, copper, sulphur, mercury, platinum, gold.

4. The attractions of the undecompounded bodies for sulphur have not been determined to any extent. Potassium and sodium seem to have the highest attraction of any substances: then iron, copper, antimony, palladium, lead, and silver.

5. No bodies combine with phosphorus with more energy than the metals of the fixed alkalies: and after them platinum, zinc, antimony, and sulphur, appear to have the strongest attractions; but no very definite knowledge has been as yet obtained on the relations of the phosphurets.

6. The general phænomena of the decomposition of the binary compounds, by undecompounded bodies, can require no illustration. Potassium separates chlorine and oxygene from all known bodies; usually it produces potassa, but sometimes by acting on compounds containing abundance of oxygene, it forms the peroxide of potassium. Carbon, in reducing metallic oxides, forms either carbonic acid, or gaseous oxide of carbon, according as the oxygene is more or less strongly attracted by the basis. When oxides are decomposed by sulphur, sulphureous gas and sulphurets are almost always formed.

7. Some of the instances which were formerly supposed instances of single attractions are now known to be connected with double attractions. This is remarkably the case in the production of potassium by iron. The water in the hydrat of potassa and the potassa seem to be decomposed at the same time; the iron unites to the oxygene of both; the hydrogene and potassa combine; and their gaseous compound deposits potassium on cooling.

IV. *On the Methods of separating the undecomposed Bodies from each other.*

1. General methods of separating the undecompounded bodies from each other may be learnt from a consideration of the processes by which they are procured; but there are other modes which apply to many of their compounds, and which are still more simple.

2. As all the undecomposed bodies differ in the manner in which they are affected by heat, many of them may be separated from compounds, by exposing them to different temperatures. Thus oxygene, chlorine, mercury, phosphorus, and sulphur may be detached from many bodies by the process of ignition.

3. In most cases, however, complicated methods are necessary, particularly in cases when the bodies are united to oxygene and acids or to chlorine; the compounds of chlorine differ very much in volatility, and in cases when they are mixed together, they appear to act upon each other with very little energy only: hence, if it is possible to combine all the elements of a compound with chlorine, by the action of the gas, or of muriatic acid, or nitro-muriatic acid, they may be easily separated by the application of a heat gradually increased. Amongst the metallic combinations, that of tin when saturated with chlorine rises first, then those of arsenic, antimony, tellurium, iron, zinc, bismuth, in the order in which they have been named.

Silver is easily separated from solutions in which it exists by muriatic acid, with the chlorine of which it forms an insoluble compound; and in the same way chlorine is separated, and its quantity in any substance ascertained by means of solution of silver.

Oxide of iron is separated from solutions by succinate of ammonia, with which it forms an insoluble salt. The oxides of copper, nickel, and cobalt, are all soluble in ammonia. Those of zinc, tellurium, tin, and platinum, in solution of potassa. Acids are separated by alkalies; and alumina, silica, zircona, ittria, glucina, and the alkaline earths, may with facility be detached from their combinations by the action of acids, alkalies, and carbonates. Oxide of lead and baryta may be easily separated from other bodies, in consequence of their forming insoluble compounds with sulphuric acid.

4. The order in which metals precipitate each other from solutions, is nearly in the ratio of their attraction for oxygene; and in all cases of neutral compounds, the precipitating metal takes the oxygene and acid of the metal thrown down. Iron readily precipitates copper; zinc readily throws down tin, lead, tellurium, bismuth, &c. and in general the metallic substances, as has been stated page 83, attract oxygene, and precipitate each other in a ratio connected with their electrical relations; those that are positive with respect to others having the highest attractive powers for oxygene and acids.

By Volatic electricity all substances are separated from their compounds with oxygene and chlorine; or alkalies, earths, and oxides are separated from acids, as has been mentioned page 90, and that in an uniform order and in definite proportions, so that Voltaic electricity offers general methods of decomposing all compounds soluble in water; and for most experiments of this kind very small combinations only are necessary: if small quantities of the materials are employed, two or three double plates are sufficient for decomposing most metallic solutions. The energies of small powers in acting upon bodies by diminishing the quantities exposed to their agency, has been happily shewn by Dr. Wollaston, in the decomposition of water by a common small electrical machine, by passing the electricity from surfaces of about the $\frac{1}{1000}$ of a square inch; and the same philosopher has produced the ignition of platinum in leaf of $\frac{1}{1000}$ of an inch in thickness, by a single series of double metals of a few inches square: the zinc is circular, forming a small hollow tube, and surrounded by copper opposed to each side of it, and bent so as to correspond to the form of the zinc; when the two metals are exposed to the action of an acid, and connected by the leaf of platinum, the effect is produced.

V. *General Observations, and Conclusion of Part First.*

1. Few of the undecompounded bodies, or even of the primary compounds, as is evident from what has been said, are found in an uncombined state on our globe; their tendency to unite with each

other is constantly exerted; and a series of decompositions and recombinations are constantly occurring in the phænomena of nature, and in the operations of art. The compounds containing more than two elements, will form the subjects of consideration for the second part of this work, and their arrangements in the mineral, vegetable, and animal kingdoms: when the principles that have been advanced in the preceding pages, will be applied to the elucidation of an important series of changes belonging to inorganic and to organic matter. As far as our investigations have extended, the same elements belong to the same parts of the system. The composition of the atmosphere and the ocean are analogous, as far as the heights of one, and the depths of the other have been examined. The matters thrown out by volcanoes are earthy or stony aggregates, and they may owe their origin to the action of air and water upon the metallic bases of the earths and alkalies; an action which may be supposed to be connected with the production of subterraneous fires. Even the substances that fall from meteors, though differing in their form and appearance from any of the bodies belonging to our earth, yet contain well-known elements, silica, magnesia, sulphur, and the two magnetic metals, iron and nickel.

2. A few undecompounded bodies, which may perhaps ultimately be resolved into still fewer elements, or which may be different forms of the same material, constitute the whole of our tangible universe of things. By experiment they are discovered even in the most complicated arrangements; and experiment is as it were the chain that binds down the Proteus of nature, and obliges it to confess its real form and divine origin.

The laws which govern the phænomena of chemistry, produce invariable results; which may be made the guide of operations in the arts; and which insure the uniformity of the system of nature, the arrangements of which are marked by creative intelligence, and made constantly subservient to the production of life, and the increase of happiness.

On the Mode of calculating the Numbers representing the Elements.

Note referring to page 60.

THE smallest quantity bearing a definite relation to another quantity or quantities, is always the datum, whether it is the first, second, third, fourth, or any other added quantity in the combination. Potassium forms two combinations with oxygene; page 183, 100 of potassium in weight unite to 20.1 of oxygene to form pure potassa, and to 57.8 to form the orange oxide of potassium. 20.1, the the smallest number, is taken, and as 20.1 : 100 : : 15, the number representing oxygene, to 74.99; or adding the minute fractional part to 75; and 57.8 is nearly 3 times 20: and the difference may be easily explained by supposing that in experiments on the peroxide, it is scarcely possible to convert the whole of the metal into potassium.

To give another instance in which the datum is taken from the peroxide: the peroxide of lead contains from 3 to 3.5 per cent. more oxygene, than minium; and the first oxide known, massicot, consists of about 100 of lead to 7.52 of oxygene; minium of 100 to between 10 and 12; and the puce-coloured oxide of 100 of metal to about 15; and the smallest proportion amongst these is 3.76 of oxygene, and 3.76 : 100 : : 15 is to 398, the number representing lead; and massicot is supposed to contain twice this quantity of oxygene, 398 : 30 : : 100 is to 7.53.

Plate I.

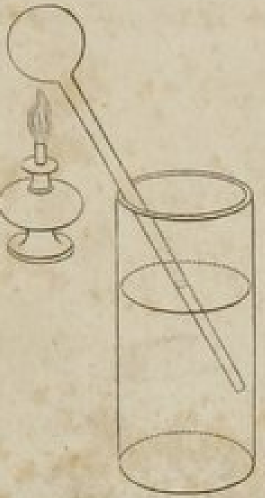
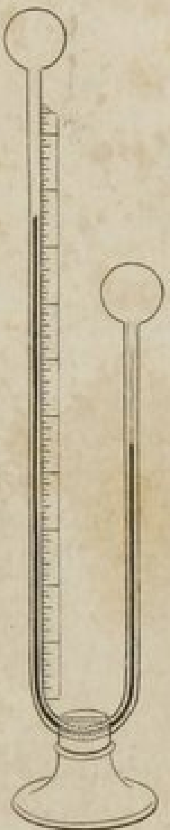


Fig. 1.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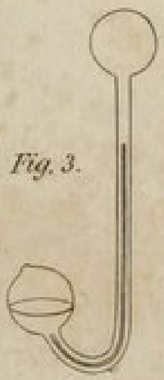
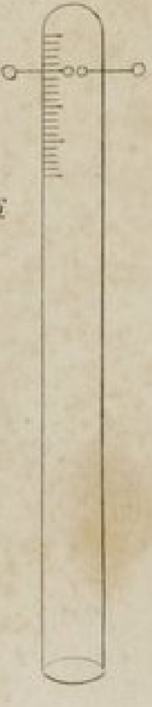


Fig. 3.


Fig. 4.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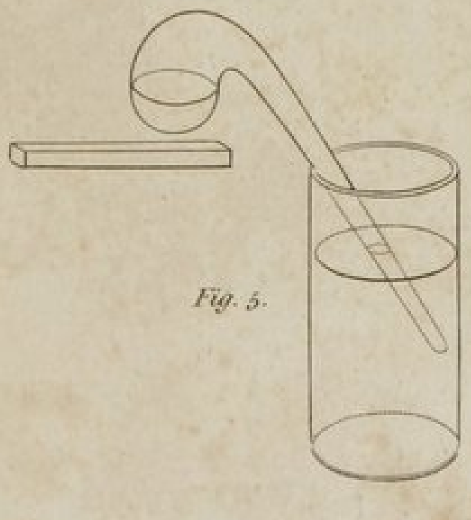


Fig. 5.

Plate II

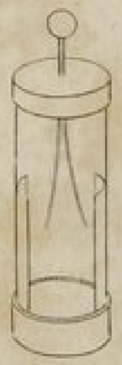
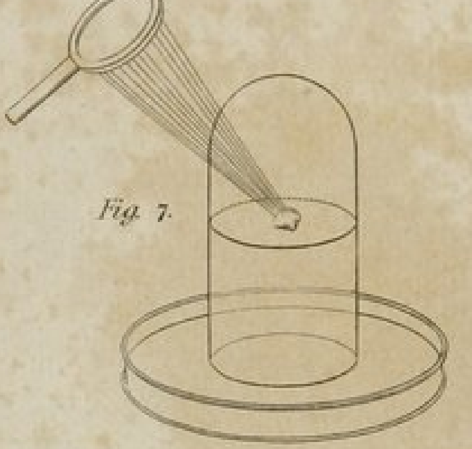


Fig. 10.



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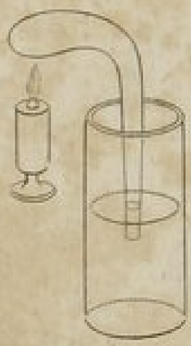

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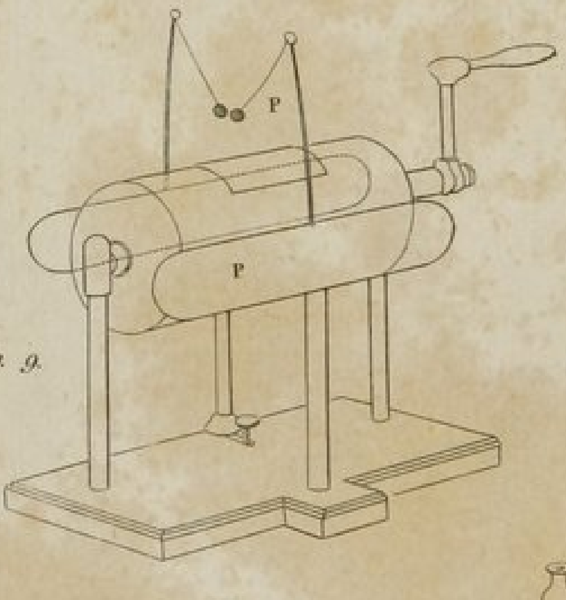


Fig. 9.

Fig. 12.

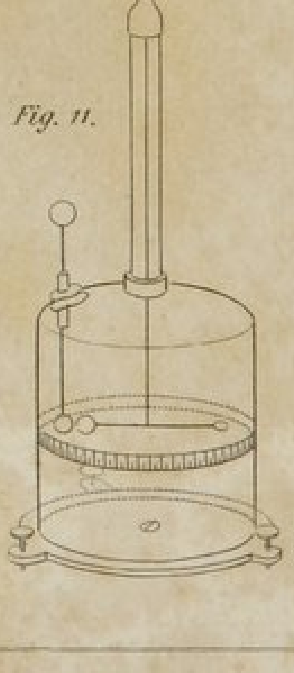
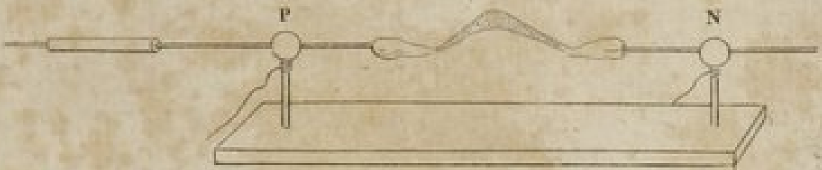


Fig. 11.

Plate III

Fig. 18.



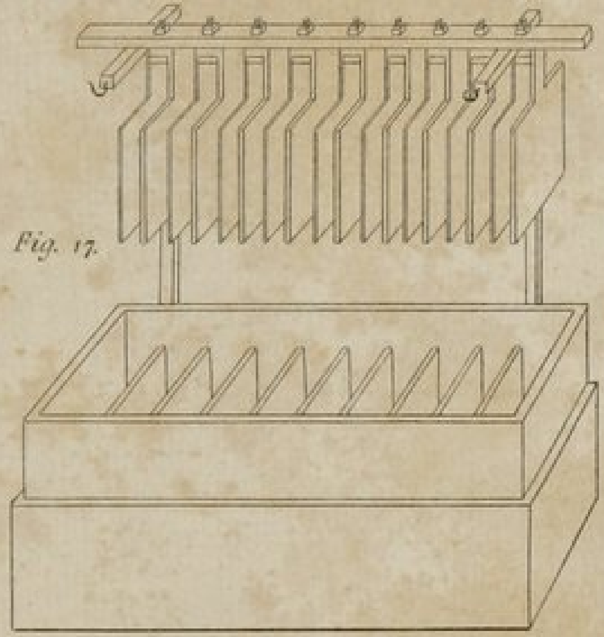


Fig. 17.

Fig. 14.

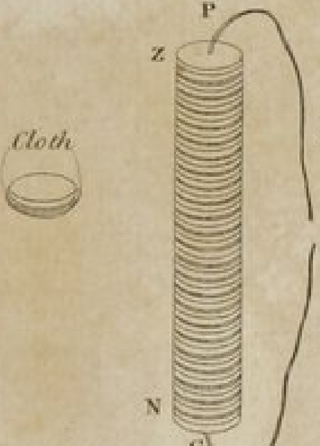


Fig. 16.

Fig. 15.

Fig. 13.

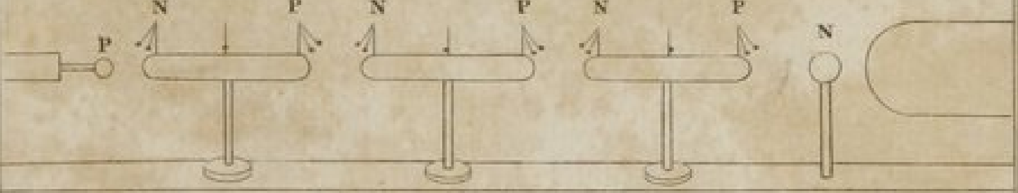
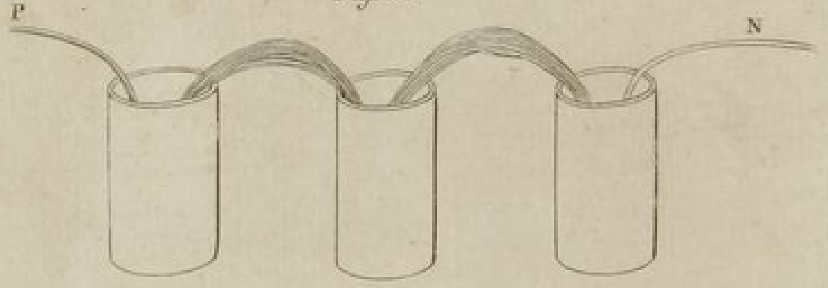


Plate IV.

Fig. 20.



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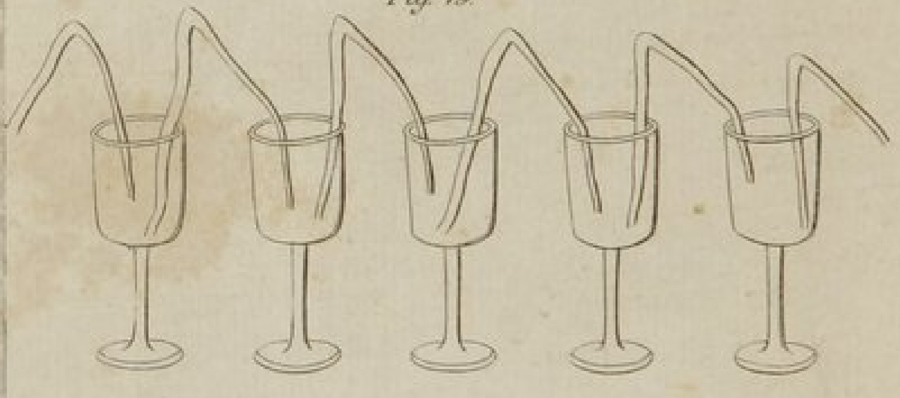
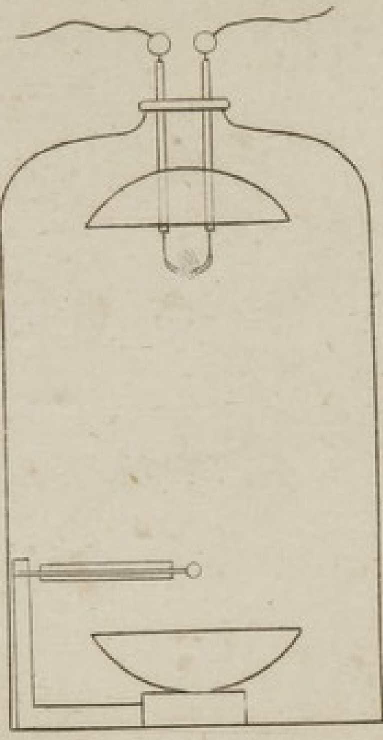


Plate IV

Fig. 22.



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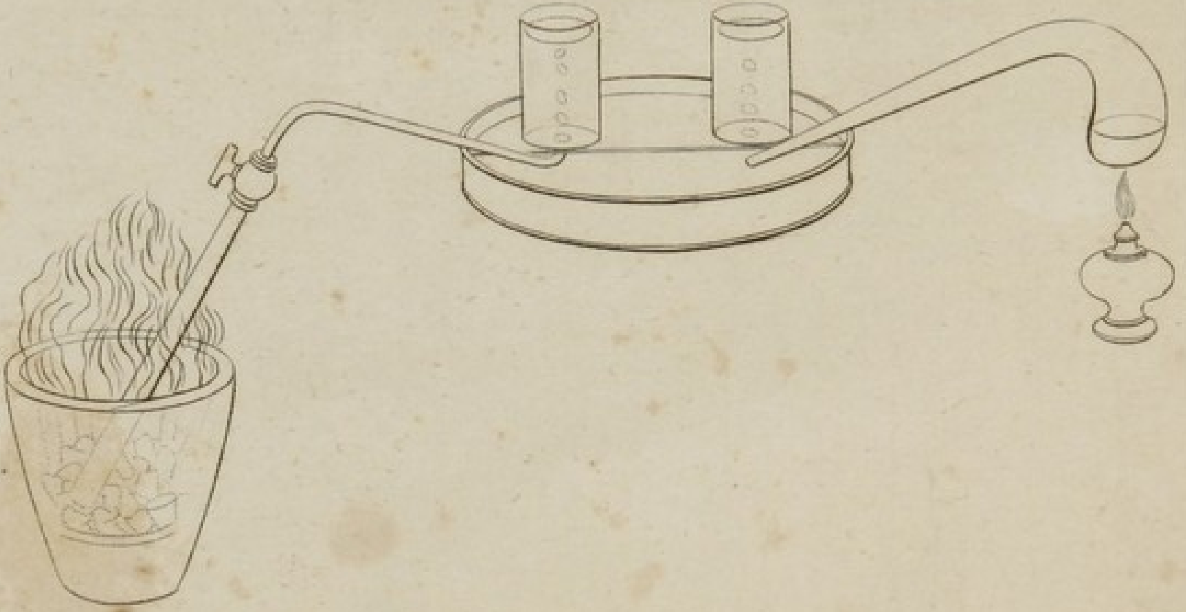


Fig. 21.

Fig. 26.

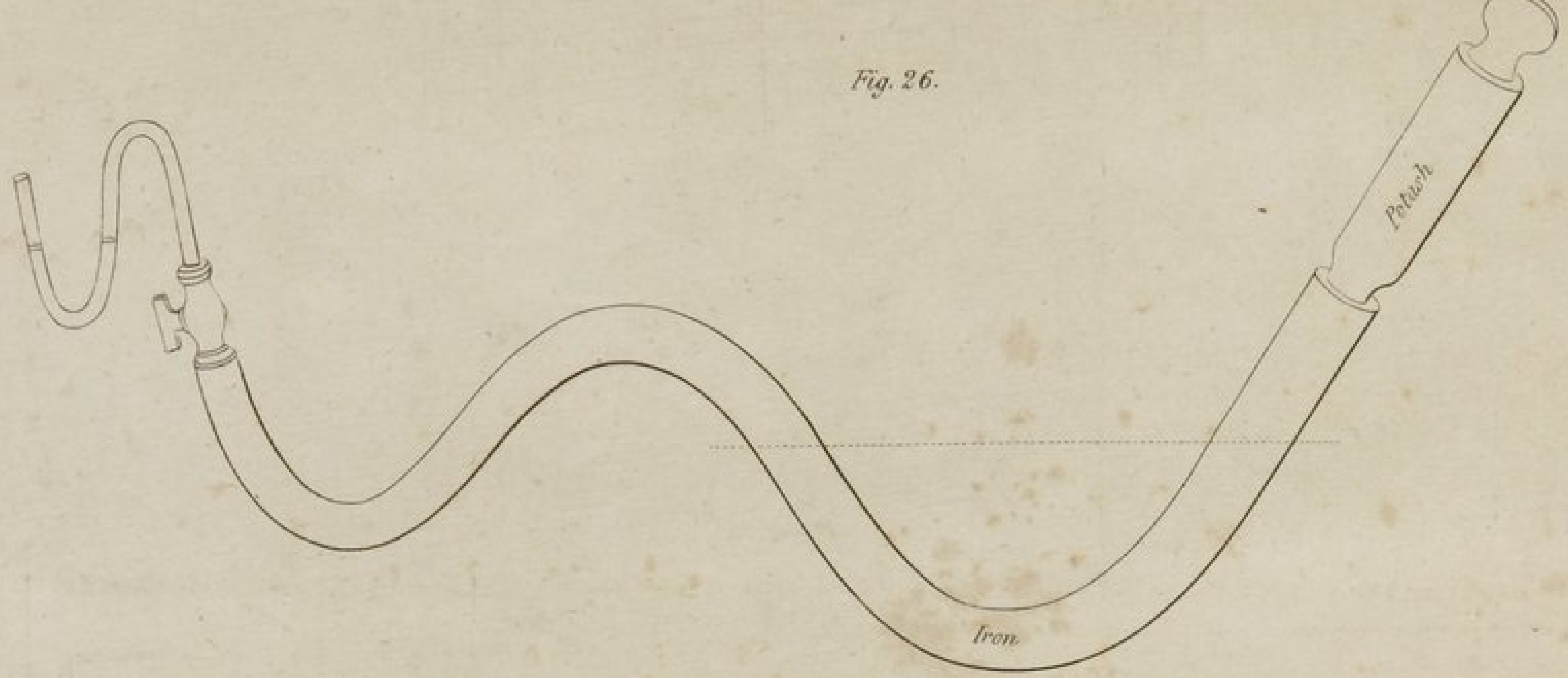


Plate V.

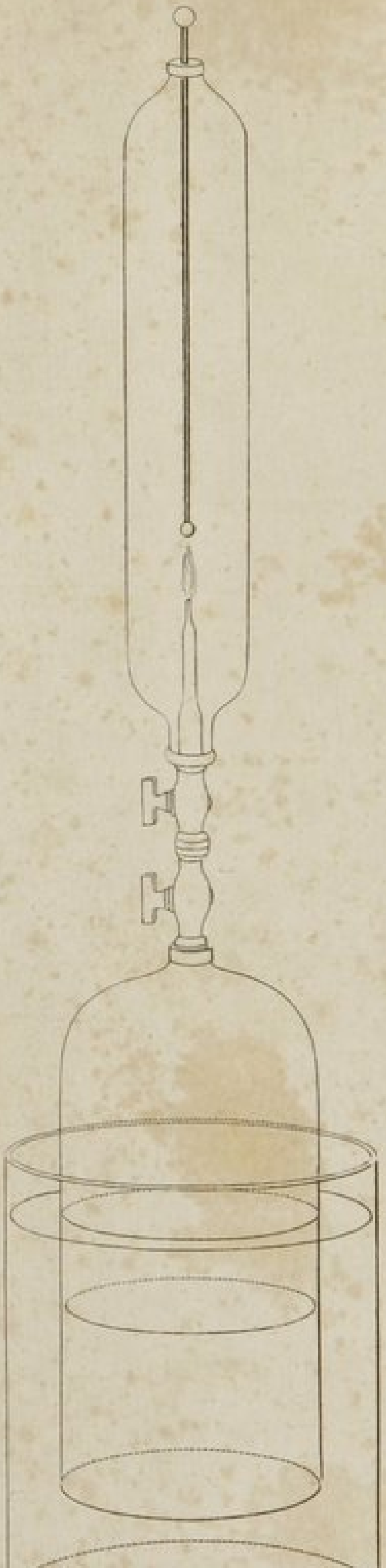


Fig. 25.

Plate VII.

Fig. 27.

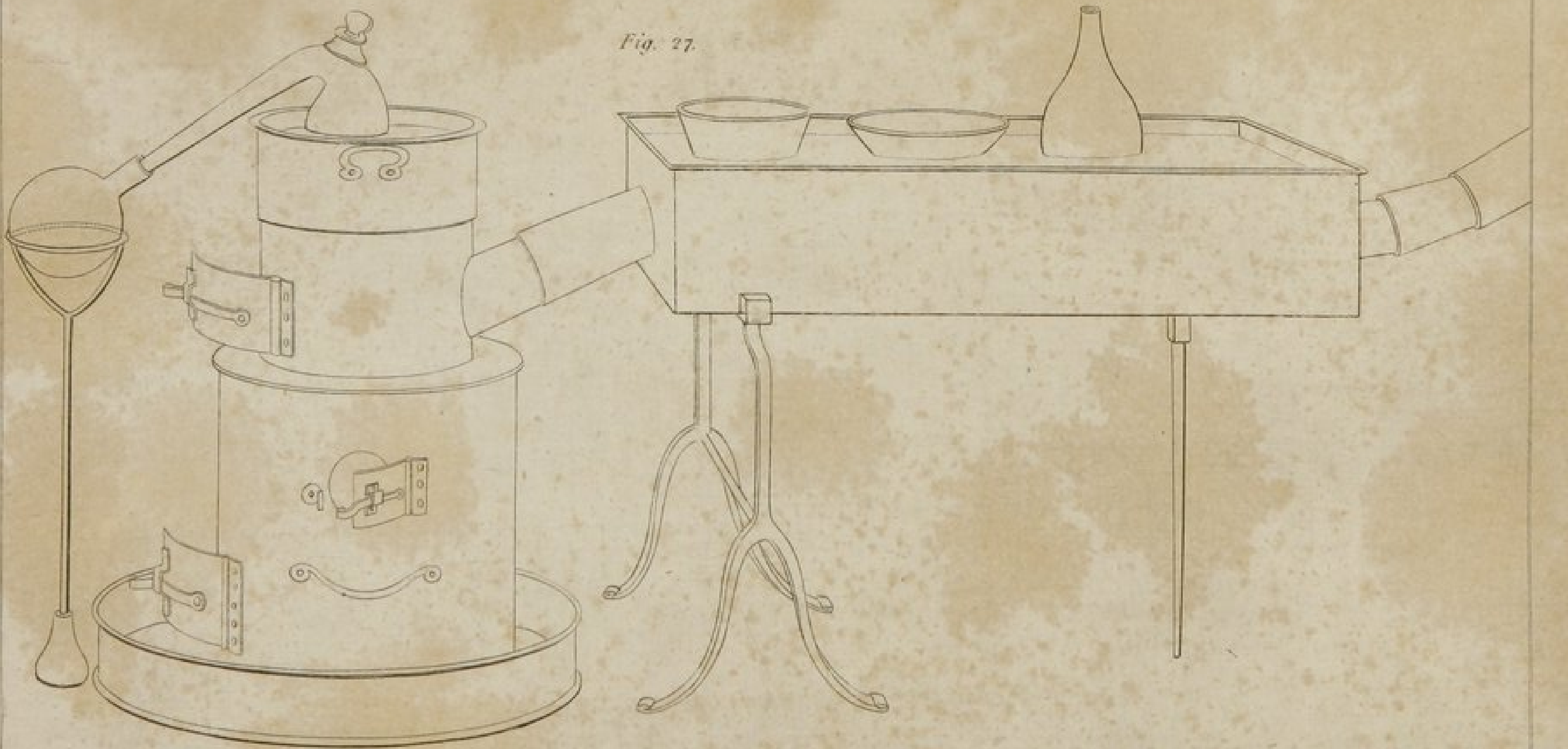


Plate VIII.

Fig. 28.

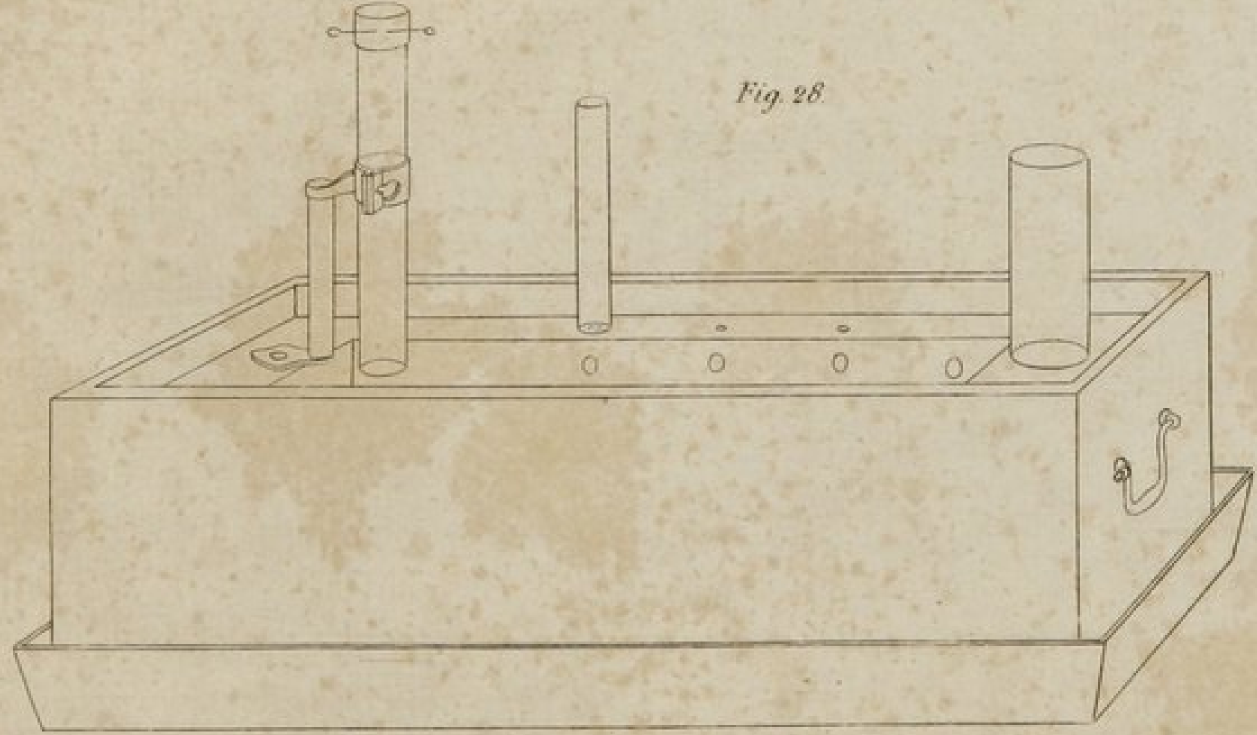


Fig. 30.

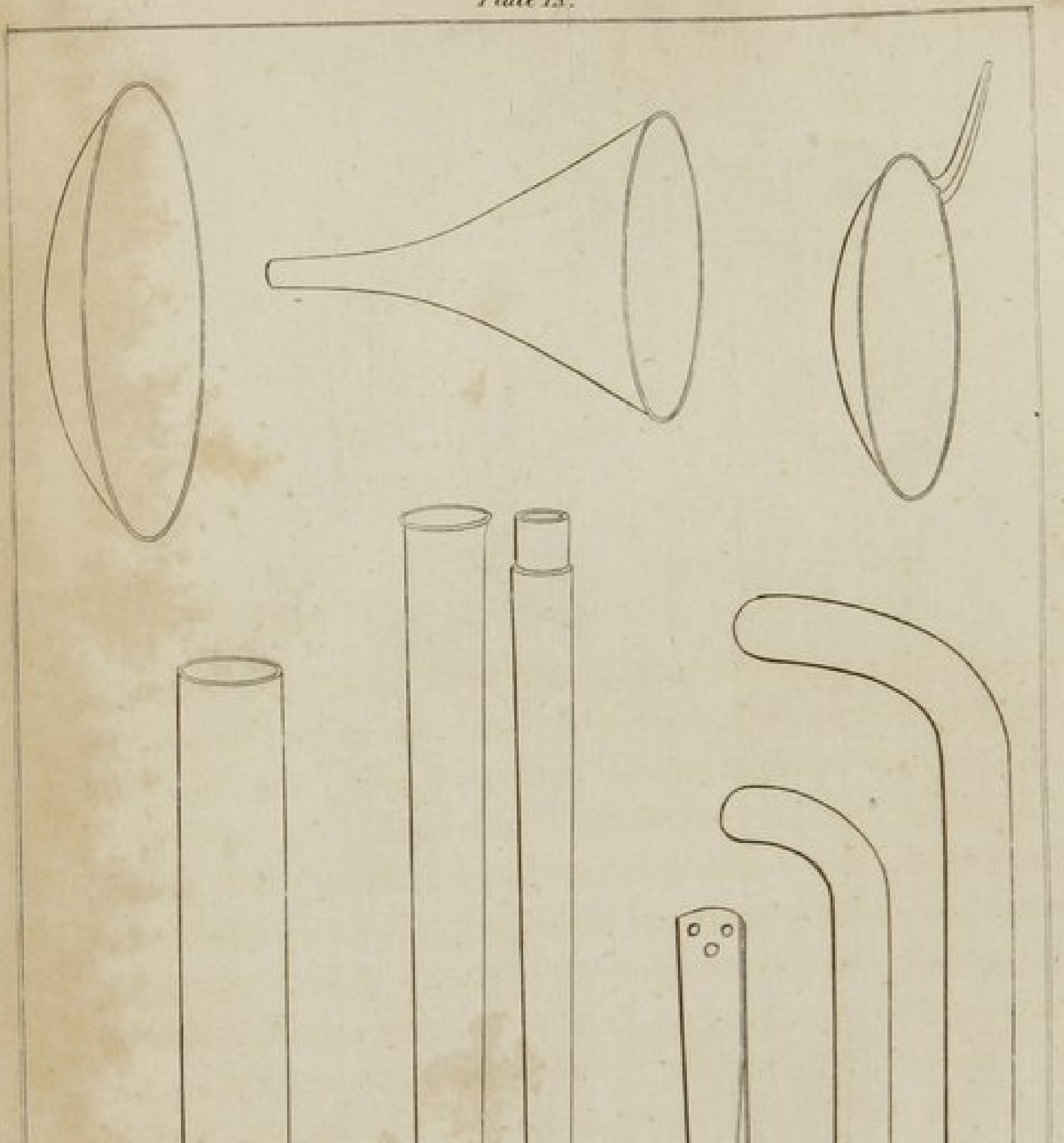
To face Plate VII.

Plate VII. Fig. 27, represents a furnace for the general purposes of experiments. The upper part of the furnace is a sand bath. The lower part may be employed for fusion or distillation, or for igniting tubes. It may be used in any room where there is a flue, and it serves the purpose of a stove.

Plate VIII. Fig. 28, represents the mercurial apparatus. The tube in the frame represents the apparatus for detonating mixtures of gasses: it is connected with a spiral spring.

Fig. 30, represents another apparatus for detonation.

Plate IX.



To face Plate IX.

THE opposite plate represents an apparatus for minute experiments; the instruments are delineated of their real size. The cups should be of platinum, the tubes and small retorts of glass; the blow pipe may be of silver, with an extremity of platinum. By the help of these instruments, and a little wooden trough holding a few pounds of mercury, an electrophorus for giving a spark to act upon mixtures of gasses, or compound gasses; and a few bottles containing acids, alkalies, and precipitants, a number of useful experiments may be made. Boxes containing the apparatus on a very small scale, are neatly made, and sold at reasonable prices, by Mr. Newman, 10, Old Lisle-street, London.

Plate X.

Fig. 31.

To face Plate X.

THE opposite plate represents a Gasometer, by which a stream of oxygene gas may be thrown upon ignited charcoal, for the purpose of fusing or burning bodies, &c.

APPENDIX.

SINCE the last sheet has been sent to the press, M. Berzelius has had the goodness to communicate to me the following estimates, some of which agree very nearly with those given in the preceding pages; others are new, and all afford evidences of the truth of the theory of definite proportions. It is peculiarly satisfactory to me, to be able to state the coincidence of so many of the conclusions of this distinguished chemist with my own results, obtained usually by very different methods of operation.

Of the Oxides of Antimony.

	Metal.	Oxygene.	Metal.	Oxygene.
First Oxide	100	4,65	96,826	3,174
Second	—	18,6	84,517	15,683
Third	—	27,9	78,19	21,81
Fourth	—	37,2	72,85	27,15

The Sulphuret of Antimony, is composed of 100 parts of Metal, and of 37,25 parts of Sulphur.

Oxides of Tin.

	Metal.	Oxygene.	Metal.	Oxygene.	
First	100	13,6	88,03	11,97	
Second	—	20,4	83,13	16,87	1½
Third	—	27,2	78,61	21,39	2

The Sulphurets of Tin.

	Metal.	Oxygene.	Metal.	Oxygene.	
First	100	27,234	78,6	21,4	
Second	—	40,851	71,8	28,2	1½
Third	—	34,468			2

The Oxide of Tellurium.

100 parts of Metal with 24,83 parts of Oxygene.

Telluretted Hydrogene.

Tellurium 100 parts. Hydrogene 1,948.

The Oxides of Gold.

	Metal.	Oxygene.	Metal.	Oxygene.	
First	100	11,026	96,13	3,87	1
Second	—	12,077	89,225	10,775	3

The Oxides of Platinum.

	Metal.	Oxygene.	Metal.	Oxygene.	
First	100	8,287	92,35	7,65	1
Second	—	16,574	85,9	14,1	2

The Oxide of Palladium.

Metal 100. Oxygene 14,055.

Sulphuret of Palladium.

Metal 100. Sulphur 28,15.

The Oxides of Manganesum.

	Metal.	Oxygene.	Metal.	Oxygene.	
First	100	7,0266	93,435	6,565	
Second	—	14,0533	87,68	12,32	2
Third	—	28,1077	78,1	21,9	4
Fourth	—	42,16	72,25	27,75	6
Fifth	—	56,215	64	36	8

Metallic Oxides examined by other Swedish Chemists.

Oxides of Mercury, by M. Sefstrom.

First, Metal 100.	Oxygene 3,95	1
Second, —— 100.	—— 7,9	2

Oxide of Bismuth, by M. de Lagerhielm.

Metal 100. Oxygene 11,275

Oxide of Nickel, by M. de Rolhoff.

First, Metal 100.	Oxygene 27,3	1
Second, —— —.	—— 40,95	1½

Oxide of Cobalt, by the same.

First, Metal 100.	Oxygene 27,3	1
Second, —— —.	—— 40,95	1½

Oxide of Cerium, by M. de Hisinger.

First, Metal 100.	Oxygene 17,41	1
Second, —— —.	—— 26,115	1½