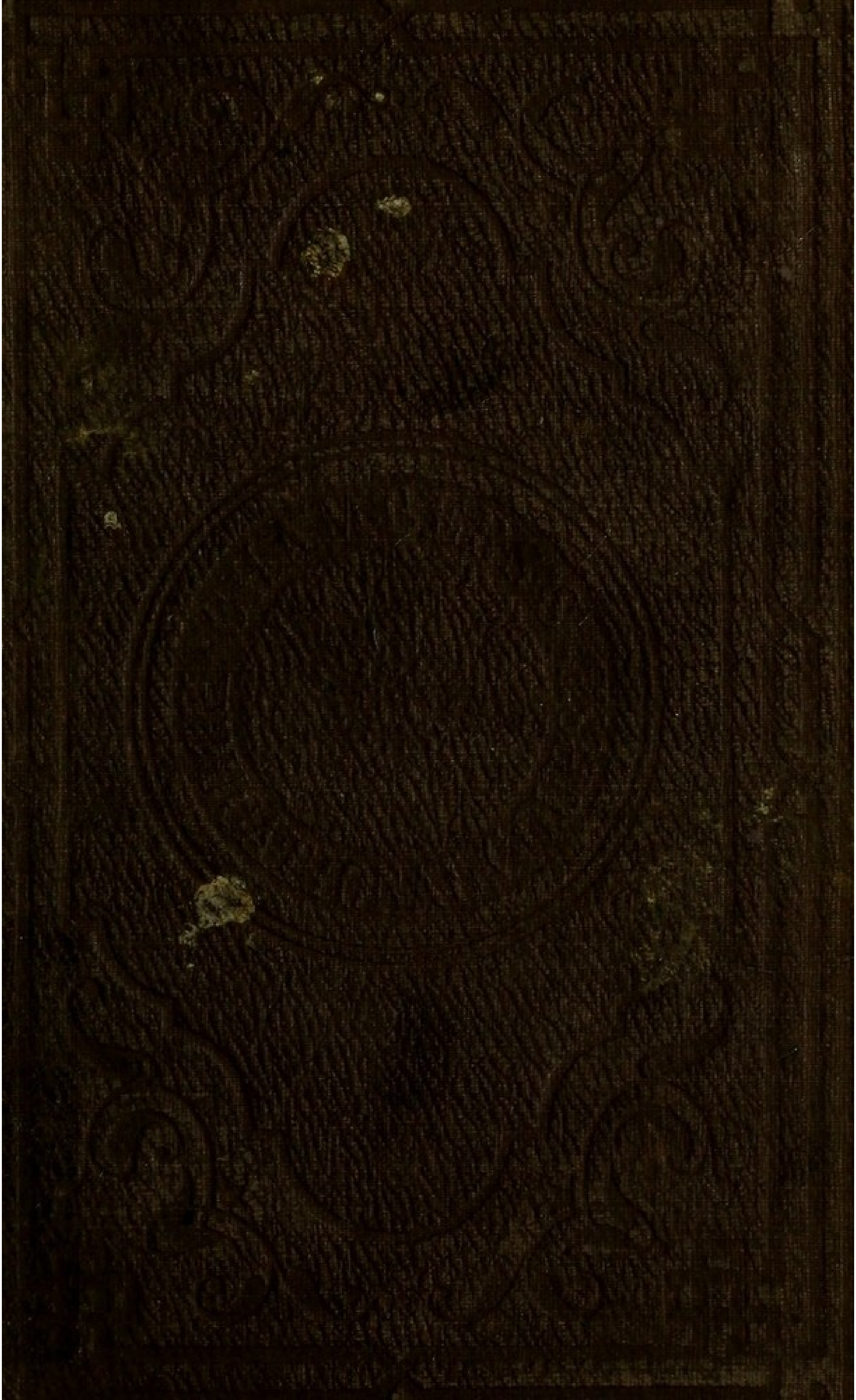
Chemistry / by George Wilson.



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CHEMISTRY

By GEORGE WILSON, M.D. F.R.S.E.

PROFESSOR OF TECHNOLOGY IN THE UNIVERSITY OF EDINBURGH.

WILLIAM AND ROBERT CHAMBERS,
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Thomas [redacted] Esqr

Thomas R. McVee

PREFACE.

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So many excellent text-books on Chemistry have been published within the last few years, that some apology seems necessary for the issue of another. It may be found in the fact that, admirable as are the extant treatises on the science, they are too extensive in their aim, too bulky, and too costly, for a large class of students who are anxious to acquire some knowledge of a branch of learning of which few can at the present day afford to be altogether ignorant.

The want of such a work has been felt so strongly by many, that the publishers of this volume have seen the necessity of meeting it in connection with their Educational Course, and, in compliance with their request, I have prepared the following treatise.

Its object is strictly elementary; its purpose being to introduce the student to a knowledge of the more important fundamental laws of Chemistry, and to make him familiar with the properties of the chief elementary substances and their more remarkable compounds. In conformity with this aim, much greater space has been devoted to the discussion of such subjects as the General Properties of Matter, Weight, Chemical Affinity, the Laws of Combining Proportion, the Atomic Theory, Chemical Nomenclature, Chemical Notation, &c. than has been customary in works of the kind. Heat and Electricity have also been discussed in their chemical relations as fully as the limits of the work permitted, and quite as amply as beginners require.

Less space has been assigned to Organic Chemistry than it may seem to merit. It is a department of the science, however, beyond the beginner, and requiring for its appreciation an acquaintance with anatomy, botany, physiology, geology, and agriculture, such as cannot be expected in any but advanced and perhaps professional students. At the same time, it admits of much less striking experimental illustration than Inorganic Chemistry, and the substances with which it deals cannot readily be procured or consumed in quantity. Its study, accordingly, can scarcely be pursued without attendance on systematic lectures, and in a regularly-equipped analytical laboratory. Those who have proceeded that length, however, will be past the guidance of elementary works, and must have recourse to more elaborate treatises for instruction. Let it be observed, nevertheless, that the extent to which Organic Chemistry is discussed in this volume, is such as to include a fair representation of its general character, as well as the discussion of a considerable number of the more curious chemical compounds directly or indirectly derived from plants and animals. Professional students, indeed, must prosecute Organic Chemistry more fully than it is discussed in the following pages; but for obvious reasons, that large section of it which refers to medical science is omitted from a work intended as a text-book for young persons of both sexes. Otherwise, as much Organic Chemistry as most beginners can be expected to follow with interest is given; and to have treated it more fully, would have necessitated great enlargement of the volume, and consequent increase in price, which would have defeated one chief object of its issue. A special treatise on Organic Chemistry is requisite for those who wish to prosecute, even to a limited extent, its important but difficult and intricate details.

In using this work, the teacher or pupil is recommended to read the first twenty-eight pages with some care before proceeding further. The beginner must not expect to understand the introductory portions at once, but must go back from time to time to their study, when he will find them become more and more intelligible as he grows familiar with the properties of chemical substances explained in the later pages. On the other hand, some acquaintance with the contents of the preliminary chapters is essential to an intelligent study of the chemical elements, so that the earlier and the later chapters or sections must be studied alternately or together.

The laws of Combining Proportion, and all that follows to the end of page 90, should be left unconsidered till the properties of oxygen, hydrogen, nitrogen, and their compounds, as detailed from page 91 to 126, have been studied, after which the laws of Combining Proportion and the Atomic Theory should be thoroughly learned.

A knowledge of Chemical Nomenclature and Notation cannot well be acquired too early; but it will depend greatly on the age, number, and capacity of the pupils, at what stage in their progress these subjects can best be introduced. This general direction, however, may be given:—A portion of each lesson should be devoted to the study of the properties of the various elements and their compounds, with as full experimental illustration as circumstances permit, whilst another part of the lesson is devoted to such subjects as Chemical Nomenclature, &c.; or the lessons may be alternated—an hour, for example, being devoted on one day to experiment and the exposition of phenomena, and on another to the explanation of laws and theories. In this way one set of lessons would begin at page 91, with Inorganic Chemistry, and the other at page 1 or page 16, with the general principles of the science; whilst Heat and Electricity might be taken at intervals—for example, once a-week—so as to introduce variety. The volume should supply materials for an hour's lesson daily for at least six months.

A single remark further seems called for. Greater importance is given to Chemical Notation in the following pages than in similar elementary works, and the immense majority of the chemical changes discussed are illustrated by symbols. Their employment has been objected to by some, as needlessly perplexing beginners. In this work, however, as far as possible, every chemical change has been explained in words as well as by symbols, so that those who choose may disregard the latter. It is not desirable, nevertheless, that this should be done; students, instead of disliking, prefer symbols, and rapidly acquire familiarity with their use, especially if gradually habituated to their employment (see note, p. 57). In the present state of Chemistry, indeed, a student of the science is wronged if he is not made familiar with the chemical symbols, for they are employed by all chemists, and Organic Chemistry, instead of being simplified, would become more perplexing if symbols were exchanged for words.

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CHEMISTRY.

INTRODUCTION.

1. It would be of great advantage to the beginner in Chemistry if it were possible to give a simple but sufficient definition of the nature of the science on the study of which he is about to enter, so that he might have some conception of the nature of the facts about which he is to be busied, and a certain preparatory acquaintance with the kind of knowledge with which chemistry deals.

2. Before, however, a single science can be properly defined, we must know not only it, but all other sciences perfectly, otherwise we may exclude from our definition something which it should have contained, or include something which in reality belongs to the definition of another science. As man, however, is not omniscient, he is unable to give perfect definitions of any of the sciences.

3. It is further to be remembered that the division of human knowledge into various branches, such as Chemistry, Natural Philosophy, Electricity, and the like, is to a great extent made, not because we can show that a sharp line of demarcation separates each of these so-called sciences from all the rest, but because the limitation and feeble grasp of our faculties compel us to parcel out universal science, so as to restrict ourselves to departments of it, small enough to be investigated during the comparatively short life of a single individual.

4. Waiving, then, any attempt at logical definition, we may nevertheless endeavour to convey by description an idea of the nature and object of chemistry, sufficient to enable the pupil to begin his studies profitably.

5. The chemistry we are about to prosecute is that of the earth, our knowledge of the nature of the other heavenly bodies being far too slender and doubtful to permit their

chemistry being discussed in this treatise. Our globe, then, to which we restrict ourselves, may be considered as divided like a great kingdom among the students of the physical sciences. The astronomer, for example, explains its relations to the sun, the moon, and the other heavenly bodies, besides much else which we cannot stop to particularise. The geologist discusses the changes which have occurred on its greater masses since its creation, and dwells on the age, origin, and nature of rocks, fossils, volcanoes, mountains, valleys, rivers, seas, &c. The mineralogist, a kind of lesser geologist, breaks down the great rocky masses into their smaller constituents, and points out the ores, spars, and crystals, which, by their union, form hills and mountains. The botanist unveils the forms, structures, and actions of dead and living plants; and the anatomist does the same in regard to animals. The natural philosopher expounds the properties which belong to matter in its different physical conditions, such as liquidity, solidity, and the gaseous state; and explains the laws which determine the motion and rest, as well as many of the properties of solids, liquids, and gases, besides much more which cannot here be enlarged upon. When these philosophers have exhausted all the resources of their respective sciences in explaining the physical characters of our planet, there still remains, among others, one most important question undecided, which the chemist comes upon the field to answer.

6. The problem which the chemist solves, will be best understood by putting a question to certain of the philosophers to whom we have referred. The geologist, then, is asked to explain why coal and marble are so different from each other: Does each of them consist of one substance, and both of the same, or are they made up of many unlike ingredients; and if so, what are they? The mineralogist is requested to account for the difference in properties exhibited by the diamond and the ruby, and to say whether each consists of one kind of matter, or of several unlike kinds. A similar answer is required at the hands of the anatomist as to the cause of the difference in properties which distinguishes blood and milk from each other; and the natural philosopher, in like manner, is applied to, to determine whether water and oil are in nature, essence, or composition, in all respects identical, or differ totally as regards their component ingredients. To these questions no answers could be returned by any of the sciences to which we have referred. All of them would reply that it lay beyond the resources of their knowledge to furnish a solution of the problem. The science which solves it is chemistry, and the chemist may be represented as effecting its solution somewhat

thus:—He begins, as it were, by asking himself the question, Does our globe consist of but one kind of matter, or of several; and if of several kinds, of how many? He commences his practical work by arranging in classes all known substances according to their differences in external or sensible properties, such as weight, colour, odour, taste, &c. This preliminary labour is to a great extent done to his hands by his brethren the students of the other sciences, so that he receives, as it were, from the geologist and mineralogist, rocks and minerals, such as sandstone, granite, marble, opal, garnet, calcedony; from the botanist and anatomist, woody fibre, sap, colouring matter, milk, blood, bone; and from the natural philosopher, oil, water, alcohol, and other liquids, besides solids and gases, with their sensible or physical characters accurately noted and recorded for his use.

7. The first point the chemist seeks to ascertain in reference to every substance, whether derived from the animal, vegetable, or mineral kingdom, is, does it consist of one kind, or of several kinds of matter? The determination of this point enables him to make a primary division of all bodies into two great classes—simple and compound. Simple bodies consist of but one ingredient, as, for example, the various metals. Compound bodies of more than one constituent. Thus water contains two, sugar three, dry alum four, and pure white of egg six.

8. The processes which the chemist employs in order to discover whether bodies are simple or compound are various. The most common perhaps of all the agents which he brings to bear upon them is heat. Nearly every substance, for example, derived from plants and animals can be proved to be compound by simply heating it. Other bodies which resist the decomposing power of high temperatures, give way at once when exposed to the action of electricity, and separate into their constituent parts. Many compounds which are indifferent both to heat and electricity are at once broken up by simply mixing them with other substances. Thus the strong acids, nitric, sulphuric, and hydrochloric, decompose with great rapidity the majority of mineral substances. Light, especially sunlight, has a considerable power of effecting decomposition, and so have purely mechanical agencies, such as pressure and violent concussion. The forces resident in living plants and animals, which, in our present ignorance of their exact nature, we distinguish as if quite peculiar by calling them *vital*, have also very remarkable decomposing powers. Those may be regarded as the chief forces which the chemist employs for effecting decomposition, and they supply

him with the means of distinguishing simple from compound bodies. Compound bodies may, accordingly, be defined to be those substances which, when subjected to heat, electricity, light, mechanical agencies, or the vital forces, applied singly, or taken, where that is possible, together, suffer resolution or decomposition into two or more ingredients, which cannot, by subjection to the same processes, be similarly decomposed. Simple bodies, on the other hand, are those substances which resist the decomposing power of the forces referred to, and after the most protracted and repeated exposure to their influence, remain with every essential property altogether unchanged.

9. This exposure of substances to all known decomposing forces is spoken of by the chemist as their subjection to chemical *analysis*, a word derived from the Greek ανα, *up, or back to its sources*, and λυω, *to loose*, and signifying the separation or resolution of any complex or compound thing into its primary constituents, or ultimate elements, or the process by which that resolution is effected. Compound bodies admit of analysis—that is, every substance consisting of two or more ingredients admits of being analysed or decomposed into those ingredients, so that they can be shown apart. Simple bodies, on the other hand, consisting of but a single substance, are, in relation to chemical analysis, one and indivisible, and do not therefore admit of being analysed.

10. As analysis is the foundation of all chemistry, though by no means sufficient of itself to constitute it a science, it is of the utmost importance that at the very outset the mode in which it is applied to furnish a basis for the science should be appreciated. To illustrate this, the following examples are given :—

11. The most familiar of all liquids—water—was, from a very early period, considered an element or simple body. If a powerful electrical current, however, be sent through it, it analyses the water into two gases unlike each other, and unlike the water. The last, for example, at ordinary temperatures, is a liquid not itself combustible, and in which ordinary inflammables do not burn. The one of the gases into which it is resolved is called by the chemist hydrogen, and besides many other remarkable properties, is highly combustible. The other gas, named oxygen, causes a lighted body plunged into it to burn with much more brilliancy than in common air. Water, then, is a compound of two ingredients, hydrogen and oxygen. The question now arises, Are the oxygen and hydrogen compounds of two or more constituents, as water is? According to the present experience of chemists,

they are not. Heat, light, electricity, and the other agencies already referred to, effect no analysis of them into simpler substances. Both are regarded, accordingly, as consisting entirely of a single peculiar kind of matter.

12. A piece of marble, which is pure limestone, presents no characters as of colour, weight, density, and the like, by the mere inspection of which we can tell whether it consists of one or of several ingredients. We know, accordingly, that for ages it was looked upon as a simple substance, and called, with a multitude of others, Earth. If a piece of marble, however, be strongly heated, as limestone is every day in our lime-kilns, it is decomposed or analysed into two totally-unlike substances. The one of these is the familiar body, quicklime, or lime-shell; the other is a gas, which, when it was first observed, as derived in this way from marble, was called fixed air, because it had previously been in a state of fixation in the solid limestone. Marble, then, is a compound of at least two substances, lime and fixed air: but are these simple, or may they not be made up of ingredients, as the marble was made up of them? When lime is subjected to a galvanic current, it is decomposed into two bodies, the one a brilliant, silver-white metal, called calcium, the other the gas oxygen; but neither the calcium, nor, as we have already seen, the oxygen, can by any process be resolved into two or more ingredients. Each appears, like the elements of water, to consist of but one kind of matter. The fixed air, in like manner, when heated with certain metals, is resolved into carbon or charcoal, and into the same gas oxygen, which was found in lime and in water; but the charcoal resists all decomposing agents, and seems, like the oxygen and calcium, to be a simple substance.

13. In the way thus illustrated, the chemist proceeds, subjecting all substances to his analytical processes; and whenever he comes to one which does not admit of analysis, he sets it apart, and calls it a *simple* or *elementary body*. In the present state of our knowledge, we count some sixty bodies as simple, elementary, or not susceptible of analysis. The metals are all simple bodies. Thirteen substances which are not metallic belong also to this class.

14. Out of some sixty elements, then, the thousands of chemical compounds known to us are made up. There is no body which contains them all, or even a majority of them. The greater number of substances contain a very few, and consist of only two, three, four, five, or six ingredients. Some of the simple bodies, moreover, form a much greater number of compounds than others. Certain of them, indeed, occur

only in very small quantity in the globe, as constituents of rare minerals.

15. The sixty bodies referred to above, which cannot be analysed, will hereafter be spoken of throughout this work as the Chemical Elements, or elementary bodies. They bear the same relation to the various compound substances which belong to the animal, vegetable, and mineral kingdoms, that the letters of the alphabet do to the works written in the language which they make up. Thus every English word is a compound of two or more letters, into which it can be grammatically analysed. The twenty-six letters themselves, however, admit of no analysis, but are the primary symbols out of which the language is constructed. Certain of these letters occur much more frequently in words than others; thus one or more vowels are found in nearly every part of speech, whilst the letter Z enters into the composition of very few terms. The chemical elements may thus be called the alphabet of chemistry as a science, and the different compound bodies correspond to the words which are made up of the alphabetical letters. Thus water is like a word of two letters, marble like one of three, alum of four, white of egg of six. We subjoin a list of the chemical elements, to which we shall return again :—

TABLE OF ELEMENTARY SUBSTANCES.

Aluminum
Antimony (Stibium)
Arsenic
Barium
Bismuth
Boron
Bromine
Cadmium
Calcium
Carbon
Cerium
Chlorine
Chromium
Cobalt
Copper (Cuprum)
Didymium
Erbium
Fluorine
Glucinum
Gold (Aurum)
Hydrogen
Ilmenium
Iodine
Iridium
Iron (Ferrum)
Lanthanum
Lead (Plumbum)
Lithium
Magnesium
Manganese
Mercury (Hydrargyrum)
Molybdenum
Nickel
Niobium
Nitrogen or Azote
Norium
Osmium
Oxygen
Palladium
Pelopium
Phosphorus
Platinum
Potassium (Kalium)
Rhodium
Ruthenium
Selenium
Silicium or Silicon
Silver (Argentum)
Sodium (Natrium)
Strontium
Sulphur
Tantalum or Columbium
Tellurium
Terbium
Thorium
Tin (Stannum)
Titanium
Tungsten (Wolfram)
Uranium
Vanadium
Yttrium
Zinc
Zirconium

16. Analysis, or the resolution of bodies into their simplest

ingredients, however, constitutes but half of the characteristic work of the chemist. In the case of a language, we do not merely resolve words into their component letters, but we combine these letters, so as to form new words, such as were not in existence previously. Thus, by analysing the hieroglyphics on the Egyptian monuments into their simplest constituents, we have discovered the grammatical elements of what for centuries was a lost language. We employ the knowledge so attained in reading the Egyptian inscriptions; but we might, in addition, construct new words out of the hieroglyphics, such as no Egyptian ever saw or made use of. In like manner, the chemist does not content himself with merely analysing the compounds which nature presents ready-formed to his hand, but determines, by his interference, the production of new ones, such as did not exist in the world till he effected their formation. Chloroform, for example, affords a striking illustration of a chemical substance which, so far as we know, occurs nowhere ready-formed on the globe, but which has been called into existence by human interference within the last few years. It is not to be forgotten, however, that man has no real power of creating chemical compounds. He may bring together two elements which never met till he mingled them; but the combination which occurs between them is not effected by him, but results from the action of certain properties which the Author of all things has conferred upon these elements. It is only, therefore, in a secondary and subordinate sense that the chemist creates. The importance, however, of his office in this respect is not on that account to be overlooked. Few of our more valuable medicines, dyes, pigments, and other substances largely employed in the useful arts, are found native. The greater number of them must be prepared by complicated processes from what may be called the raw material, which alone is furnished by nature. Glass, for example, and soap, are in one sense artificial compounds, for they occur nowhere native; but in another are quite natural combinations, for had there not existed laws of nature determining their production, man could never have caused their formation.

17. This creation of new compounds by the union of their elements is called their production by chemical *synthesis*, a term which stands exactly contrasted in meaning with *analysis*, signifying the binding together or union of bodies previously uncombined. Thus, if we send an electrical current through water, we effect its analysis into oxygen and hydrogen; but if we send an electric spark through a mixture of these gases, their synthesis is determined: in other words,

they unite and reproduce water. The chemist's labours, which are thus partly analytic, partly synthetic, may be considered as beginning with analysis. He prosecutes it till he has resolved the globe, and everything on it, into sixty primary constituents or elements. He then betakes himself to Synthesis—turning round, as it were, and retracing his steps, so as to pass now from simplicity to complexity; and by mingling the sixty elements in innumerable ways, creates an endless number of novel substances. These in their turn he subjects to analysis, in order that he may discover their exact nature and composition; and thus Analysis and Synthesis constantly alternate, and frequently proceed together.

18. The prosecution of analysis and synthesis is in great part, however, only a mean to an end. The new elements which the one, and the new compounds which the other brings to light, are each of them carefully studied as to all its properties. Thus the chemist examines, in regard to every substance, simple or compound, its shape, if it be a solid; its specific gravity, whether it be solid, liquid, or gas; its colour, odour, taste; its melting, freezing, or boiling point; its power to refract, reflect, and otherwise modify light; its solubility in water and other liquids; its action on living bodies; the mode in which it affects other chemical substances; the conditions essential to its entering into combination with these, and to its separation from them; the proportion, by weight and volume, in which it combines with unlike bodies; besides many other particulars. It is further to be observed that analysis and synthesis are not the only means by which the chemist extends his science. There are many other important methods of investigation, springing out of the relations of bodies to heat, light, electricity, magnetism, the forces which effect crystallisation, &c. which are constantly had recourse to for the extension of chemistry; but it would be premature to enter at present on the discussion of these.

19. It will quite suffice for the beginner to regard Chemistry as the science which takes cognisance of the fact, that our globe, including its contents and inhabitants, does not consist of one, but of many species or kinds of matter; and which investigates the differences that are presented by those kinds of matter, and the properties of the bodies formed by their union with each other. To return to our original illustration: if our globe consisted of but one chemical element—for example, were it a ball of lead, the astronomer could still discuss the problems of his science in relation to it; the geologist, and perhaps the mineralogist, would have something to describe concerning it; the natural philosopher would have

still more to explain regarding it; but the chemist would have nothing to proclaim in reference to such a globe. For all the sensible characters of a mass of lead, considered alone, fall under the notice of the philosophers previously referred to, who would leave nothing undescribed for the chemist to record. His characteristic office is to investigate the *differences* which subsist between unlike kinds of matter; but if there were but one kind—namely, lead—in existence, there could be nothing different to admit of comparison with it; so that in a globe of but one element, there could be no work for the chemist to do. Two elements as constituents of a world—lead, for example, and sulphur—would permit our science to come into action; and its range would widen as the number of elements increased. Our existent Chemistry is the exposition of the differences which subsist between sixty elements, and the record of all the properties and material relations of each of these elements, and of all its compounds.

⁂ The word *Chemistry* is derived from the Greek χημεια (chemeia), which occurs for the first time in certain works of the eleventh century, and is used by their writers to signify the *art of making gold artificially*, so that it originally denoted what we now generally indicate by the word Alchymy—namely, the supposed art of transmuting the common metals into gold. The root of the word is exceedingly doubtful. Some derive it from *Ham*, the son of Noah, one of whose immediate descendants is said to have been the first chemist; others from *Chemia*, one of the ancient names of Egypt, in which chemistry is said to have originated; some deduce it from the Coptic root *chems*, obscure or secret; and others from the Greek *chymos*, a liquid or juice—the aqua-regia of the alchemists being the liquid *par excellence*. Several other derivations have been proposed; but all are very uncertain, and none of them throw any light on the modern meaning of the word.

GENERAL PROPERTIES OF MATTER.

20. The general properties of matter are discussed in a separate volume of this series of works,* and therefore are not enlarged upon here. There are certain of them, however, which must be briefly referred to, on account of the frequency with which allusion is made to them in all chemical discussions.

21. The masses of matter (liquid, solid, and gaseous) which present themselves at the earth's surface are looked upon as made up of certain minute particles, molecules, or atoms, which, being arranged together in close approximation, build up larger solids, as a massive edifice is constructed by placing a multitude of hewn stones or moulded bricks together. To make the comparison complete, we must suppose the component stones to be very small, and that the joints or spaces between them are invisible. A block of iron is thus represented as the aggregation of a multitude of minute particles of the metal, kept united to each other by the attraction of cohesion, as the attraction of magnetism enables a loadstone to hold in contact with it a piece of steel. In like manner a liquid or a gas, in which the particles move freely on each other, may be compared to a battalion of soldiers clad in uniform. If looked at from a considerable distance, such a body of men, when each is motionless, appears as one indivisible mass. If approached more nearly, it is seen to consist of a multitude of individuals standing close to each other. When the battalion begins to move, it becomes apparent that its alterations in shape, and its movements as a whole, are occasioned by each soldier of which it consists systematically changing his place. Liquids and gases are, as it were, battalions of small particles, each of which corresponds to the individual soldier; but these particles are so minute, that we cannot get sight of them, or perceive the manner in which they determine the movements of the fluids they make up.

22. It is certain that all visible masses consist of particles

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* Laws of Matter and Motion, p. 84.

much smaller than the mass they make up by their union. A cannon ball, for example, can be reduced to portions so minute, that a single one is invisible, and so light, that it will not affect the most delicate balance. Whether, when these particles are reduced to a certain smallness, they do not admit of further reduction in size and weight, or, on the other hand, permit division of their substance to an indefinite extent, has been much discussed by philosophers. The question does not admit of decision by experiment, and speculative philosophy holds the balance even between the rival views. As it will greatly conduce to perspicuity, however, and does not bind the pupil to a final conclusion to adopt for the time one of the two views entertained as to the divisibility of matter, we shall throughout the following pages speak as if there certainly is a limit to the division of particles. Each of these will be regarded as an exceedingly small portion of matter, which, however treated, never becomes smaller, but retains, in all circumstances, the same size, and weight, and shape. The last is best conceived of as round or spherical, so that each particle may be regarded as a microscopically-small sphere, or minute solid ball, some million times smaller than a grain of mustard seed.

23. These smallest portions of matter are distinguished by three names already introduced, and all of which we shall have occasion to employ. 1. They are called *particles*, or *ultimate particles*, a term which needs no explanation; 2. *Molecules*, a title derived from the Latin, signifying a very small portion of matter; 3. *Atoms*, from the Greek ατομος, indivisible, a word made use of to imply that the molecules of matter are not divisible by any of the forces which cause them to unite with each other, or separate them when combined.

24. The molecules of matter are constantly exposed to the influence of two opposing forces, which change the physical or mechanical condition of the masses which result from the aggregation of many particles. These counteracting forces are cohesion and heat; the former approximates the particles of bodies, and renders them more dense and solid, or diminishes their volume; the latter (speaking generally) separates the molecules from each other, lessens the density and solidity of the mass, and expands its bulk. These opposing forces, according to their relative intensity, determine three unlike, but most important forms or conditions of matter — those, namely, of solidity, liquidity, and the gaseous state, or gaseïty. In one, the attraction of cohesion prevails over the repulsive power of heat. This is the state of solidity. In another, heat has quite overcome cohesion, and we have, as

a consequence, the gaseous form of matter. In the third, the opposing forces are balanced, or nearly so, cohesion still prevailing to a certain extent, and the resulting condition is that of liquidity.

25. A solid is distinguished from a liquid and a gas by the fact, that we cannot move one particle of it without moving the whole. In other words, the particles of a solid are bound so firmly and so closely together, that they cannot be made to glide over each other. A propelling force, accordingly, if directed against a single particle or limited portion of a solid, either produces no result, or, if effective, moves the entire mass. In liquids and gases, on the other hand, we can put in motion some of the particles, and leave the remainder at rest, or have one set of molecules moving in one direction, and another in an opposite, as we see daily illustrated by the currents passing in unlike directions, which influence bodies of gas and of liquid, such as the atmosphere and the ocean.

26. It thus appears that in solids cohesion is so predominant, that the particles have for the time lost all freedom of motion among themselves. If the solid, however, be exposed to heat, and is not liable to decomposition, its particles immediately begin to move away from each other, and expansion or enlargement of bulk occurs. When the heat is withdrawn, the cohesive attraction recovers its power, and the particles move together again. Thus a rod of iron lengthens when placed in a fire, and shortens again when withdrawn from it. In liquids, as already observed, cohesion manifests itself, though much less strikingly than in solids. Detached drops of water or quicksilver run together into larger globules, showing that attraction is operating upon them; but the force of cohesion is so small, that the particles are free to move with little obstruction upon each other, so as to admit not only of a general movement of the liquid, but of partial, smaller motions among its molecules.

27. In consequence of the smaller force of cohesion to be overcome in the case of liquids, heat expands them much more than it does solids. Liquid thermometers, accordingly, are more sensitive to the influence of heat than those constructed of metallic rods or bars.

28. Upon the particles of a gas cohesion has ceased to exert any power; they repel, instead of attracting each other, and when relieved from pressure, or raised in temperature, recede from each other to the utmost attainable limit. Gases, as well as liquids and solids, contract or diminish in volume when cooled, but not for the same reason as these do—namely, because the withdrawal of heat has allowed cohesion to come

into play—but simply because the diminution of the temperature of a gas lessens the mutual repulsive action of its molecules, so that they do not recede so far from each other.

29. All chemical substances, then, whether simple or compound, present themselves as solids or fluids, the term fluid being used as a generic or general one to include two species or kinds, *liquid fluids*, or *liquids*, and *elastic fluids*, or *gases*. The same substance often presents itself in all the three forms, according to the temperature at which we examine it; and its chemical properties differ materially according as it is a solid, a liquid, or a gas. No other example need be given at present than that of water, which at the freezing point is a crystalline solid; at ordinary temperature, a limpid liquid; and at its boiling point, an invisible vapour. Ice, liquid water, and steam, differ strikingly in chemical relations from each other.

WEIGHT—SPECIFIC GRAVITY—ATOMIC WEIGHT.

30. Weight, or the pressure downwards (or rather towards the centre of the earth) which all bodies exhibit, in obedience to GRAVITY, is a character of matter which each of the physical sciences requires to consider. Chemistry is specially concerned with three relations of weight, which should be clearly apprehended by the student, and carefully distinguished from each other. These are—1*st*, *Absolute Weight;* 2*d*, *Specific Weight;* 3*d*, *Atomic Weight.* Absolute weight is a term used as the expression of the whole amount of ponderable matter in any body. Thus the absolute weight of one fluid ounce of pure water (half a wine-glassful) is 437½ grains Troy.

31. In order to express absolute weight, we have recourse to one or other of the divisions or systems of weights in common use, as in the preceding example we have employed one of the denominations of the Troy system. This is the one most frequently used by chemists in this country, and will be generally adopted in the following pages. Avoirdupois, or, as it is now called, Imperial Weight, is also occasionally made use of by the chemist—as, for example, in stating the results of the analysis of mineral waters. The value of the grain, however, is the same in both systems; so that, by generally giving weights in grains, we shall avoid any confusion between the two. Thus the Troy pound consists of 5760 grains, the imperial pound of 7000. Each is a multiple by a different number of the same fundamental unit or grain.

32. Those who perform experiments will often find it essential to success to weigh accurately the materials which are to be employed. It should be kept in remembrance, accordingly, that the small weights which accompany the scales used by the apothecary are, when taken in grains, identical in value with Troy and Imperial weight. The phrase 'Apothecaries' Weight' refers only to the names given to the multiples of the grain, not to a difference in the grain itself. Thus the apothecary has a weight which he calls a scruple, and another which he calls a drachm—denominations neither of which occurs in Troy or Imperial Weight; but the scruple is nothing

more than twenty, and the drachm sixty, Troy or Imperial grains. The weights, therefore, of the apothecary's box may be employed, whether we are following the Troy, Avoirdupois, or Apothecaries' system of division.

33. *Specific Weight*, or, as it is generally called in this country, *specific gravity*, is a phrase employed to express the relation that subsists between the absolute weight of any substance and the volume or space which that weight occupies. In order to ascertain it, the same bulks or volumes of substances are taken, and the weight of these identical volumes determined. Bodies which, within the same volume, contain the same amount of ponderable matter, are said to have the same specific gravity. If one of them weigh more than another, it has a higher specific weight than it; if it weigh less, its specific gravity is smaller. Thus, if two pieces of iron be taken, each of exactly the same dimensions as the other, and be placed, the one in one pan of a pair of scales, and the other in the opposite, they will exactly balance each other, as their weights will be identical. Here, within the same space, or bulk, or volume, we have exactly the same amount of ponderable matter. If, now, we substitute for one of the pieces of iron a piece of the metal platina, of precisely the same dimensions, and place the metals in opposite scales, we shall find that they do not balance each other, as the two pieces of iron did, but the platina will prove much the heavier; so that if, for example, the piece of iron we took weighed between 7 and 8 grains, the mass of platina of the same size would weigh 21½, or the latter would be about three times heavier than the former. Within the same space, then, there is three times as much ponderable matter in platina as there is in iron, which is expressed by the chemist by saying that the specific gravity of platina is three times greater or higher than that of iron.

34. Specific gravity is thus the expression of the difference that subsists between the weights of equal volumes of bodies; or it may be more shortly stated thus: the specific gravities of bodies are the relative weights of equal volumes of them. In order to express the difference between the weights of equal volumes, we fix upon one body, and call its density 1, or unity, writing after it the figure 1, or 1000. Bodies which have a greater specific gravity have that indicated by some higher number than 1; bodies which have a lower specific gravity by a number less than unity, according to their relative differences in weight. For many reasons, water has been selected as the body whose density shall be called unity, in so far as liquids and solids are concerned. Water, accordingly, is said to be the standard of specific gravity for liquid and

solid bodies. Thus, if we compare the weight of a certain volume of water with exactly the same bulk of iron, we shall find that the iron is nearly 8 times heavier than its own volume of water, whilst platina is 21½ times denser than an equal bulk of that liquid. We express this numerically thus:—

Water, sp. gr. (specific gravity)	1·	or	1000
Iron, sp. gr.	8·	or	8000
Platina, sp. gr.	21·5	or	21,500

In other words, these numbers express this fact, that a space which, when quite filled at a certain temperature and pressure of the atmosphere, contained 1000 grains of water, would, at the same temperature and pressure, hold 8000 of iron, and 21,500 of platina.

35. Gases are so much lighter than water—air, for example, being 815 times lighter—that it would be found extremely inconvenient to make water the standard of specific gravity for elastic fluids. Air, accordingly, is substituted for it, and the specific gravity of air is called 1 or 1000. Thus the gases carbonic acid and chlorine are heavier than air; nitrogen, on the other hand, is lighter. The exact numbers denoting their specific gravity are the following:—

Air,	1000
Nitrogen,	972
Carbonic Acid,	1524
Chlorine,	2440

These numbers, like those already given, express the fact, that a vessel which, when full of air at a certain temperature and pressure, contains a thousand grains of that gas, will, at the same temperature and pressure, though filled quite as full, contain only 972 grains of nitrogen; whilst, when filled no fuller by the heavier gases, it will contain 1529 grains of carbonic acid, and 2440 of chlorine. The containing vessel having been the same in all the trials, and filled each time, there cannot be any difference in the volumes of the gases taken. The difference in weight is determined solely by the fact, that within exactly equal spaces, different bodies contain unlike quantities of ponderable matter.

36. Many precautions and niceties are necessary in the practical determination of specific gravity. The methods and minutiæ, which require attention, must be learned from works on natural philosophy. No character of a body, however, is more frequently referred to by the chemist than its specific gravity; hence our detailed discussion of it. The specific

gravity of every important substance will be mentioned whilst describing its properties.

37. *Atomic Weight*, or, as it might be called, *equivalent chemical weight*, is the term used to express the relation that subsists between the different proportions by weight in which substances unite chemically with each other. Thus water, which we have already seen to consist of two bodies, oxygen and hydrogen, contains these ingredients, not in a variable, but in a quite fixed or constant proportion by weight, and each element in a different proportion. Every specimen of water contains a weight of oxygen eight times greater than that of hydrogen. This fact the chemist expresses by saying that the atomic weight of oxygen is eight times greater than the atomic weight of hydrogen. He calls it *atomic* weight, because he assumes that the difference in question depends upon the fact, that every ultimate particle, molecule, or atom of oxygen, is eight times heavier than each similar atom of hydrogen. This relation of weight, however, cannot be understood till certain important laws have been explained. We adjourn its discussion, therefore, till they have been considered.

CHEMICAL AFFINITY.

38. As there is of necessity a much greater number of compound than of simple chemical substances, one of the earliest things which the chemist has to consider is the nature of those compounds, and the means by which they are to be distinguished from their elements, from each other, and from mechanical mixtures. We offer here, accordingly, some preliminary observations on those points.

39. Every chemical compound consists of at least two elements, although, as we have seen already, it may contain many more. For simplicity's sake, however, we shall confine ourselves in the following remarks to a compound of only two elements, and select, in the first place, water as the example. When the gases oxygen and hydrogen are mingled together, they become uniformly diffused through each other, but no chemical combination occurs between them. If, however, a light be applied to the mouth of a vessel filled with the gases mixed in certain proportions, or an electric spark be sent through the mixture, great evolution of heat and light occurs, a sharp report or explosion is heard, and the gases become changed into steam, which, as it cools, condenses into water. The oxygen and hydrogen are now said to have entered into chemical combination, and to have formed water. The smallest conceivable quantity, or minutest particle of water, is supposed to consist of one molecule or atom of hydrogen, and one of oxygen, not fused or run into one larger particle, as two drops of a liquid metal like quicksilver flow into a bigger drop, but consisting of two distinct and unlike particles, kept near each other by a peculiar constraining force, to which the name has been given of *chemical affinity.* So long as the particles of oxygen and hydrogen are under the influence of this power, they cease to present the properties which characterise oxygen and hydrogen when uncombined—the associated particles acting for the time as if they were but one, which manifests the properties peculiar to water. When water, again, is decomposed—for example, by a galvanic current—the particles of hydrogen separate from those of oxygen, and all

those of one kind go together; the properties of water cease to appear, and those of hydrogen on the one hand, and of oxygen on the other, become manifest.

40. Chemical affinity was at one time called chemical attraction, as if it were a force, like mechanical attraction or cohesion, bringing the molecules of bodies into closer contact. There can be no doubt that in many cases the particles of elementary bodies do come nearer each other when they combine chemically; thus, if two measures of hydrogen and one of oxygen be caused to unite, three measures of steam, or water vapour, are not procured, but only two; or the particles of oxygen and hydrogen have approached so much closer to each other, that they occupy only two-thirds of the space they did before they combined. In other cases, however, compounds are found to occupy exactly the same space as their elements did before combination, and sometimes they occupy a greater space. Where this happens, there is no evidence that an attracting or approximating force is at work upon them. The student is recommended, therefore, not to employ the term chemical attraction, but rather to use the more metaphorical one *affinity*, which expresses only, that in every chemical compound there is an unknown force at work, which acts as a bond or tie, or link of union, between its elements. In virtue of this, they do not separate so long as it is in operation; but remaining together, confer upon the compound the properties which distinguish it from its elements, and from a mere mechanical mixture of these. It is necessary, nevertheless, to point out the characters which distinguish a mechanical combination resulting from the operation on the particles of matter, of the attraction of cohesion, from a chemical compound, which is produced by the influence of affinity. In the first place, then, chemical affinity acts only upon unlike particles. It does not, for example, unite atom of iron to atom of iron, or of sulphur to sulphur, or of oxygen to oxygen, or of hydrogen to hydrogen; but comes into play only when the molecules consist of different kinds of matter. It binds sulphur, for example, to iron, and oxygen, as we have seen, to hydrogen. Cohesion, on the other hand, is seen most strikingly manifested when uniting particles of the same kind of matter to each other; thus it unites iron to iron, water to water, and marble to marble. But cohesion, like affinity, also unites dissimilar particles: one metal, for example, can be made to cohere to another by powerful compression, as when silver is inlaid with steel. Copper, by a different process, is mechanically united to tin; and iron is coated with zinc. Equally striking, and more familiar examples, are furnished

by the action of gum, paste, or glue, when employed to unite unlike substances, as paper and leather, or wood and stone. A mechanical combination, however, of unlike kinds of matter, is readily distinguished from a chemical compound by the following characters: The properties of the mechanical combination are always either the sum, or the mean or average of the properties of its components. Thus a watch is a mechanical aggregation of gold, silver, copper, steel, enamel, jewels, and glass. Its absolute weight is the sum of the absolute weights of all those: its specific gravity is the mean of their several densities; nor has it any properties which are not either equal to, or the sum of, the properties of its constituents, or the mean or average of these. So also the physical characters of the board of a book are exactly the sum or the mean of the properties of the leather, paper, pasteboard, and glue, which make it up.

41. The properties of a chemical compound, on the other hand, are not, with one exception, so far as we at present know, either the sum or the mean of those of their components. The exception occurs in relation to absolute weight, which, as well in chemical as in mechanical compounds, is exactly the sum of the weights of the constituent ingredients. The other properties are all new, so that a knowledge of the qualities of the elements does not enable us to anticipate or predict what the properties of the compound will be, which we can to a great extent foresee in the case of mechanical combinations. Thus the specific gravity of steam is not identical with that of either oxygen or hydrogen, or that of a mixture of them; nor is it the sum or the mean of the densities of those gases, taken singly or mingled. Its action on light, its conducting power for sound, its relation to combustion and to animal life, and a multitude of its other physical characters, are totally unlike those of a mechanical mixture of oxygen and hydrogen.

42. Of the changes in physical properties which chemical affinity produces, none is so likely to strike the beginner as the difference in colour between a chemical compound and its elements, or a mixture of these. Thus, if the pale yellow sulphur and the bluish-white quicksilver be heated together, they form the bright red vermilion, a tint which cannot be produced by any mechanical mixture of blue, yellow, and white colours. In like manner, if a piece of the reddish-brown copper be dissolved in the colourless liquid, nitric acid, it forms a deep blue compound. When the bluish-black bodies iodine and lead combine, they give rise to a bright yellow substance. When charcoal and sulphur unite, the resulting compound is

neither black nor yellow, nor of any intermediate tint, but as colourless as water. Multitudes of other examples might be given, but these may suffice so far as change of colour is concerned.

43. The other properties of the chemical elements, however, are quite as much altered when they combine as their tints are. Thus the heavy metal antimony, which we are accustomed to see as a massive solid, forms an invisible gas when it combines with hydrogen. The greenish-yellow gas chlorine, on the other hand, when it unites with quicksilver, forms white crystals of corrosive sublimate. Solid sulphur and charcoal change into a very volatile liquid. Phosphorus, which resembles wax in appearance, and oxygen, a colourless, invisible gas, form phosphoric acid, a body exceedingly like snow. Nitrogen and oxygen have no taste; neither has a mixture of them. One of their compounds, laughing gas, is pleasantly sweet to the palate; another, nitric acid, intensely sour. Charcoal, hydrogen, and oxygen, are all tasteless; gum is one combination of them, arrow-root another, sugar a third.

44. Chlorine gas has a suffocating odour; common salt, of which it forms more than one-half by weight, is odourless. Charcoal and hydrogen, on the other hand, have no odour; nevertheless, a large number of our choicest perfumes, such as attar of roses, oil of bergamot, and oil of citron, consist solely of those two elements. In like manner the scentless nitrogen and hydrogen are the only constituents of one of the most odorous of all substances, spirits of hartshorn, or ammonia.

45. Again, the deadly poison prussic acid is made up of carbon, hydrogen, and nitrogen, which, taken singly or mixed, are not injurious to animal life. Oxalic acid, another poison, consists of charcoal, hydrogen, and oxygen. The same elements constitute spirits of wine and sulphuric ether.

46. The preceding examples of change in specific gravity, colour, form, taste, odour, and relation to living animals, will serve, in the meanwhile, to prove how totally dissimilar in properties a chemical compound is, from a mere mechanical mixture of its elements.

47. Every chemical compound exhibits this character of newness of properties. No substance, indeed, is entitled to be called a chemical compound in which the properties are only the sum or the mean of those of its ingredients. The characteristic difference between the products of mechanical attraction and chemical affinity may be illustrated thus: the least complex kind of combination being selected to be commented on. If we call the one element of the mechanical mixture A,

and the other B, then the mixture itself is equal merely to A plus B, or A added to B, each of which can be traced in the compound. But when A and B represent the elements of a chemical compound, although analysis proves that they are as distinctly present in it as they are in the mechanical mixture, we lose all traces of their separate existence, and their combination is equivalent to a perfectly new substance which, judging by its properties, we should not call AB, but distinguish by a special letter, as by naming it C.

48. Having thus, then, settled what a chemical compound is, we are now to consider how many kinds of such compounds there are. It may be observed, as preliminary to what we have to say on this subject, that compounds differ in complexity. Thus marble consists, in the first place, of two bodies—carbonic acid and lime; but each of these, in its turn, consists of two bodies; the carbonic acid of charcoal and oxygen; lime of the metal calcium and oxygen. Alum consists primarily of four bodies, potass, alumina, sulphuric acid, and water; but all of these are themselves compound, oxygen being present in each of them, united to metals (aluminum and potassium), in alumina and potass; to sulphur in sulphuric acid; and to hydrogen in water. Many compounds, also, although totally different in properties, contain exactly the same elements, but these are in different proportions. Thus the medicinal substances calomel and corrosive sublimate contain the same two ingredients, chlorine and mercury; but calomel contains twice as much mercury as corrosive sublimate.

49. We are now ready to discuss the laws according to which the simpler compounds are formed out of the elements, and the more complex combinations out of the simpler compounds.

LAWS OF COMBINING PROPORTION.

50. The laws of chemical combining proportion are four in number. They refer to combination by *weight*, not to combination by volume, which will be referred to in another portion of the work. They explain certain exceedingly simple principles which regulate the relative quantities or proportions by weight, according to which chemical substances unite with each other to form combinations. A knowledge of them is essential to the successful prosecution of chemistry, whether as a science or an art. It is of the utmost importance, therefore, that the student should clearly comprehend them.

51. Before mentioning those laws, we direct attention to another, which does not refer to the quantity or weight of elements or ingredients in a body, but simply to the *nature* of its constituents. This law may be called **THE LAW OF CONSTANCY OF ELEMENTS OR INGREDIENTS.** We use the word element here in the sense in which we have formerly defined it, to indicate the simplest chemical substances. The term ingredient, for distinction, we apply to a body, itself a compound, but which, by union with others, forms a combination still more complex than itself. Thus in water we have two elements, oxygen and hydrogen; whilst in marble we have two non-elementary components, or, as we shall call them, ingredients—carbonic acid and lime. The law, then, we are about to announce applies equally to the simple element and the compound ingredient. It may be expressed thus: **THE SAME COMPOUND CONSISTS INVARIABLY OF THE SAME ELEMENTS OR INGREDIENTS.** Water, for example, is invariably composed of oxygen and hydrogen, and of nothing else; common salt consists equally invariably of chlorine and sodium; and vermilion of sulphur and mercury. *Marble*, in like manner, always exhibits as its constituent ingredients carbonic acid and lime; *Glauber's salt*, always sulphuric acid and soda; *sal ammoniac*, always muriatic acid and ammonia. To this law there is no exception, so that one accurate analysis of a compound for ever decides the nature of its ingredients.

52. We now proceed to the laws of proportion. The first

is best entitled THE LAW OF CONSTANT PROPORTION. It teaches that THE ELEMENTS OR INGREDIENTS WHICH FORM A CHEMICAL COMPOUND ARE ALWAYS UNITED IN IT, IN THE SAME PROPORTION, BY WEIGHT. Water not only consists invariably of oxygen and hydrogen, but the weight of oxygen present is always eight times greater than that of hydrogen. Common salt always contains 35½ parts of chlorine to 23 of sodium; vermilion, 16 of sulphur to 101 of mercury; so also marble has always 22 of carbonic acid to 28 of lime; Glauber's salts, always 40 sulphuric acid to 31 of soda; sal ammoniac, 36½ of muriatic acid to 17 of ammonia.

53. In virtue of this law, numbers can be found for all substances, simple or compound, expressing the relative quantity by weight in which they combine with all other bodies. We shall illustrate this more fully after explaining the second law. In the meanwhile, however, it is important to observe how much chemistry is simplified by the existence of such a law as we have just explained. We have mentioned already that a single accurate analysis for ever settles what the ingredients of a compound are. It equally settles what the proportion of these ingredients is. It is true that in actual practice the chemist never contents himself with a single analysis, but he does this, not because he expects one specimen, for example, of water, to differ in composition from another, but because his methods of analysis, however refined, still fall far short of absolute accuracy. It is essential, accordingly, to make several analyses which yield results differing very slightly from each other, and the mean or average of those several determinations is taken as representing the true composition of the body. After all, however, the several imperfect analyses are only equal to a single accurate one.

54. In the case of mechanical mixtures, on the other hand, or of combinations, consisting partly of definite chemical compounds, and partly of indefinite mixtures, the labours of the chemist are enormously greater, and one analysis applies only to the particular specimen upon which it is made. Thus clay, mortar, garden earth, or soil, many dyes, perfumes, and medical preparations, &c. are not constant chemical compounds. To determine the composition of a single specimen would require, as in the case of a chemical compound, several analyses, the mean of all of which should afterwards be taken. But the very next parcel of the substances named, which called for a knowledge of its composition, would require an analysis to be made as carefully as if no other specimens of those bodies had been previously examined. It is otherwise with chemical compounds. The composition of one specimen

of water is the composition of all specimens of water. The marble of Italy is identical with the marble of Ireland. The vermilion made in China is identical with that sold in England.

55. If the analytical chemist's labour is thus greatly abridged by the existence of the law we are considering, the memory of the student is not less aided by it. If the composition of a chemical compound be once apprehended, it will not afterwards require correction or enlargement, or apply with a certain truth to one specimen, but with a quite different one to another.

56. The service which a knowledge of this law renders to chemistry as a practical art is not less striking. In the preparation of dyes, pigments, medicines, metallic alloys, such as brass, and important chemical compounds, such as glass, soap, carbonate of soda, and the like, the chemical manufacturer can avoid all useless waste of material on the one hand, and all unwise economy of it on the other. There is one proportion, and one only, in which the ingredients of the substance he is manufacturing require to be supplied. The employment of more than that proportion is a waste of material; the employment of less is a detrimental withholding of it. We shall have more to say of this law after explaining the next.

57. The second law of combining proportion is a little more intricate than the first. It is named THE LAW OF RECIPROCAL PROPORTION, and teaches that IF TWO BODIES COMBINE IN CERTAIN PROPORTIONS WITH A THIRD, THEY COMBINE IN THE VERY SAME PROPORTIONS WITH EACH OTHER. Thus 16 parts of sulphur combine with 8 of oxygen, and 28 parts of iron combine with 8 of oxygen; but 16 parts of sulphur is the very quantity that combines with 28 of iron. We may reverse the numbers: 8 of oxygen combine with 28 of iron, and 16 parts of sulphur with 28 of iron; but 8 of oxygen is the very quantity that combines with 16 of sulphur. Or a third time: 8 oxygen and 28 iron combine respectively with 16 sulphur; but 28 iron is the quantity that combines with 8 oxygen.

58. The law of reciprocal proportion may also be stated in another way, which brings out its importance more clearly: THE PROPORTION IN WHICH ANY TWO BODIES COMBINE WITH EACH OTHER, IS THAT IN WHICH THEY COMBINE WITH EVERY OTHER. Thus the proportion in which oxygen and hydrogen unite with each other is as 8 to 1; in other words, a given weight of hydrogen always unites with neither more nor less than 8 times its weight of oxygen; or, reversely, a given weight of oxygen unites with an eighth of its weight of hydrogen. But when each of these bodies is made to unite with all the other bodies with which it can

combine, the same proportion is maintained. The compounds of oxygen contain a weight of oxygen 8 times greater than the similar compounds of hydrogen do of hydrogen. Thus oxygen combines with carbon to form a gas, called *carbonic oxide;* and hydrogen combines with carbon to form a gas, called *olefiant gas.* In both these compounds the amount of carbon may be represented by the same number, 6; but the amount of oxygen in carbonic oxide is 8 times greater than the amount of hydrogen in olefiant gas; or oxygen and hydrogen, when they unite with carbon, exhibit the same proportion, 8 to 1, which they show when uniting with each other; and what is said here of carbon applies to all the elements. Each of them unites with 8 times more of oxygen than of hydrogen, and each of them has one fixed proportion in which it combines with all the rest.

59. This law may be regarded as an extension of the first. It simply taught that the same compound always contains the same quantity of the same ingredients. The law we are discussing goes further, and shows that the proportion in which an element or ingredient occurs in one compound is likewise the proportion in which it occurs in all compounds. Thus, if we call the proportion of hydrogen in water 1, and that of oxygen 8, we shall find that the same numbers will suffice to express the relative proportions in which hydrogen and oxygen unite respectively with all other bodies.

60. It is in relation to this law more than to the others that the combining weights of bodies are termed their *equivalents,* the best title by which they can be distinguished. This term expresses, in a way no other does, that a certain weight of one body is equivalent to, or goes as far as, a certain but different weight of another in the construction of a similar compound. One part by weight of hydrogen, for example, goes as far in combining with 8 of oxygen to form an oxide, as 28 of iron, 33 of zinc, or 98 of gold. These compounds have all the same value; the weight of oxygen is the same in all, and the 98 parts of gold do not neutralise the 8 of oxygen 98 times more effectually than the 1 of hydrogen does, but only *as* well, and with the production of a *similar* compound. The same remark applies to the different but equivalent quantities of all the other substances referred to.

61. In virtue of the laws of constant and reciprocal proportion, a number can be found for every body, simple or compound, expressing the ratio in which it combines with every other. Any series of numbers may be taken to represent these combining ratios, provided a certain proportion is maintained among them. Thus analysis demonstrates, as we have seen

already, that the combining quantity of oxygen is 8 times greater than that of hydrogen; so also it shows that the combining quantity of charcoal or carbon is 6 times greater than that of hydrogen; that of nitrogen 14 times; that of sulphur 16 times; that of iron 28 times. Now any scale of numbers may be taken to represent these relative combining quantities, provided only that the number for carbon be 6 times greater than that for hydrogen; that for oxygen 8 times greater; that for nitrogen 14 times; that for sulphur 16 times; and that for iron 28. Thus we might call iron 1; nitrogen would then be $\frac{1}{2}$, or 0·5; and hydrogen would be $\frac{1}{28}$. Or oxygen might be made 1, in which case hydrogen would have its combining quantity expressed by $\frac{1}{8}$, and sulphur by 2. We may give any value we please to any one of the elementary bodies we choose to fix upon for a commencement, and call it 1, 10, 100, 1000, $\frac{1}{2}$, $\frac{1}{4}$, or any other integer or fraction; but here our liberty ceases. The relations between the numbers are absolute, though their individual value is not; and from the settled figure we must count upwards or downwards, or both ways, so as to maintain inviolate the relative values throughout the series.

62. Different scales of combining numbers, accordingly, are in use among chemists. Thus, for analytical purposes it is preferable to call oxygen 100; but in teaching, it is found much more convenient to begin with hydrogen, and to call it 1, so that we count only upwards. The numbers in this scale are all small, and do not, in the majority of cases, go beyond two integers. We subjoin this scale at full length, but before introducing it, place side by side, for the sake of comparison, the combining weights of some of the elementary bodies on the hydrogen and oxygen scales:—

Name of Element.	Hydrogen Scale. Hydrogen equal to 1.	Oxygen Scale. Oxygen equal to 100.
Carbon,	6	75
Nitrogen,	14	175
Sulphur,	16	200
Iron,	28	350
Hydrogen,	1	12·5
Oxygen,	8	100

63. Those numbers follow exactly the same proportion; 12·5 bears the same relation to 75 that 1 does to 6; 175, the number for nitrogen, is exactly 14 times greater than 12·5, the number for hydrogen. The same numerical relation, accordingly, is expressed by both scales. We shall always employ the hydrogen series as giving small numbers easily apprehended and remembered.

64. Tables such as the following are said to represent the combining proportions, chemical equivalents, or atomic weights of substances. The table we give includes only the elementary bodies; but when we have discussed the remaining laws of combining proportion, we shall find that special tables are not needed for compound substances. The object and meaning of the letters named *symbols* placed opposite each element will be explained in a future paragraph:—

TABLE OF ELEMENTARY SUBSTANCES.

Names of Elements.	Symbols.	Equivalents.
		Hydrogen = 1.
Aluminum	Al	13·69
Antimony (*Stibium*)	Sb	129·03
Arsenic	As	75
Barium	Ba	68·64
Bismuth	Bi	70·95
Boron	B	10·90
Bromine	Br	78·26
Cadmium	Cd	55·74
Calcium	Ca	20
Carbon	C	6
Cerium	Ce	46
Chlorine	Cl	35·50
Chromium	Cr	28·15
Cobalt	Co	29·52
Copper (*Cuprum*)	Cu	31·66
Didymium	...	...
Erbium	...	...
Fluorine	F	18·70
Glucinum	Gl	26·50
Gold (*Aurum*)	Au	98·33
Hydrogen	H	1
Iodine	I	126·36
Iridium	Ir	98·68
Iron (*Ferrum*)	Fe	28
Lanthanum	Ln	48
Lead (*Plumbum*)	Pb	103·56
Lithium	Li	6·43
Magnesium	Mg	12·67
Manganese	Mn	27·67
Mercury (*Hydrargyrum*)	Hg	100·07
Molybdenum	Mo	47·88
Nickel	Ni	29·57
Niobium	Nb	...
Nitrogen	N	14
Norium	No	...
Osmium	Os	99·56
Oxygen	O	8
Palladium	Pd	53·27
Pelopium	Pe	...
Phosphorus	P	32
Platinum	Pt	98·68
Potassium (*Kalium*)	K	39
Rhodium	R	52·11
Ruthenium	Ru	52·11
Selenium	Se	39·57
Silicium	Si	21·35
Silver (*Argentum*)	Ag	108
Sodium (*Natrium*)	Na	22·97
Strontium	Sr	43·84
Sulphur	S	16
Tantalum	Ta	92·30
Tellurium	Te	66·14
Terbium	...	...
Thorium	Th	59·59
Tin (*Stannum*)	Sn	58·82
Titanium	Ti	24·29
Tungsten (*Wolfram*)	W	94·64
Uranium	U	60
Vanadium	V	68·55
Yttrium	Y	32·20
Zinc	Zn	32·52
Zirconium	Zr	33·62

65. The third law of combining proportion is related to the circumstance, that the same elements in almost every case combine in more than one proportion to constitute several compounds. If this, in truth, were not the fact, we should never succeed, even with sixty elements at our disposal, in accounting for the enormous variety of substances found in our globe. This law is named that of MULTIPLE PROPORTION, and enforces the truth, that WHEN ONE BODY COMBINES WITH ANOTHER IN SEVERAL PROPORTIONS, THE HIGHER PROPORTIONS ARE MULTIPLES OF THE FIRST OR LOWEST. Thus oxygen and hydrogen are contained in water in the ratio of 8 parts of the former to 1 of the latter. Those elements, however, unite to form a second compound, named the peroxide of hydrogen, or oxygenated water, in which the oxygen is to the hydrogen in the proportion of sixteen to one, or the hydrogen remaining the same as in water, there is exactly *twice* as much oxygen. The illuminating power of coal-gas is owing to the presence in it of two substances, each a compound of carbon and hydrogen. In the one (olefiant gas) there are 6 parts by weight of carbon to 1 of hydrogen. In the other (fire-damp), 6 of carbon to 2 of hydrogen; or the weight of carbon being the same in both, there is exactly twice as much hydrogen in the second as in the first. A substance named the protoxide of manganese contains 28 parts of the metal manganese to 8 of oxygen. Another compound of the same elements, named black oxide of manganese, contains 28 parts of the metal to 16 of oxygen. A third combination, manganic acid, 28 of the metal to 24 of oxygen: 16 is twice 8, and 24 is thrice 8; so that the amount of oxygen in the black oxide is a multiple of that in the protoxide by 2; and the oxygen in manganic acid a multiple by 3.

66. If we now write down in a row the compounds we have named, the multiple relation will be more clearly perceived:

Water = Hydrogen 1, Oxygen 8.
Peroxide of Hydrogen = Hydrogen 1, Oxygen 16, or twice 8.

Olefiant Gas = Carbon 6, Hydrogen 1.
Fire-Damp = Carbon 6, Hydrogen 2, or twice 1.

Protoxide of Manganese = Manganese 28, Oxygen 8.
Black Oxide of Manganese = Manganese 28, Oxygen 16, or twice 8.
Manganic Acid = Manganese 28, Oxygen 24, or thrice 8.

67. One of the most remarkable examples of this law occurs in the compounds of nitrogen and oxygen, which are five in number. The proportion of nitrogen is the same in all, and may be represented by the number 14, while that of the

oxygen, which in the lowest, may be expressed by 8; in the second, is 16, or twice 8; in the third, 24, or three times 8; in the fourth, 32, or four times 8; and in the fifth, 40, or five times 8. The higher proportions are thus multiples of the lowest by 2, 3, 4, 5, at which last number, in this case, they stop. This will appear more distinctly by the following table, containing the names of the five compounds of nitrogen and oxygen:—

Nitrous Oxide, .	Nitrogen 14,	Oxygen 8
Nitric Oxide, . .	Nitrogen 14,	Oxygen 16 = 8 × 2
Hyponitrous Acid,	Nitrogen 14,	Oxygen 24 = 8 × 3
Nitrous Acid, .	Nitrogen 14,	Oxygen 32 = 8 × 4
Nitric Acid, . .	Nitrogen 14,	Oxygen 40 = 8 × 5

68. In every series of compounds we find the same law operating. If a substance can combine with more than 8 parts of oxygen, the least next quantity it combines with is 16. It never combines with $8\frac{2}{3}$, $8\frac{4}{5}$, $8\frac{3}{10}$, or any other fraction whatever; but if it overstep the 8, goes right on to the 16 before it is again saturated. It may go past the 16, but in that case it cannot stop at any intermediate number short of 24. It need not halt at 24, however, if it can go on to 32; or at 32, if it can combine with 40; and it may pass at once from 8 to 40, or to any other quantity, however large, provided it be a multiple of the original 8. The only unalterable decree is, that whatsoever smallest quantity of one body another can combine with, every higher compound must contain in increasing multiples.

69. The law of multiple proportion furnishes a great help to the memory in recollecting the composition of complex compounds. Analysis only can tell us exactly how much of any ingredient is present in a compound; but of this we are certain before, and indeed without analysis, that each constituent will be present either in its smallest combining quantity, or in a multiple of that. The amount of oxygen in all its compounds may be expressed by 8, or a multiple of 8. All combinations of sulphur contain either 16 parts of it, or if not, then 32, 56, or some other multiple of 16. Iron occurs in quantities of 28, 56, 84, &c.—that is, its quantity, if above 28 parts, can always be expressed by a number divisible by 28 without a remainder.

70. This law modifies in a peculiar way the law of reciprocal proportion. Elementary bodies do not, in all their similar compounds, show themselves equivalent in every respect to each other if taken in their smallest combining quantities. It sometimes happens that two or more combining proportions

of one substance are requisite to replace or act in the same manner as one of another body. In every case, however, if we have more than one equivalent, we have it doubled, tripled, quadrupled, or otherwise presenting itself as a multiple of the lowest combining quantity. This will be particularly referred to under the head of specific heat and crystallography.

71. The fourth and last law we have to consider is a very simple one, and will not require much illustration. It may be called the law of COMPOUND PROPORTION, and teaches that THE COMBINING PROPORTION OF A COMPOUND BODY IS THE SUM OF THE COMBINING PROPORTIONS OF ITS COMPONENTS. The combining proportion of water, for example, is found by experiment to be 9 (or a multiple of 9), hydrogen, as before, being taken as unity; but 9 is the sum of 8 parts of oxygen and 1 of hydrogen, its constituents. The equivalent of carbonic acid appears, upon trial, to be 22; but carbonic acid is found, on analysis, to consist of 6 parts of carbon and 16 of oxygen, which exactly make up 22. The combining weight of lime is 28, but lime consists of 20 calcium and 8 oxygen, which are also 28. Lastly, marble has the combining proportion 50, but it is composed of 22 carbonic acid and 28 lime, which are also 50.

72. This law, like the last, is modified by the law of multiple proportion. Thus a great number of substances contain water as a constituent. In many of them the quantity is expressible by the number 9. Thus slaked lime contains, for every 28 parts of lime (28 being the combining number for lime), 9 of water. In the greater number of salts, however, which contain water we have more than 9 parts. Thus, an equivalent of blue vitriol, or sulphate of copper, is associated with 45 parts of water; an equivalent of Epsom salts, or sulphate of magnesia, with 54; an equivalent of carbonate of soda with 90. Those numbers, however, are all multiples of 9. The first salt contains 5 times 9, the second 6 times, the third 10 times 9 parts by weight of water. The same remark applies to other compounds; but the fact we are explaining does not interfere with the existence of the law of compound proportion, or require its statement to be modified. A multiple of a multiple must be a multiple of the numeral with which the multiplication began. A multiple of 16 must be a multiple of 8; a multiple of 27, one of 9; a multiple of 24, one of 6; and so on. The combining number of a compound body is always the sum of the combining numbers of its components, but these are not necessarily present in their lowest combining quantities—that is, in single equivalents. Com-

pounds, on the other hand, may contain many equivalents of all their ingredients or elements. Sugar, for example, contains 12 equivalents of hydrogen, of oxygen, and of carbon.

73. As the combining proportion of a compound body can be found by adding together the numbers expressing the combining numbers of its elements, tables of the equivalents of non-elementary bodies are not given in treatises on chemistry as a science. The more important of them, however, are recorded in works discussing chemistry as an analytical art, and will be stated in the following pages.

⁂ The laws of combining proportion, and the atomic theory which occupies the next chapter, cannot be profitably studied by those who are entirely unacquainted with the names and properties of chemical substances. It is advisable, therefore, to postpone the study of the laws and theory till the properties of at least oxygen, hydrogen, and nitrogen, as discussed under these titles, have been explained and illustrated. The student will then be familiar with a sufficient number of examples of combinations in different proportions to follow, without difficulty, the exposition contained in this chapter; nor is it desirable to adjourn its discussion to any later period than the earliest at which it can be intelligently followed.

ATOMIC THEORY.

74. The laws of combining proportion, which have been explained, are not doubtful theories or hypothetical speculations. They are the expression or statement of facts, ascertained by direct and multiplied observation; and any one who questions their truth, can satisfy himself of their reality by accurately analysing a few chemical compounds.

75. These laws, however, were first made known to chemists by their chief discoverer, Dalton, in connection with a peculiar atomic hypothesis, or, as it is less properly, but more commonly called, theory, which supplied a beautiful and complete explanation of the existence of such laws, and furnished at the same time a very simple and easily-followed mode of teaching them. It was with great ingenuity and boldness conjectured by this chemist that the ultimate atoms of the elementary bodies do not possess the same, but different weights, and that the difference between their weights is identical with that which subsists between the combining proportions of the elements themselves.

76. As oxygen, for example, has a combining proportion eight times greater than that of hydrogen, so the ultimate atom of oxygen is assumed to be eight times heavier than the ultimate atom of hydrogen. As the combining proportion of nitrogen is fourteen times that of hydrogen, so the atom of nitrogen is supposed to be fourteen times heavier than that of hydrogen: and in like manner the relative weights of the atoms of the other elementary bodies are supposed to differ by the same numbers that the relative weights of their combining proportions differ by. Dalton, it will be observed, thought that if it were possible by any means to select single atoms of each of the elementary bodies, and weigh them one by one, we should find, *first*, that different atoms of the same element possessed all the same weight, so that whatever was the absolute weight of any one, would be found to be the weight of each of the others of the same kind; and if one atom of hydrogen weighed the millionth of a millionth of a grain, each of the hydrogen atoms would weigh the millionth

of a millionth also; *secondly*, we should find that all the oxygen atoms were 8 times heavier than the hydrogen ones; all the nitrogen atoms, 14 times heavier; all the silver atoms, 108 times; all the gold atoms, 98 times heavier. In short, the proportions in which bodies combine with each other are supposed to depend upon the weights of the atoms which make them up, and to be identical with these weights. All the numbers, accordingly, which, before this hypothesis is considered, represent combining proportions, as soon as it is adopted, come to represent weights of ultimate atoms, or atomic weights.

77. It may seem singular that it should be considered important to explain Dalton's atomic views, seeing that it is not at all certain that there are such things as atoms, much less that they differ in relative weight.

78. The conception, nevertheless, of the combining proportion of each element, as dependent on the special and constant weight of the ultimate particles of which masses of the element consist, greatly facilitates the apprehension and remembrance of the laws of combining proportion. Whether an atom is absolutely indivisible, is not a question which chemistry requires to decide. It is enough for the solution of the problems of the science if we concede that in fact those atoms do not suffer division; in other words, are not lessened in weight when chemical combination or decomposition occurs. It is much less easy to grasp the idea of a constant numerical ratio, or combining proportion, than it is to conceive of a solid, ponderable mass, which is as unchangeable in relation to gravity as the weights of a balance. Nor is the value of this latter conception in simplifying the study of chemistry affected by the fact, that the solid, ponderable masses referred to may admit of reduction in size, and therefore in weight, by forces other than chemical.

79. A homely comparison may assist in making this clear. Many of our rare or valuable articles of commerce are offered for sale in fixed quantities, so that the purchaser must either take a certain amount at a time, or obtain none. Thus, attar of roses is brought to this country in small stoppered phials, which the dealer will not open so as to dispose of less than the whole contents of the phial at a time. Still more familiar examples are afforded by the dealers in the more valuable teas, who sell these only in packages of a fixed weight; for example, a pound. Weighed quantities of arrow-root, in like manner, are offered for sale in boxes, which the seller will not open. We may liken the different elementary bodies to substances sold in this way. Each of them may be regarded

as furnished by nature, made up into small parcels or quantities having a fixed weight, which is the same for each parcel of the same element. Hydrogen can be obtained in quantities smaller than any of the other elementary bodies. Each little parcel of carbon is 6 times heavier than each little parcel of hydrogen. Nitrogen is supplied in quantities 14 times, and iron in quantities 28 times, greater than hydrogen. None of these bodies is found occurring in nature otherwise than parcelled out in the way we have supposed, and none of them is made up into larger parcels or made down into smaller ones during any chemical change. This is all the atomic theory need be considered as contending for.

80. The beginner, then, adopting this view, may at once exchange for the abstract and shadowy conception of numerical ratio, or combining proportion, the distinct and easily-apprehended idea of a solid ponderable atom. 1 is to be considered as stamped upon every particle of hydrogen, as if the whole amount of it in the globe had been coined at the same mint into pieces of exactly the same value. Carbon, in like manner, has its atoms stamped with 6 upon them, sulphur with 16, iron with 28.

81. When the elementary bodies, moreover, enter into combination, their atoms bearing the unalterable stamp upon them, follow of necessity laws such as we have discussed in the preceding section. Thus, if every atom of oxygen is 8 times heavier than every atom of hydrogen, then different specimens of water must be identical in composition. Nine grains of it will, on analysis, yield 8 grains of oxygen and 1 grain of hydrogen; 9 tons, in exactly the same way, will afford 8 tons of the one element, and 1 of the other, because the constituents of water existing in it in the proportion of 1 atom of the one to 1 atom of the other, and the atom being unalterable in weight, every specimen of water must yield exactly the same number of atoms of oxygen weighing 8 as of hydrogen weighing 1, so that it will be found to contain a ninth of its weight of one gas, and eight-ninths of the other. The law of *constant* proportion, then, is easily accounted for.

82. The law of *reciprocal* proportion is an equally inevitable result of the constancy in weight of the atom; for if each atom of sulphur is 16 times heavier than each atom of hydrogen, then it will exhibit this excess of weight over the hydrogen atom as much when it combines with one body as with another. Thus, in referring to this law in the preceding section, it was stated that while 16 represents the proportion in which sulphur combines with 8 parts of oxygen, it equally exhibits the proportion in which it unites with 28 of iron,

which is equivalent, upon the atomic view, to saying that if the sulphur atom is 16 times heavier than the hydrogen one when weighed in a state of combination, and therefore along with an atom of oxygen (8 times heavier than the hydrogen atom), then it will continue to be 16 times heavier than the hydrogen atom, when weighed along with an atom of iron, which is 28 times heavier than that of hydrogen. Neither will its weight suffer any change by weighing it along with any other of the elementary or compound bodies, for the weight of an atom is a constant quantity; it cannot be lessened, or increased, or annihilated.

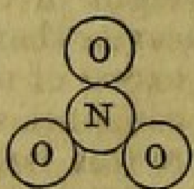
83. The law of *multiple* proportion is equally necessary, for an atom of one element is the smallest quantity that can be added to a compound containing an atom of it already, and whatever was the weight of the first atom will be that of the second also, so that an exact duplication of the first proportion, without any fractional lack or excess, must take place. And if more than one atom be added at a time, it must be atoms, not an atom and a-half, or one and a-third, or any other fraction or fragment; for this cannot be, seeing that the atom is chemically indivisible.

84. In the five compounds of nitrogen and oxygen already considered, the first, which contained 14 parts by weight of the former to 8 of the latter, was to be taken as a compound of a single atom of each. The second must contain 16 oxygen, because the next highest compound must be one of two atoms; the third 24, because there are three atoms, each weighing 8; the fourth 32, because the atom is quadrupled; and the fifth, of necessity, 40, for a similar reason. The following diagram will illustrate this. Each atom is represented by a circle with the initial letter, representing the name of the element, of which it is an ultimate particle:—

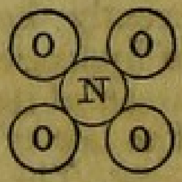
Nitrous Oxide,

Nitric Oxide,

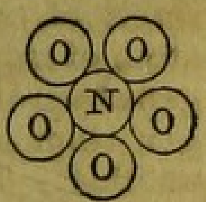
Hyponitrous Acid,



Nitrous Acid,



Nitric Acid,



85. If the beginner has any difficulty in following the last statement, he may be helped by the following comparison: Let

our copper penny piece, with its value 1, be taken to represent hydrogen, each coin standing for an atom. Let the sixpenny piece, in like manner, stand for carbon, whose combining proportion is 6 times greater than that of hydrogen. Suppose, then, that we throw into a bag sixpenny and penny pieces at random, purposely avoiding to notice how many of each we cast in. If we afterwards empty the bag, and ascertain the amount of money which it contains in each kind of coin, we shall certainly find the amount of copper money a multiple of 1—that is, one penny. There will be no halfpence, farthings, or mites—that is, no halves, fourths, or eighths, or other fractions of the original unit. In like manner, the amount of silver coin will certainly be a multiple of six. We shall have silver equal to 24 pence, 48, 60, or some higher number; but it will be a multiple of 6. We can quite confidently predict that the number representing the amount of pence in the silver coin will be divisible by 6 without a remainder. So, in every compound containing hydrogen, the quantity of that element will be expressible, if not by 1, then by a multiple of 1. And the quantity of carbon in its compounds will be representable by 6, or a multiple of 6.

86. Lastly, the law of *compound* proportion could not fail to manifest itself according to the atomic; for the aggregation of atoms does not alter their weight, and the atom is not divisible by the forces which effect chemical analysis, so that its weight should be shared among smaller molecules. Had the atom been divisible, it might have been otherwise; and when two or more atoms entered into combination, they might have broken up into lesser particles, among which the original weight was parcelled out.

87. According to the atomic theory, however, the atom is chemically indivisible; the combining proportion, therefore, or atomic weight of water, for example, is necessarily 9, because it consists of 2 atoms weighing respectively 8 and 1. The atomic weight of water is as necessarily 9 as the value of a penny and a sixpenny piece taken together is sevenpence.

88. We have now learned three names representing the ratio in which each chemical substance unites with all others. Those were—*combining proportion*, *chemical equivalent*, and *atomic weight*. The second is the best, as being the most expressive and least hypothetical of the three. In practice, it is shortened by omitting the adjective; so that we say the 'equivalent' of sulphuric acid, for example, is 40. The term atom is shorter, and provided the student does not attach to it the character of absolute, but only of relative or chemical indivisibility, it may be employed in exactly the same sense as

'equivalent.' Thus we do not hesitate to speak of an atom of water, although the so-called water-atom is certainly divisible—namely, into particles of oxygen and hydrogen.

12

⁂ A series of coloured balls, with a different colour for each of the chief elements, will be found of service in illustrating the atomic theory. A white ball, for example, may represent an atom of oxygen, and a black ball one of hydrogen; whilst the two placed together represent a compound atom of water. A better device, however, is a set of cubes of wood, with the initial letters or symbols of the elements marked upon them. If the cubes are stained black, they may be lettered with chalk, and eight or twelve will be sufficient. They have the advantage over balls of standing securely, and admitting of being placed close together in vertical or horizontal rows. The letters also upon them are much more significant than colours, and they may be employed with great advantage to illustrate the nature and steps of all the chemical reactions which are discussed throughout this work. Each cube will admit of six *symbols*, or initial letters, being marked upon it, one on each face: but it is not advisable to letter more than one face of each cube.

R Purcell Esq

Clongowes Wood

CHEMICAL NOMENCLATURE.

89. The names or appellations by which the chemist distinguishes the various simple and compound substances are as much as possible constructed on a system, so as to supply information concerning the properties of the body; and if it be a compound, to tell the nature, and also the proportion, of its elements.

90. The nomenclature of chemistry is in this respect much superior to that of many of the other sciences, which give to everything they have to name a quite arbitrary title, so that the learner has first to make an effort of the memory to retain the term, and next, by a separate endeavour, to recollect what it denotes. Thus in mineralogy many substances are named in honour of individuals; and we read, accordingly, of Greenockite, Dolomite, Thomsonite, &c.—terms which give no information whatever concerning the nature and properties of the mineral.

91. Chemical nomenclature, notwithstanding, is defective, and will long remain so. Only a perfect knowledge of chemistry could secure a perfect nomenclature. In the meanwhile, our knowledge has outrun our skill in devising names, the system on which we set out at the beginning of this century having proved not nearly expansive enough to supply appellations for the multitude of unexpected new substances which have recently been discovered. It would be unwise, however, till we are acquainted with a much greater number of compounds than we yet know, to make a fundamental change in chemical nomenclature.

92. As names have been given to chemical substances since the earliest times, and long before chemistry became a science, many bodies have several titles, although there is generally one preferred as the most scientific.

93. The rare and valuable metals, having attracted the attention of mankind from the remotest historical periods, have received names which are still to a great extent retained. The combustible constituent of oil of vitriol has the two names

brimstone and sulphur. Most of the familiar salts have more than one title, as nitrate of potass is called also nitre and saltpetre; sulphate of copper, bluestone and blue vitriol; sulphate of iron, copperas and green vitriol.

94. A few names have come down to us from the languages of the civilised nations of antiquity. The root, for example, of the word ammonia (spirits of hartshorn) is some thousand years old—Ammon, from which it is derived, having been the name of one of the gods worshipped by the ancient Egyptians, from whom the Romans transmitted the name to us.

95. In the ninth century the Arabians were the most distinguished chemists, and several of the names they introduced still survive. Many of them may be recognised by commencing with the Arabic definite article Al. Thus we have alcohol, alkali, alembic.

96. During the fifteenth and sixteenth centuries, the European alchemists were the most famous students of chemistry. We still retain many of their quaint, fanciful, but often expressive names; such as spirit of wine, spirit of hartshorn, spirit of salt, flowers of sulphur, aqua regia.

97. Astrology and alchymy went hand in hand, nor have we yet ceased to use some of the terms introduced by the astrological chemists. They associated the metal lead and the planet Saturn together, and we still speak of solutions of lead as Saturnine solutions. Nitrate of silver still bears the name of Lunar caustic, and crystallisations of silver are called the tree of Diana: silver and the moon (Luna or Diana) having been astrologically connected. In like manner, in unscientific works, one of the compounds of iron is still styled crocus Martis, in reference to the planet Mars, with which iron was associated. The metal quicksilver is not likely soon to lose its astrological name of Mercury.

98. In the seventeenth century, the adoption of an erroneous theory of combustion led to the adoption of a nomenclature now totally abandoned. As none of its terms occur systematically in works of the present day, we say no more concerning it. Those, however, who wish to read works on chemistry published in the last century, many of which are of the greatest interest and importance, must make themselves acquainted with this nomenclature, which continued to be employed till the very close of the eighteenth century.

99. At that period the recognition of another theory of combustion, the discovery of many new gases, the detection of the composition of the air, and of that of water, revolu-

tionised all chemistry, and led to the introduction of the nomenclature which we now employ.

100. It serves, upon the whole, very conveniently for the distinction of inorganic bodies from each other; but when we come to organic chemistry, we shall find that it has not proved sufficient to meet its wants.

101. The names of the elements we have given already. They are entirely arbitrary, and many of them were words of common language before they were adopted as scientific terms. In the case of the elements more recently discovered, an endeavour has been made to give names of similar termination to those which resemble each other. Thus all the metals discovered within this century have their names terminated in *um*, as potassium, sodium, lanthanum; and the names of all the metals terminate similarly, if their Latin appellations be used. Thus lead in Latin is *plumbum*, copper *cuprum*, antimony *stibium*, &c. With one exception, moreover (selenium), no element which is not a metal has its name terminated in *um*.

102. It is of importance to the student to remember this, and to notice that the table of elementary bodies is a list rather of Latin than of English names. The proof of this will be given in the next section.

103. Three of the elements, resembling each other in properties, and in several respects unlike the others, have their names ending in *on*—namely, carbon, boron, silicon. Some regard the last as a metal, and call it silicium. The names of another remarkable group of elements end in *ine*—chlorine, bromine, iodine, and fluorine.

104. No community of property is intended to be represented by the termination in *gen*, common to oxygen, hydrogen, and nitrogen. Sulphur and phosphorus had received names long before our present system of nomenclature was devised; but these being distinctive and euphonious, and readily permitting adjectives to be derived from them, were willingly retained. The titles of the elements will be further considered in treating of each.

105. The names of compound bodies are as far as possible constructed so as to express their composition, and at the same time to indicate the class of compounds to which they belong.

106. With a view to this, compounds are arranged into three divisions:—1*st*, Binary compounds, or those which consist but of two elements—as water of oxygen and hydrogen, common salt of chlorine and sodium, vermilion of sulphur and mercury. 2*d*, Ternary compounds, which contain three

elements—as marble, which consists of carbon, oxygen, and calcium; copperas, of sulphur, oxygen, and iron; nitre, of nitrogen, oxygen, and potassium. 3*d*, Quaternary compounds, which contain four elements—as dry alum, which consists of sulphur, oxygen, aluminum, and potassium.

107. The chief binary compounds are those of the non-metallic elements, such as oxygen, sulphur, and chlorine with each other, or with the metals. Compounds of oxygen are called oxides, originally spelled *oxydes.* Thus red lead is a compound of lead and oxygen; it is termed by the chemist oxide of lead. Jeweller's putty consists of tin and oxygen; it is oxide of tin. Iron rust, in like manner, is oxide of iron.

108. Compounds of chlorine are termed chlorides. Common salt, a combination of sodium and chlorine, is the chloride of sodium; calomel is the chloride of mercury; chloroform, the chloride of formyle.

109. Compounds of sulphur are more generally called sulphurets than sulphides, although the latter term is now coming into use. Thus vermilion, consisting of sulphur and mercury, is the sulphuret or sulphide of mercury; king's yellow, consisting of sulphur and arsenic, is the sulphuret of arsenic ; galena is the sulphuret of lead.

110. The names of the other non-metallic elements yield terminations in *ide*, like oxygen, or in *uret*, like sulphur. Thus the binary combinations of bromine, iodine, and fluorine, are called bromides, iodides, and fluorides.

111. Nitrogen, carbon, boron, silicon, selenium, and phosphorus, are said to form nitrurets, carburets, borurets, siliciurets, seleniurets, and phosphurets (or nitrides, carbides, borides, silicides, selenides, and phosphides) of the element with which they combine. Thus steel and cast-iron contain the carburet, and frequently also the siliciuret, of iron. The other names do not often require to be used.

112. When the non-metallic elements combine with each other, the term derived from oxygen, or from the body most like it, goes first; thus water is called the oxide of hydrogen. A compound of charcoal and sulphur is called the sulphuret of carbon, not the carburet of sulphur. A compound of chlorine and sulphur, on the other hand, is not called the sulphuret of chlorine, but the chloride of sulphur.

113. We have seen that the same elements combine in several proportions; we require, therefore, to distinguish different binary compounds of the same element from each other. Thus many metals combine with oxygen in several proportions. To distinguish them from each other, the Greek and Latin numerals are employed.

114. A combination of one equivalent of another body with one equivalent of oxygen is called a *protoxide,* from the Greek πρωτος (*protos*), first.

115. To prevent confusion, however, the term protoxide is not used in its precise etymological meaning, to signify *first* oxide in the sense of lowest, or oxide containing the least quantity of oxygen. The title is restricted to oxides containing 8 parts, or one equivalent of oxygen to one equivalent or atom of the body united to it. Thus the black oxide of copper contains 31 parts of copper to 8 of oxygen; it is called the *protoxide.* The red oxide of the same metal consists of 62 parts of copper to 8 of oxygen; or for each equivalent of copper there are only 4 parts, or half an equivalent of oxygen. It is named the *suboxide.*

116. When the same body combines with oxygen to form a higher compound than the protoxide, the former is called the *deutoxide;* if there be a third, it is named the *tritoxide;* if a fourth, the *quadroxide;* but, for a reason to be mentioned presently, the two last terms are very rarely employed.

117. The term deutoxide signifies simply second oxide. Many deutoxides contain, however, twice as much oxygen as the protoxide. To indicate this, the Latin numeral is taken, and they are called *binoxides,* from *bis,* twice. Thus laughing-gas is the protoxide of nitrogen; the next oxide—namely, nitric oxide—is at once the deutoxide and the binoxide of nitrogen; for it contains 16 parts of oxygen, whilst laughing-gas contains 8. The deutoxides of iron and of manganese, on the other hand, are not binoxides. It is the third, or tritoxide of manganese which is its binoxide.

118. Similar prefixes are employed to indicate the proportion of the other non-metallic elements in their binary compounds. Thus calomel, according to many chemists, is the *protochloride* of mercury; corrosive sublimate, which contains twice as much chlorine, is the deutochloride, and at the same time the bichloride of mercury.

119. Iron pyrites is the *bisulphuret* of iron; it contains twice as much sulphur as another mineral called the *protosulphuret.*

120. In the same way we speak of *proto-iodides* and *biniodides* in reference to the compounds of iodine; *proto* and *bibromides* in relation to those of bromine; and so with the other non-metallic elements.

121. The highest binary compound of the same elements is frequently distinguished not by a numerical prefix, but simply by the Latin particle *per,* which signifies, in com-

bination, *highest or most intense*. Thus the black oxide of manganese is generally called the *peroxide*, not the binoxide.

122. Red oxide of iron, in like manner, is called the peroxide. Corrosive sublimate is frequently named the perchloride of mercury. So also we speak of periodides, persulphurets, &c.

123. Oxides, which contain a large proportion of oxygen, generally exhibit acid properties. We shall afterwards particularly explain what an acid is, but in the meanwhile the sour taste which characterises the stronger ones, and is familiar to every one, may be accepted as the property marking a body to be an acid. Thus the oxides of sulphur, of arsenic, and of antimony, and the tritoxide and quadroxide of nitrogen, are all acids, and are named in relation to their acidity, so that we never see them distinguished by such terms as tritoxide and quadroxide.

124. Names are formed for these acid oxides, or, as they are more frequently called, oxygen acids (or oxacids), by forming an adjective, ending in *ic*, from the noun representing the substance combined with oxygen, and in consequence acidified. Thus the quadroxide of manganese is called manganic acid; one of the oxides of the metal chromium, chromic acid; and one of sulphur, sulphuric acid.

125. It very frequently happens that there are more acid oxides than one of the same element. The binoxide of sulphur (SO_2) is an acid as well as the deutoxide (SO_3). When there are thus two acid oxides, the termination in *ic* is given to the one containing the greater amount of oxygen, and the lower oxide is denoted by an adjective ending in *ous*. Thus, whilst the deutoxide of sulphur is sulphur*ic* acid, the binoxide is sulphur*ous* acid. We have in like manner arsen*ic* acid, containing five equivalents of oxygen to one of metallic arsenic; arseni*ous* acid, containing three equivalents of oxygen to the same amount of metal. So also we have nitric acid, with its five atoms of oxygen, and nitrous acid with four; phosphoric acid and phosphorous acid; antimonic and antimonious; selenic and selenious acids.

126. When a body forms with oxygen more than two acids, the adjective endings which our language affords being exhausted, the terminations already mentioned, *ic* and *ous*, are qualified by prefixing to them the Greek prepositions *hyper*, signifying *over*, or *above*, or *more than;* and *hypo*, signifying *under*, or *less than*, to indicate the relation of the amount of oxygen in the new acid to that in those already furnished with names. Thus, after sulphurous acid had been named, a lower acid oxide was discovered, containing sulphur

and oxygen in the proportion of atom to atom, so that it contains only half as much oxygen as sulphurous acid. This compound has been named *hyposulphurous* acid, to signify that it contains *less* oxygen *than* sulphurous acid.

127. In like manner an acid containing *less* oxygen *than* sulphuric, and more than sulphurous acid, is called *hyposulphuric* acid.

128. Those prefixes generally suffice; but where there are more than *four* acid oxides of the same element, as is the case with sulphur, peculiar and complex appellations require to be given. The compounds, however, necessitating such names are too rare to call for mention here.

129. The highest acid oxide is frequently distinguished simply by the prefix *per*. Thus we have perchloric, periodic, and permanganic acids.

130. Other binary compounds, besides oxides, are acids. To distinguish them from the oxygen acids, the name of the substance which replaces oxygen is made to form part of the adjective denoting the acid. Thus many of the binary compounds of hydrogen are acids; for example, its chloride, bromide, iodide, and fluoride. These, when spoken of as acids, are called hydrochloric, hydrobromic, hydriodic, and hydrofluoric (and sometimes chlorhydric, bromhydric, iodhydric, and fluorhydric) acids.

131. The student must guard very carefully against confounding this class of acids, which are distinguished as the hydrogen acids, or hydracids, from the oxacids. The caution is the more necessary, as the same substance often forms an acid both with hydrogen and oxygen. This is the case, for example, with sulphur. The oxacid is called sulphuric acid; the hydracid hydrosulphuric acid. So also chlorine forms with oxygen chloric acid, with hydrogen hydrochloric acid; iodine with oxygen iodic acid, with hydrogen hydriodic acid.

132. Sulphur also, as well as hydrogen and oxygen, forms acids by combining with the other elements. These are distinguished by prefixing to the usual terminations in *ic* and *ous* the word *sulpho*, or *sulph*.

133. Thus a compound of three atoms of sulphur and one of arsenic is called sulpharsenious acid. Another sulphuret of the same metal, containing two atoms more of sulphur, is called sulpharsenic acid. This may suffice for binary compounds.

134. The most important ternary compounds are the substances termed the oxysalts, being the compounds produced when oxygen acids unite with other oxides which are neither acids nor neutral bodies (see 360).

135. The oxides in question are distinguished by the name

basic oxides (and are such bodies as soda, magnesia, and oxide of iron), so that an oxysalt is said to consist of an acid oxide and a basic oxide; or, more shortly, of an acid and a base. It will be afterwards stated, however, that other bodies act as bases besides the basic oxides. When sulphuric acid meets soda, it combines with it, forming Glauber's salt. When the same acid is added to magnesia, it forms Epsom salt. When it combines with oxide of iron, oxide of copper, and oxide of zinc, it forms the salts known familiarly as green, blue, and white vitriol.

136. All salts produced in this way result from the union of two binary compounds; but as each of the latter contains a common constituent—namely, oxygen—after union, there are but three elements; for example, in the vitriols mentioned above, sulphur, oxygen, and the metal iron, copper, or zinc.

137. The oxysalts, therefore, are all ternary compounds, or combinations of three elements. They are named, however, as if the acid, though combined with, was yet distinct from, the basic oxide, or base in the salt.

138. Their nomenclature is very simple. If they contain an acid whose prefix terminates in *ic*, then the name of the salt containing the acid ends in *ate*. If, on the other hand, the affix of the acid ended in *ous*, then the name of the salt is terminated in *ite*. Thus salts containing sulphuric acid are called *sulphates*, those containing sulphurous acid *sulphites*: in like manner the salts of hyposulphurous acid are hyposulphites. So also nitric, phosphoric, and arsenic acids form nitrates, phosphates, and arseniates; and nitrous, phosphorous, and arsenious acids, nitrites, phosphites, and arsenites.

139. Acids containing hydrogen or sulphur instead of oxygen, have their last syllable or syllables modified in the same way, so as to supply names for the salts they form. Thus a salt consisting of hydrochloric acid and a base is called a hydrochlorate, and one containing hydriodic acid a hydriodate. Combinations of sulpharsenious and sulpharsenic acid with bases are called sulpharsenites and sulpharseniates. There are peculiarities, however, connected with the hydrogen and sulphur acids which affect their nomenclature, and are too intricate for discussion in the present place. They will be referred to when discussing the more important hydracids. The remarks that follow must be considered as applying solely to the salts of the oxygen acids. The oxysalts are arranged into classes according to their acids. Thus we have phosphates, sulphates, nitrates, &c. They are divided into species according to the oxide they contain, and the species is marked by stating the name of the oxide, preceded by *of*.

140. Thus the combinations which sulphuric acid forms with the oxide of iron, of copper, and of zinc respectively, are called sulphate of the oxide of iron, sulphate of the oxide of copper, and sulphate of the oxide of zinc.

141. These names are often abbreviated. It is taken for granted that every one is aware that a sulphate containing a metal, contains that metal in the state of an oxide. In naming salts, accordingly, the words '*of the oxide*' are very frequently omitted, so that we say simply sulphate of iron, sulphate of zinc, sulphate of copper. Certain oxides, which were familiar substances, before the fact of their being oxides was discovered, are allowed to retain their earlier names, as soda (the oxide of sodium) and lime (the oxide of calcium), and this enables us to shorten the titles of their salts without even the appearance of inaccuracy. Thus we may, when wishing to speak very precisely, call Glauber's salt the sulphate of the oxide of sodium, and stucco, the sulphate of the oxide of calcium; but they are almost universally named sulphate of soda and sulphate of lime.

142. The same acid frequently combines in more proportions than one with the same base. Numerical prefixes are then employed, similar to those made use of in the case of the binary compounds. Thus, besides the carbonate of soda, we have another salt, containing twice as much carbonic acid. It is named the *bi*carbonate of soda. In like manner we have the sulphate and bisulphate of potass, the chromate, bichromate, and terchromate of potass, and the oxalate, binoxalate, teroxalate, and quadroxalate of the same base. The other terms employed in speaking of salts will be explained when we have occasion to use them.

143. Quaternary compounds generally consist of two salts, each containing the same acid, united together, and the name of the common acid is stated only once, for brevity's sake. Thus dry alum, which is a compound of the sulphate of alumina and the sulphate of potass, is called simply sulphate of alumina and potass. The chloride of platinum combines with the chloride of potassium. The word chloride is used only once in the title of the compound salt—the chloride of platinum and potassium. More complex quaternary compounds, such as a combination of the chloride of gold with the bromide of potassium, can be distinguished only by lengthened appellations. They do not, however, often call for mention; and we shall find in the next section that complex combinations need not be named at all, but may be denoted in another and simpler manner.

CHEMICAL NOTATION.

144. The deficiencies of chemical nomenclature are happily supplied by what is called NOTATION, which bears the same relation to nomenclature that the Arabic ciphers, or Roman numerals, or algebraic signs, bear to written numbers. Thus a date of a year may be written down eighteen hundred and fifty, or 1850, or MDCCCL. In the same way we denote the most familiar of liquids by calling it water, or oxide of hydrogen, or by using the letters HO.

145. For this purpose each of the elementary bodies is indicated by one or two letters, which are called its symbol. When a single letter is employed, it is printed as a capital; when two are used, the second is printed small. The first of these is in every case (Tungsten excepted) the initial letter of the name of the element; but it is not the commencing letter of the English appellation, unless where that is identical with the Latin one. Thus the symbol of lead is not L, but Pb, from its Latin name plumbum; antimony is not an An, but Sb, from stibium; and tin not T, but Sn, from the Latin stannum.

146. A great advantage is gained by this employment of Latin rather than English letters, as the same nomenclature is thus intelligible to all the civilised nations of the world who are acquainted with the ancient Roman tongue; and the English student, on his side, reaps the benefit of finding an old and familiar notation when he reads German, French, or other foreign works on chemistry.

147. As several of the elementary bodies begin with the same alphabetical letter, it is necessary to distinguish carefully their symbols from each other. Thus the names of no fewer than eight of the elements begin with C. To the most important of them, Carbon, the solitary initial letter is given as its symbol, whilst the others, as the tables will show, have, in addition to the common letter, a vowel or consonant to distinguish them. Thus Calcium is Ca, Chlorine Cl. Great care must be taken not to confound the symbols. Thus NO is laughing gas; NaO, soda; SO_3 is sulphuric acid; SeO_3,

selenic acid; SiO_3, silicic acid. The omission, or addition, or alteration, thus, of the secondary consonant or vowel, totally alters the meaning of the symbols as expressing the nature of a compound.

148. The symbol of a substance, when used alone, represents not merely that body, but a combining proportion, or equivalent of it. Thus O stands for 8 parts, or one equivalent of oxygen; N for 14 parts, or one equivalent of nitrogen; Fe for 28 parts, or one atom of iron.

149. When more than one equivalent of a body requires to be expressed, it is done by placing a number to the *right* hand of the symbol. Thus O_5 is five equivalents of oxygen; C_3, three equivalents of carbon; Fe_2, two atoms of iron. The number employed to multiply the symbol is, as shown in the text, much smaller than the alphabetical letter, and is written at the upper or lower, generally at the lower, right-hand corner of the symbol.

150. When two symbols are placed side by side, they denote a compound of one atom of each ingredient—as HO, water; NO, laughing-gas; HgS, vermilion.

151. When one of the associated symbols has a number placed to the *right* of it, the number multiplies *only* the symbol after which it is placed. Thus NO_5, nitric acid, signifies a compound of *one* equivalent of nitrogen and *five* equivalents of oxygen; the 5 multiplying only the O, or oxygen. Fe_2O_3, red oxide of iron, signifies a compound of *two* equivalents of iron to *three* of oxygen; each symbol being affected only by the number placed to its right, or following it.

152. When a number, on the other hand, is placed before, or at the *left* hand of associated symbols, it multiplies *all* which follow it as far as the first comma, + (*plus*) sign, or full stop. To prevent confusion, the numbers placed to the left of symbols are generally made as large as the alphabetical letters they precede. Thus HO_2 is the peroxide of hydrogen, a component of one equivalent of hydrogen and two of oxygen. 2HO is two atoms of water, or it is equal to HO,HO; $3NO_5$ is three equivalents of nitric acid; $Fe_2O_3,3SO_3$ is persulphate of iron, a compound of one atom of red oxide of iron and three of sulphuric acid; $PO_5,2NaO,HO$, or $PO_5+2NaO+HO$, is one equivalent of phosphoric acid, two equivalents of soda, and one equivalent of water.

153. Symbols arranged together, as in the preceding illustrations, are called the formulæ of compounds, or chemical formulæ.

154. The term symbol, however, is not restricted to the elementary bodies, but is occasionally employed in the same

sense as formula, but only in relation to the simpler combinations, such as binary compounds. Thus HO is as frequently termed the symbol as the formula for water, but the expressions for oxysalts and other combinations, which require at least four elementary symbols to denote them, are always called formulæ.

155. The two most important points to be attended to are, *first*, that in the formulæ of binary compounds the symbol of the metal or body *which least resembles* oxygen is written first, or to the left. Thus oxide of iron is FeO, not OFe; sulphuret of mercury is not SHg, but HgS; chloride of sodium is NaCl; and iodide of potassium KI.

156. *Second*, in the formulæ of oxysalts, the symbols of the base precede those of the acid. Thus sulphate of soda is NaO,SO_3; carbonate of lime, CaO,CO_2; nitrate of potass, KO,NO_5.

157. The reason why this apparently capricious inversion of the symbols is followed is, that the symbols represent Latin, not English words; and in arranging them into formulæ, a law of Latin grammatical construction is followed. Thus the symbol for oxide of iron, FeO, when written in full, becomes the words FERRI, *of iron*, OXIDUM, *oxide*, according to a familiar rule of Latin grammar, which teaches that when one noun governs another in the genitive, the genitive goes first. Fe, when taken alone, represents the nominative, FERRUM; but when associated with another symbol, it stands for FERRI, the genitive, which accordingly goes first.

158. Those who are unacquainted with Latin may accept as a safe and sufficient rule that, in arranging the symbols into formulæ, the former should be placed in exactly the reverse order of that which they would occupy if they were written as English words. Thus, in putting down the formula of the oxide, sulphuret, chloride, bromide, iodide, or fluoride of a metal, the symbol of the metal goes first, and that of the non-metallic body follows it.

159. A similar remark applies to the formulæ of salts. Thus FeO,SO_3, the formula for sulphate of (the oxide of) iron, stands for three Latin words, *ferri oxidi sulphas*—that is, *of iron the oxide, the sulphate;* so that again the English order is reversed.

160. In the case of the more complex combinations derived from plants and animals, the application of those laws is not so easy nor so evident, but it is followed as far as possible. Thus gum, starch, sugar, and similar compounds, which consist of oxygen, hydrogen, and carbon, have the carbon ex-

pressed first, and the oxygen last. Vinegar, or acetic acid, for example, is $C_4H_3O_3$.

161. The rules laid down are, with slight exceptions, followed by the chemists of all countries, and the student should on no account wantonly or capriciously depart from them. It is not desirable to burden the memory by endeavouring to acquire at once a familiarity with the symbols and atomic weights of all the elementary bodies. It is quite enough if he learn the symbols and equivalents of each element and its compounds whilst he is studying it.

162. In class-rooms it will be found of great advantage to have a large table of the elements, their symbols, and atomic weights, displayed at every chemical lesson; and the various decompositions illustrated by symbols in succeeding portions of this volume should be gone over, step by step, on the black board by the teacher, and the pupil made to exercise himself on the same subject with his slate.

⁂ The importance of familiarising even very youthful students of chemistry with chemical notation cannot be overrated. It should be taught, however, to beginners gradually, and rather indirectly than formally. By the constant employment of the symbols and formulæ in explaining chemical changes to a class, the pupils rapidly become familiar with their use, and soon prefer to have changes explained by means of them. A single lesson will never demand reference to a great number of formulæ; and if the signification of each is explained when it is shown, the discussion of the first four elements will supply a sufficient number of examples to enable this chapter to be completely understood.

It should never be forgotten that chemical symbols are not like ciphers, mere substitutes for words, but are further supplements to them. Thus the symbols HO,NO_5, and NH_3, are not simple synonymes of *water*, *nitric acid*, *and ammonia*, but tell us the nature and relative amount of the elements of these bodies, which the words do not. The study of organic chemistry cannot be prosecuted without extensive reference to symbols; for the names, such as Chloroform, Creozote, Methyle, Napthaline, Glycocoll, &c. &c. tell little or nothing of their nature. The chemist, in truth, should be as familiar with his symbols as the arithmetician with his ciphers.

LAW OF GASEOUS VOLUMES.

163. Several of the elementary bodies, and many of their most important compounds, are, at ordinary temperatures, gases, or may be converted into them by the application of heat.

164. Bodies which assume the condition of elastic fluids at such a temperature as 60° of Fahrenheit's thermometer, which is described in the section on heat, are generally distinguished as *gases*, whilst those which require a higher temperature to convert them into aërial fluids are called *vapours*. Thus oxygen is called a gas, steam a vapour.

165. There is no distinction, however, of kind, but only one of degree, between a gas and a vapour. Each requires the addition of a certain amount of heat to it to make it an elastic fluid; and both, when deprived of that heat, become liquids or solids. A gas and a vapour, accordingly, differ from each other only in so far as the one requires a different amount of heat from the other to maintain it as an elastic fluid; otherwise they are identical. A vapour may be called an easily-condensed or temporary gas; a gas, a highly-incondensible or permanent vapour. Gases and vapours shade away insensibly into each other, so that no sharp line of demarcation can be drawn between them. This is discussed more fully in a succeeding section on latent heat.

166. The relation between atomic weight and volume we are about to explain applies equally to gases and to vapours. In stating it, however, we shall dispense frequently with the word vapour, and call all elastic fluids gases, whether they are easy or difficult of condensation.

167. When the gases are taken in equivalent quantities by weight, and examined as to the relative volumes they furnish, we do not find that each occupies a different space, as each has a different atomic weight; neither do they all occupy the same space. A very simple relation, however, subsists between the volumes they do occupy.

168. It is of practical importance to be acquainted with this, for it is a much more easy thing to measure out a certain

volume of a gas, than it is to weigh accurately a required amount of it; and it is thus highly desirable to know what relation subsists between atomic weight and gaseous volume, so that we may be able to replace the difficult process of weighing by the more easy and accurate one of measuring.

169. Gases are measured in cylindrical glass vessels or jars, open at one end, and shut at the other, the sides of the jar being marked with lines, denoting how many cubic inches of gas the vessel can contain. When such a jar is used as a measure, it is filled with water or quicksilver, and placed standing with its mouth down in a basin or trough, containing the same liquid. The gas to be measured is then passed up through the water or quicksilver, which it displaces more or less, occupying its room, and filling, according to the amount of liquid displaced, a larger or smaller portion of the vessel. The number of cubic inches to which it amounts is then ascertained, by noting the figure marked upon the graduated jar, at the line where the gas and liquid meet.

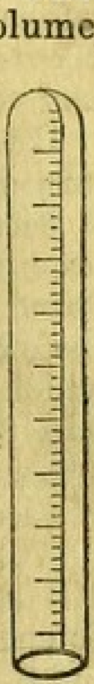


Fig. 1.

170. As gases expand or occupy a greater space when heated, and contract or fill a smaller one when cooled, it is necessary, when making comparative experiments, to examine each at the same temperature. A convenient one for this purpose is 60° Fahrenheit.

171. Gases alter their volume also when the pressure of the air changes, contracting into a smaller bulk when the pressure is great, and occupying a greater one when it diminishes. The barometer is a measure of this pressure, and its alterations enable us to follow those which occur in the atmosphere.

172. The pressure of the air is greatest when it can support a column of mercury in the barometer 30 inches long, and diminutions in its amount are denoted by the column shortening to 29 or fewer inches. Comparative experiments as to the volume of gases require, accordingly, to be made with the barometer standing at the same height at each trial. The height generally taken is between 29 and 30 inches, but nearer the latter. We shall call it in round numbers 30.

173. At this settled temperature, then, of 60° Fahrenheit, and with the barometer standing at 30 inches, the volumes which equivalent weights of the gases occupy are ascertained. The relation which has been discovered will perhaps be best understood if explained a little in detail, as follows:—

174. Equivalents of each of the elements are supposed to be taken in grains; and, in the first place, 8 grains of oxygen

are accurately weighed and introduced into the graduated jar, so as to ascertain the space they occupy at the settled temperature and pressure. A glass stoppered bottle is then provided, exactly sufficient to contain the number of cubic inches to which the 8 grains of oxygen amount.

175. An equivalent of arsenic, or 75 grains, is then examined as to the space it occupies as a gas, by heating it till it becomes a vapour, and receiving it in the stoppered bottle previously emptied of the 8 grains of oxygen, when it is found to fill exactly, without excess or defect, the vessel that the oxygen filled. In other words, a bottle, jar, or other vessel which, at a certain temperature and pressure, will exactly contain 8 grains of oxygen, will, at the same temperature and pressure, contain neither more nor less than exactly 75 grains of gaseous arsenic.

176. In like manner an equivalent or 32 grains of phosphorus is found in the gaseous state to fill, without superfluity or deficiency, the same vessel which contained 75 grains of arsenic and 8 of oxygen. So also 100 parts by weight of oxygen, 937½ of arsenic, and 400 of phosphorus, or any other quantities taken in the relative proportions indicated by their atomic weights, would, as gases, exactly fill vessels of the same capacity.

177. Chemical equivalents, then, of the three bodies mentioned, occupy, as gases, exactly the same space, or give equal volumes; so that, in experimenting, it will come to the same thing whether we weigh out equivalents of oxygen, arsenic, and phosphorus respectively, or measure out equal volumes of them as gases.

178. To point out the fact, that equal volumes of these bodies correspond to equivalents of them, we mark against each an outline square of the same size; thus—

Oxygen, □ Arsenic, □ Phosphorus, □

179. All gases, however, do not yield volumes identical with those afforded by the substances mentioned above. If an equivalent of hydrogen, or one grain, be introduced into the stoppered bottle which contained equivalents of the three bodies referred to, the vessel will be found to contain no more than exactly half of it, so that we should require two such bottles as sufficed for the equivalent of oxygen to contain the equivalent of hydrogen. In other words, 1 grain of hydrogen occupies, as gas, twice the space that 8 of oxygen, 75 of arsenic, and 32 of phosphorus do.

180. A pretty proof of this, so far as oxygen and hydrogen are concerned, is furnished by the galvanic decomposition of water, so conducted as to receive the hydrogen in one vessel

and the oxygen in another of the same capacity. The hydrogen in the one tube will be seen to occupy twice the volume of the oxygen in the other.

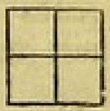
181. Fourteen grains of nitrogen, 35½ grains of chlorine, 126·36 grains of iodine, 78·26 grains of bromine, and 18·7 grains of fluorine—that is, equivalents in grains of those bodies—occupy the same space, as gases, as one grain of hydrogen, and twice the space of eight grains of oxygen.

182. If we wish to combine the bodies last mentioned in single equivalents with each other, we take them in equal volumes. Thus, to form hydrochloric acid, we take any volume of chlorine, and mingle it with the same volume of hydrogen. The result is the same as if we had weighed 35½ parts of the one, for every single part of the other.

183. If, on the other hand, we wish to combine bodies of the second or hydrogen class in single equivalents, with those of the first or oxygen division, we take two measures of the former to one measure or volume of the latter. Thus, to form water, we fill a vessel one-third full of oxygen and two-thirds of hydrogen, and determine combination by applying a lighted match to the mixture.

184. Hydrogen, and the bodies identical with it in the volumes which their equivalents yield, are denoted by squares of the same size, each exactly *double* the square placed against oxygen and its class. Thus—

Hydrogen,  Nitrogen,  Chlorine, 



185. No elementary substance yields a greater volume than hydrogen, but many compound gases give one twice as great as that of this gas, and four times that of oxygen. They have placed after them a square the quadruple of that placed against the oxygen class.

186. Those are the volumes most frequently occurring—that is to say, equivalents of the great majority of gases, simple and compound, give volumes identical with that of the equivalent of oxygen, or that of hydrogen, or four times that of oxygen.

187. One important body presents an exception to the preceding remark—an equivalent (16 parts by weight) of sulphur, when in the gaseous state, at the temperature of 900°, occupies a space three times *less* than that filled by the equivalent of oxygen; but at 1800° it occupies the *same* space as the equivalent of oxygen.

188. When gases combine with each other, they frequently unite without any change of volume occurring. In this case their combining measure is the sum of the combining mea-

sures of their components. Thus equivalents of hydrochloric, hydrobromic, hydriodic, and hydrofluoric acids, occupy a space, as gases, four times greater than the equivalent of oxygen, because each of them contains an equivalent of hydrogen along with one of chlorine, bromine, iodine, or fluorine, all of which have a combining measure twice that of oxygen; so that the acids mentioned, each of which contains two of the gases in question, gives the double oxygen measure twice over, or altogether quadruples it.

189. In the great majority of cases, however, condensation occurs, or the volume is lessened when gases combine.

190. Two volumes of hydrogen, for example, and one volume of oxygen, form only two volumes of steam; or water as a gas occupies the same space as the hydrogen in it would fill if it were free. One volume of nitrogen and three of hydrogen form two volumes of gaseous ammonia, or contraction occurs to the extent of two volumes; in other words, the compound gas occupies only half the space its elements occupied before combination.

191. The contractions which do occur are generally simple, as in the examples given. Diminutions in volume to the extent of such fractions of its original bulk as $\frac{3}{5}$, $\frac{5}{8}$, &c. never occur, so that the combining measures of the compound gases, in the great majority of cases, either agree with those of some of the elementary bodies, or are multiples of them.

192. A few of the gases occupy the same volume as oxygen; a greater number, a space twice as great, or equal to that of hydrogen; and a still larger number, a space four times as great as that of oxygen. A volume three times, and one six times, that of oxygen, occurs but rarely, if at all, and smaller combining measures than that of oxygen are still rarer, though, as we have seen in the case of sulphur, they occasionally present themselves.

193. The volume which the equivalent of a gas occupies is generally called the combining measure of the gas. It may also be named its atomic or equivalent volume.

194. These terms all express the fact, that the combining proportion, equivalent, or atom of every gas, occupies, as an elastic fluid, a certain constant volume, so that gases measured out according to those volumes will be found to present themselves in exactly the same relative proportions by weight, as if they had been weighed out according to their chemical equivalents. A given volume of hydrogen always weighs exactly eight times less than an equal volume of oxygen: 126.36 grains of iodine occupy no greater space than one grain of hydrogen. The measurement of gases, accordingly, may

often be advantageously substituted for the weighing of them.

195. In order to indicate the difference between the combining measures of the several gases, that of oxygen is called one volume, or 1, arsenic is 1, phosphorus 1, hydrogen, nitrogen, chlorine, &c. are 2, hydrochloric acid is 4, sulphur at 900° ⅓. We subjoin a short table of some of the more important gases. They will be denoted throughout the book by the squares already described:—

Gas.	Symbol.	Atomic Weight.	Combining Measure.
Oxygen,	O	8	□ 1
Phosphorus,	P	32	□ 1
Hydrogen,	H	1	□□ 2
Nitrogen,	N	14	□□ 2
Water,	HO	9	□□ 2
Carbonic Acid,	CO_2	22	□□ 2
Nitric Oxide,	NO_2	30	⊞ 4
Ammonia,	NH_3	17	⊞ 4
Hydrochloric Acid,	HCl	36·5	⊞ 4
Sulphur,	S	16	⅓
Pentachloride of Phosphorus,	PCl_5	209·5	8

196. The two combining measures placed last occur so very rarely, that symbolical squares are not employed to denote them.

197. The chief point to which the student should attend is, that the numbers expressing combining measures count from oxygen as unity, not from hydrogen, as is the case with combining weights. The atomic volume, accordingly, of every gas is, if not identical with that of oxygen, a multiple or submultiple of its volume. In the majority of cases, it is a multiple by 2 or by 4.

HEAT AND ITS CHEMICAL RELATIONS.

198. The full discussion of heat would require a volume at least as large as the present. All that we can do in this treatise is very briefly to state its most general effects, in so far as these concern chemistry.

199. Heat very readily passes from one body to another, so that we assume that it is not, like colour, a mere property of matter, but that it has a substantial existence, apart from the body whose properties it alters, by being added to, or taken from it.

200. The term caloric was introduced to denote heat as a substance, in contradistinction to heat as used to imply warmth. But the words heat and caloric are now used as exactly synonymous, and if we employ the latter occasionally, it will only be to prevent the too frequent repetition of the more familiar, but quite as expressive term.

EXPANSION.

201. The greater number of bodies, whether solid, liquid, or gaseous, which are not decomposed by heat, are expanded by it: in other words, occupy a greater space when hot than when cold.

202. Solids expand least, gases most, and liquids (speaking generally) are intermediate between them in expansibility.

203. To illustrate the expansion of solids, a rod of iron may be taken, and its length and diameter exactly measured at the temperature of the air. If it be now raised to a red heat, it will be found to have suffered an increase in length, and to be too wide to fit an aperture through which it passed before. When allowed to cool to its original temperature, it will exactly recover its previous dimensions.

204. The expansion of liquids is familiarly illustrated by heating a glass flask filled with any liquid. The liquid rapidly expands, and manifests its expansion by running over.

205. Or a long glass tube, with a hollow ball at one end of it, may have the ball filled with spirits of wine, or mercury,

and then be plunged into hot water. The liquid will indicate its expansion by rapidly rising in the tube or stem of the ball. If it be now removed from the hot water, the enclosed liquid, as it cools, will descend till it reaches the point which it occupied at first.

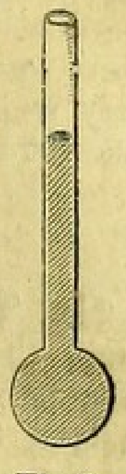


Fig. 2.

206. The expansion of gases is most simply illustrated by introducing into a bladder, or other air-tight bag, a quantity of air, less than sufficient to fill it completely. If the bladder be now tied tightly round the mouth, and warmed at a fire, it will become fully distended by the expansion of the enclosed air. When withdrawn from the source of heat, the air will contract, and the bladder collapse again.

207. The expansion of gases may also be illustrated by inverting a flask with a long neck in water —the water being left standing to some height in the neck of the vessel. If a hot coal or heated plate of metal be now approached to the flask, the liquid will rapidly descend, forced before it by the expanding air. When the heat is withdrawn, the water rises to its previous height.

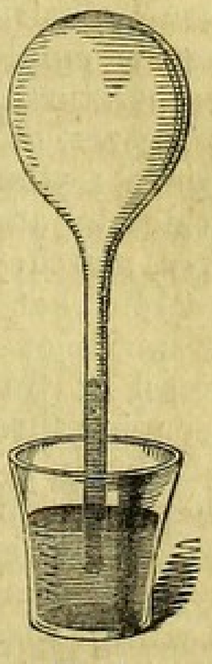


Fig. 3.

208. Nearly every solid and liquid has an expansibility peculiar to itself. Among solids, the metals are the most expansible bodies. Zinc expands most, platinum probably least, among bodies of the metallic class. Glass, brick, porcelain, marble, and stone, have small expansibilities.

209. Among liquids, we find those which are most volatile more expansible than others. Thus, spirit of wine is six times more expansible by heat than mercury. The liquefied gases, the most volatile of known bodies, are more expansible in some cases than even air.

210. Gases, unlike solids and liquids, have not specific expansibilities; but each undergoes the same amount of expansion for the addition of the same amount of heat; or at all events the departure from exact identity in expansibility is so slight, that it may be disregarded in all but very delicate researches. Thus, if we were to take common air, hydrogen, and carbonic acid, and heat them equally, we should find that they all suffered the same amount of expansion; whereas if we took any three solids or liquids, and heated them equally, we should find that each expanded to a different extent.

211. Solids and liquids expand more at high than at low

temperatures; that is to say, an amount of heat which would expand them to a certain extent, if they, at the period of its application, were at the temperature of the air, would expand them to a greater extent if, at the moment of its reception, they were at a higher temperature, such as a red heat. This has not been observed, however, to be the case with gases.

THE THERMOMETER.

212. The thermometer is an instrument in which *temperature*—that is, the *intensity of heat*—is measured by the amount of expansion it produces on solids, liquids, or gases. Solids expand too little, gases too much, to be practically available for the construction of thermometers. The only one, accordingly, to which we shall refer is the liquid thermometer universally in use.

213. The liquids employed to measure heat are two; namely, spirits of wine or alcohol, and quicksilver. The former is employed for instruments intended to measure low temperatures, for which purpose quicksilver is inapplicable, as it freezes, or becomes solid, if too much heat be withdrawn from it; whereas the strongest spirits of wine cannot be congealed by any known cold. For ordinary temperatures, however, mercury is preferable to alcohol.

214. That the expansions and contractions of the mercury or spirits of wine may be visible, the liquid is enclosed in a vessel of transparent glass. This consists of a glass tube, occupied throughout its entire length by a very narrow canal, which ends at the one extremity in a hollow ball or pear-shaped chamber. At the end furthest from this chamber or bulb, the tube is left open till the liquid has been introduced by a peculiar process, which will be found described in works treating specially of heat. The opening is then closed by heating the glass till it melts and runs together, forming as it cools a solid plug, shutting up the previously open mouth of the tube. The quantity of liquid introduced is generally little more than sufficient to fill the bulb at the lowest temperature which the thermometer is intended to indicate.

215. The instrument, as thus constructed, would only tell that one body was hotter or colder than another, without showing by how much the one exceeded or fell short of the other in temperature. Before it can record this, it requires to be what is called *graduated;* in other words, to have points marked on it which correspond to certain invariable temperatures or intensities of heat.

216. If ice or snow be placed in water, and allowed to melt

there, whilst a thermometer is plunged into the water, the mercury or spirit of wine within the instrument will be found to stand immoveably at a certain height. This phenomenon is more briefly described by saying that *the thermometer* stands at a certain height; the reference in this and similar expressions being to the enclosed liquid and its risings and fallings, which measure the variations in the intensity of the heat. If we leave the thermometer in the melting ice, it will stand steadily at the same point as long as any of the ice or snow is unmelted. However often we repeat this experiment, the thermometer will always stand at the same height, because melting ice always exhibits the same intensity of heat, or, as it is called, the same temperature.

217. In graduating a thermometer, accordingly, it is first plunged into melting ice, and left there till the enclosed liquid stands still. A mark is then placed on the glass, or on a piece of ivory, wood, or metal, attached to the tube, and called its scale. This mark or horizontal line is drawn exactly on a level with the surface of the enclosed mercury or spirits of wine whilst the instrument is still in the melting ice; and this mark is called the *freezing-point* of water, for water freezing, and ice melting, produce the same temperature.

218. The thermometer is now transferred to a vessel containing water kept at its boiling-point, the experiment being made when the barometer is at 30 inches. The instrument rapidly rises as it acquires heat from the water, but finally ceases to ascend, and remains steadily at the same point, however long it is kept in the boiling water. A second mark is placed at the surface of the liquid within the thermometer tube, and this is called the *boiling-point;* a phrase, however, rarely used.

219. In the thermometer used in this country, the space upon the stem or scale of the instrument between the freezing and boiling-points is divided into a hundred and eighty equal parts, which are called degrees, and indicated by a small circle, thus °. Divisions or degrees of the same value are then extended above and below the freezing and boiling-points to a distance from each, varying according as the instrument contains mercury or spirits of wine, and is to be used for estimating high or low temperatures. A mercurial thermometer cannot be graduated lower than 40 degrees below the freezing-point, at which temperature mercury congeals. It may be graduated upwards to 570 degrees above the freezing-point, but not higher.

220. There is no limit to the downward graduation of a spirit-thermometer, as the greatest attainable cold does not

freeze its liquid. It boils, however, at 141 degrees above the freezing-point, so that its upward graduation is much more limited than that of the mercurial thermometer.

221. In the thermometer used in this country we begin counting at 32 degrees below the freezing-point. A cipher is placed there, and it is called the zero, or nothing-point of the thermometer. The freezing-point of water thus comes to be marked by the number 32°, and the boiling-point, which is 180° higher, by 212°. Thus we say that a mixture of salt and snow reduces the thermometer to 0°, that the freezing-point of water is 32°, and that its boiling-point is 212°. In the thermometer chiefly used on the continent the space between the freezing and boiling-points of water is divided into 100 equal parts, and the graduation begins at the freezing-point, which is marked 0°, or zero. According to this thermometer, which is called the centigrade, water freezes at 0°, and boils at 100°.

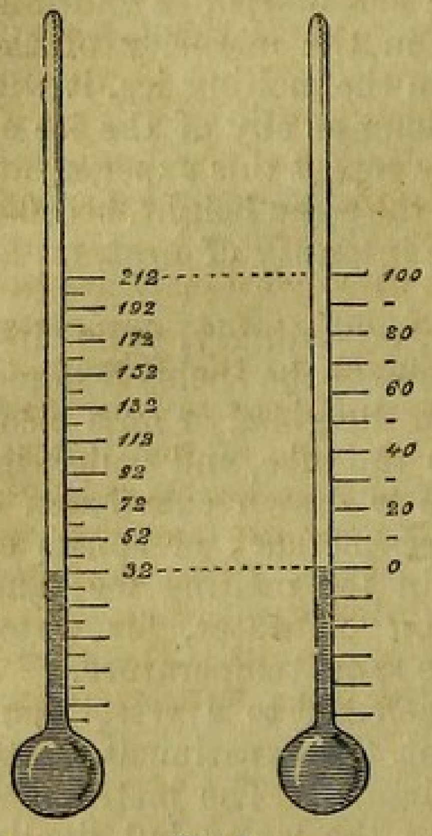


Fig. 4.

222. The centigrade thermometer is now much employed in scientific researches in this country. To prevent any confusion arising from its being mistaken for the thermometer first described, which is called, from its original maker (who was a Dutchman), Fahrenheit's, or the Fahrenheit thermometer, the letter F is placed after temperatures indicated by his thermometer, and the letter C after those denoted by the centigrade. Thus, water freezes at 32° F., or 0° C.; water boils at 212° F., or 100° C.

223. From its zero-point each thermometer counts downwards as well as upwards; and to distinguish the degrees below zero from those above it, the former are distinguished by prefixing to them the minus sign —. Thus mercury is said to freeze at — 40° F.; that is, at 40° below Fahrenheit's zero.

224. It is of the utmost importance for the student to understand what information concerning heat the thermometer supplies. In a word, then, it tells us nothing as to the *quantity* of heat in a body; in proof of which we have only

to try the simple experiment of plunging the same thermometer into a large basin of water, and then into any smaller quantity, such as a wine-glassful, taken out of the basin. The thermometer will stand at the same height in both, although it is manifest that there must be much more heat in the basinful than in the wine-glassful of water.

225. What the thermometer reveals to us is the *intensity* of the heat which affects it, as measured by its power to cause expansion. This intensity we distinguish by calling it *temperature*. Thus, if we say that a body has the temperature of 60°, we signify that it expands the mercury or spirit in the thermometer to the 60th degree.

226. When directions are given, as they constantly are, to raise the temperature of a body (from 60°, for example) to 300°, they signify that heat is to be added to the substance till it is present in a state of intensity sufficient to raise the thermometer to the 300th degree. It is often of the utmost importance in the drying, for example, of such bodies as gunpowder, or gun-cotton, to raise them to a certain temperature without exceeding this by a single degree. The thermometer enables this to be done with the utmost precision.

227. To sum up what we have said in a word. The thermometer is a measurer of the intensity of heat, but not of its quantity.

SPECIFIC HEAT.

228. Different substances require different quantities of heat to raise them to the same temperature. This is expressed by saying that each possesses a *specific capacity* for heat, or, more shortly, a *specific heat*.

229. The fact can easily be proved in three different ways. 1*st*, We may expose a variety of substances to the same source of heat, when we shall find that some of them rise more rapidly in temperature than others; and if, after they have all risen to the same temperature, they are removed to a cold apartment, those which grew hot fastest will be found also to cool most quickly, because a smaller amount of heat has sufficed to raise their temperature than that of the others, and they have the less to part with when they cool. Thus, if two vessels, containing, the one mercury, the other water, in equal measures, and at the same temperature, be immersed in a vessel containing water in a state of ebullition, the mercury will be found to rise to the temperature of the boiling water in half the time that the water does. If both, after having reached the same temperature, be set aside to cool, the mercury will fall in temperature twice as fast as the water does.

230. *2d*, If we cause equal volumes or weights of bodies, which have all been raised to the same temperature, to melt ice, we shall find that a much greater weight of it will be melted by one body than by another. Thus mercury at 212° will melt much less ice than an equal quantity of water at the same temperature will, for the mercury has much less heat to give out, so as to produce liquefaction, than the water has.

231. *3d*, If we mingle two portions of liquid, at different temperatures, the temperature of the resulting mixture will vary according to the liquids taken. If, for example, we mingle equal volumes of water, the one at the temperature of 100°, and the other at 150°, the resulting mixture will have the temperature 125°, the arithmetical mean of 100 and 150; or the hot water will lose 25 degrees of heat, and the cold will gain exactly as many.

232. In like manner, if we mix mercury with mercury, or oil with oil, the temperature of the mixture will be the mean of the temperatures possessed by the different portions of the liquid which were mingled. If, however, one liquid at a certain temperature be added to a different liquid at a different temperature, we shall not get the arithmetical mean, but something above or below it. Thus, if we add a measure of quicksilver at 150° to a measure of water at 100°, the temperature of the mixture is 120° only, instead of the mean 125°. The quicksilver has become less warm by 30°, whilst the water has grown warmer by 20° only; yet the heat which the water gained is the very same quantity which the quicksilver lost.

233. If, on the other hand, we take water at 150°, and an equal measure of quicksilver at 100°, the resulting temperature is 130°, or the water becomes less warm by 20°, whilst the quicksilver grows hotter by 30°. It thus appears that the same amount of heat exhibits a higher intensity when contained in quicksilver than when contained in water.

234. In the preceding illustrations we have referred only to liquids, but exactly similar experiments can be made with solids, and to a certain extent with gases. The last, however, present many difficulties in experimenting upon them, so that there is great uncertainty concerning their specific heats, to which, accordingly, we shall not further refer.

235. Solids are easily experimented on, and most simply, by raising them to a certain temperature, and plunging them into water or another liquid at a lower temperature. This is equivalent to the mixture of one liquid with another.

236. Specific heats are generally stated with reference to

equal weights, rather than to equal measures, of bodies. Thus a pound of water, in rising to a given temperature, absorbs thirty times more heat than a pound of mercury in rising to the same temperature; so that the capacity of water for heat exceeds that of mercury by 30, and if we call the specific heat of mercury 1, that of water will be 30. In tables of specific heat, however, the scale is commenced with water, which is called 1000; and as it excels all other bodies in capacity for heat, their specific heats are invariably denoted by some lower number. We subjoin a few examples :—

Substances.	Specific Heat of Equal Weights.
Water,	1000
Ice,	513
Wood Charcoal,	241
Sulphur,	203
Glass,	198
Diamond,	147
Iron,	113·79
Copper,	95·15
Silver,	57·01
Iodine,	54·12
Gold,	32·44

237. The great specific heat of water has a most important relation to the welfare of the living creatures on the globe. The sea, which spreads over so large a portion of the earth, cannot in the hot seasons of the year become rapidly raised in temperature, which would prove injurious alike to its inhabitants and to the dwellers on the dry land. Rapid elevation of temperature cannot occur, in consequence of the great amount of heat which must be absorbed by water before it can manifest even a moderate increase in warmth.

238. In the cold seasons of the year, on the other hand, the sea and other great beds of water cool slowly, and, moreover, in cooling, evolve much heat, which equalises the temperature of the air as well as that of the land. An ocean of mercury, even if otherwise habitable by the creatures with which we are familiar, would suffer so great an alteration in temperature during the twenty-four hours of a tropical day and night, as to prove fatal to multitudes, if not to all of them.

239. The small specific heat of mercury is nevertheless most advantageous to the chemist. It renders that liquid the fittest of all for filling thermometers, as it quickly heats, and quickly cools, and acquires, in consequence, with great rapidity, the temperature of any body in which the thermometer is placed.

240. No relation can be perceived between the numbers expressing the specific heats of different substances, as given

in the preceding table. If, however, instead of taking *equal* weights of bodies, as is done in that list, we take *equivalent* or atomic weights of them, then a very simple and beautiful relation is found to subsist between the specific heats of different bodies.

241. Thus, instead of trying how much the temperature of water at 60° will be raised by plunging into it a pound of sulphur, a pound of iron, and a pound of phosphorus, each at 212°, let us take 16 ounces of sulphur, 28 ounces of iron, and 32 ounces of phosphorus, or any other quantities, so that they be in the ratio of 16, 28, and 32—the atomic weights of sulphur, iron, and phosphorus. Let these equivalent quantities be then raised to the same temperature, 212°, and afterwards immersed in water at 60°, so as to observe how much each raises the temperature of the liquid. On making such an experiment, we shall find that the 16 parts of sulphur and the 28 of iron will raise the temperature of the water to exactly the same degree, whilst the 32 parts of phosphorus will raise it four times higher. It thus appears that the specific heats of sulphur and iron, when taken in atomic quantities, are identical, whilst that of phosphorus is exactly four times greater.

242. The following table contains the specific heats of several of the elementary bodies, as it appears when they are taken in equivalent quantities, the specific heat of lead being called 1 :—

Specific Heat of Atom or Equivalent.

Lead, Tin, Zinc, Copper, Nickel, Cobalt, Iron, Platinum, Sulphur, Mercury, Tellurium, Gold,	1
Arsenic and Silver,	2
Phosphorus,	4
Iodine,	4½
Bismuth,	⅔
Carbon,	½

243. From the preceding table, it will appear that the specific heats of the first twelve substances, which are all metals, with the exception of sulphur, are identical. These twelve bodies, therefore, taken in the proportion of their atomic weights, will be raised to the same temperature by the addition of the same quantity of heat. Arsenic and silver are identical in specific heat, but it is double that of lead and its class; whilst the specific heat of phosphorus is 4 times, and iodine 4½ times, greater than that of the twelve bodies first enumerated; bismuth is ⅔, and carbon ½ of lead and its class.

244. Although all the elementary bodies do not exhibit, when taken in equivalents, the same capacity for heat, yet a

very simple relation evidently subsists between their capacities; and the exact identity in specific heat which occurs in the case of so many as twelve, shows that some very close connection must subsist between the relation of bodies to heat and to chemical affinity; for the proportions by weight in which they are influenced by the latter, are exactly those in which they are equally modified by the former.

245. Compound bodies have also been found to exhibit an identity or simplicity of relation, so far as specific heat is concerned; but this department of the subject cannot be enlarged on here.

PROPAGATION OF HEAT.

246. Heat is transferred from one portion of matter to another in three different ways, which are termed conduction, convection, and radiation.

247. CONDUCTION implies the passage of heat from one particle of matter to another in physical contact with it.

248. CONVECTION is the conveying or carrying of heat by particles of matter raised in temperature, and set in motion.

249. RADIATION is the emission of heat by a body such, for example, as a mass of red-hot iron at rest, and not in physical contact with the substances to which it communicates heat. The name has reference to the supposition that the heat passes in radii or rays like those of sunlight, which can find their way even through a vacuum, and do not appear to require the assistance of ponderable matter to determine their transference.

Conduction.

250. Conduction is best seen in solids, and particularly in metals, which are the best conductors. A rod of iron placed with one extremity in the fire speedily becomes hot at the opposite extremity, owing to the conduction of heat from particle to particle along the rod.

251. Dense bodies are generally the best conductors; light and porous ones the worst. Feathers, down, fur, flannel, and most of the fabrics used for winter dresses, owe their so-called warmth to their low conducting power for heat. Their action is altogether negative, being limited to the prevention of the rapid escape of heat generated by the living beings whose bodies they cover.

252. Liquids and gases are very bad conductors of heat, although, from the rapidity with which they rise in tempera-

ture, when heat is applied to them, they appear to be among the best conductors.

Convection.

253. Liquids and gases rise in temperature chiefly in consequence of the convection, not the conduction of heat by their particles. If a long glass tube shut at its lower end, and filled nearly to the top with water or any other liquid, be placed obliquely, and a spirit-lamp applied so as to heat the upper portion of the tube and of the liquid, the latter will rise in temperature at the point heated, and above that, till ebullition occurs. Below the point to which the lamp was applied, the temperature of the liquid will be very slightly elevated, and hours will elapse before the heat will have sensibly affected, even to a very slight degree, the column of liquid below it. Now, the conduction of heat is not affected by the position of the body along which it is passing. Heat descends as readily as it ascends, and moves as swiftly along a body placed vertically as horizontally. Had the heat then been conducted, it would have travelled down the column of liquid as readily as up through it.

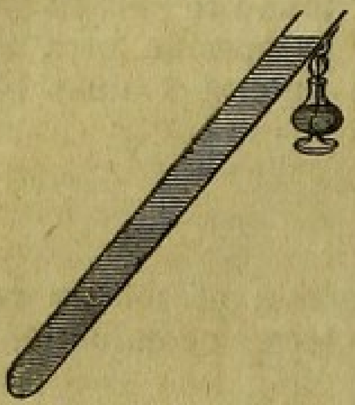


Fig. 5.

254. On the other hand, no fact is more familiar than that large quantities of liquid may be made to boil by even a small lamp, provided only the heat be applied at the bottom. Thus, if we transfer the lamp from near the top of the long tube to the shut lower end of it, the whole liquid in the tube will be made to boil in a few minutes.

255. The remarkable difference observed in the latter case as to the rapidity of transference of heat is easily explained. If a pretty large glass flask be taken (fig. 6), and a few fragments of solid blue *litmus*[*] dropped into it, after it has been filled nearly full of water, on applying heat by a small lamp to the bottom of the vessel, a central current of water, rendered distinctly visible by the blue colour it has acquired from the litmus, is seen to ascend till it reaches the surface of the liquid, when it bends over in every direction like the foliage of a palm-tree, and forms a number of descending currents. These keeping pretty near to the walls of the vessel, travel down-

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[*] A colouring matter prepared from certain lichens, and readily procured from any druggist, or dealer in dye-stuffs.

wards till they reach the heated lower portion of it, when they again ascend as a hot central current. In this way the whole liquid is thrown into circulation, for every portion of it in turn becomes heated, ascends, and losing its heat in and after its ascent, chiefly by parting with it to the walls of the vessel, the air, and surrounding objects, descends as a cold current till it reaches the bottom, when it becomes heated again.

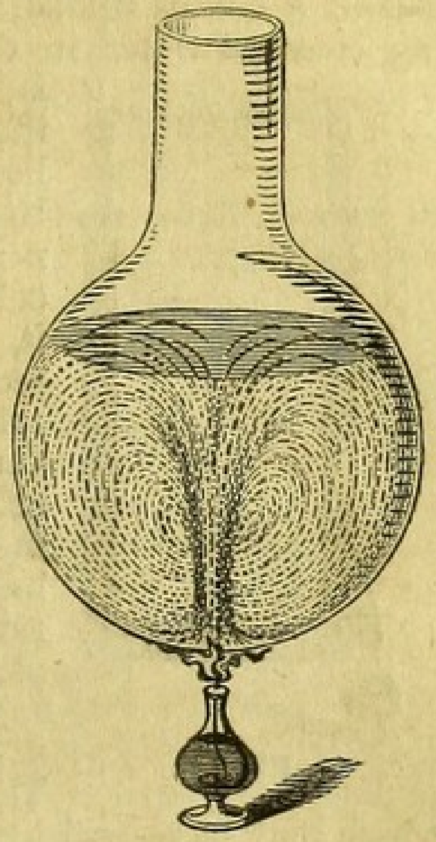
Fig. 6.

256. The currents which are thus occasioned by heating a liquid are determined by the fact, that when any portion of liquid is warmed, it expands, and has, in consequence, its specific gravity lessened. In other words, a portion of warm liquid is less dense than an equal volume of cold liquid. The result of this is, that the heated portions of the liquid being specifically lighter than the colder ones, ascend through the latter, till they reach a part or region of the liquid of the same density as themselves, and thus there is a constant ascent of lighter warm liquid, and descent of colder heavy liquid, so long as heat is applied.

257. A liquid is thus raised in temperature mainly by the operation of two causes. The one is the movement of particles through the liquid carrying heat with them, and giving this up in part to the colder molecules which they meet. This is what is styled the convection—that is, the conveyance or carrying of heat.

258. The other chief cause of the rapid rise of a liquid to its boiling-point, when heated from below, is the fact, that the circulation which convection determines, brings every particle of liquid in its turn to the source of heat, which directly effects the elevation of its temperature. Thus, whilst a solid is heated by the particles remaining at rest, and the heat travelling from one to another, a liquid is warmed by the heat confining itself almost entirely to one spot, whilst the particles of the liquid travel towards that, and receive and carry away with them certain quantities of heat. It must not be forgotten, however, that a certain amount of

heat is propagated in all directions through liquids by conduction.

259. A double siphon, as represented in the figure, containing coloured water in the lower part, with the rest of the arrangement filled with colourless liquid, illustrates the circulation of heated liquids very beautifully. A lamp is to be applied at either of the lower corners, as shown in the figure, when the coloured liquid will be seen to rise from it, and ascend the heated limb of the rectangular tube. Simultaneously the colourless water will descend in the opposite limb, and the whole contents of the arrangement will be thrown into motion, and continue to circulate so long as the heat is applied. An apparatus upon this principle is now employed to heat apartments.

Fig. 7.

260. Gases are raised in temperature in exactly the same way that liquids are. They conduct heat extremely slowly, which may be proved by enclosing any one of the gases in a glass jar, containing a delicate thermometer with its bulb placed nearly on a line with the mouth of the jar. If the vessel be now shut by an air-tight metallic cover, and sulphuric ether or any other combustible be burned upon the lid so as to raise its temperature, it will be found that this may be done for a long period without the thermometer rising, although it is placed only a little below the heated metal. After a time, however, the metal begins to radiate heat from its lower surface, and this raises the thermometer.

261. If heat, on the other hand, be applied from below to a gas contained in a vessel, the former becomes, like a liquid in the same circumstances, warmer, and specifically lighter, and ascending and descending currents rapidly effect the elevation in temperature of the whole mass of gas. Illustrations of this are familiar to every one. The column of smoke which rises from a fire is merely a current of heated air rendered visible by the soot which it carries with it. Its place is supplied by descending currents of heavier cold air, which in their turn are heated, and become light ascending ones. The roaring noise which is heard at the mouth of a furnace-door or stove is occasioned by the streams of cold air which rush in to supply the place of the column of heated gases constantly rising through the chimney.

262. It is a popular belief that a large fire in the open air makes the wind rise; and so far it is quite true. The fire can only be maintained by constant lateral and descending streams of cold air to supply the place of the ascending column. When Moscow was burned, the wind rose so high, that men and horses could with difficulty keep their feet whilst passing through the burning streets.

263. On the small scale, the circulation which occurs in heated gases may be shown by burning any substance, such as brown paper or tow, which gives a smoky flame, under a glass bell-jar. A small portion of combustible only should be taken and placed on a pedestal within the glass shade or bell-jar. A much better method, however, is to kindle a piece of roll sulphur, placed in a small cup raised upon a stalk, and then to cover it with a glass shade or globe filled with oxygen. The sulphur, in burning, produces white fumes (sulphurous acid mingled with water vapour), which rise vertically from the combustible, and ascend till they strike the dome of the bell-jar or globe, when they bend over in every direction, and travel downwards to the bottom.

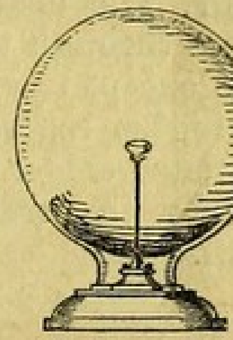
Fig. 8.

Radiation.

264. Radiation, though one of the most important modes in which heat travels from one body to another, does not very particularly concern the chemist. Its laws, moreover, are somewhat intricate, and have not yet been fully ascertained. The following points with regard to it are all we need mention:—Every hot body in the act of cooling, besides losing heat by the conductive and convective action of the solids and fluids in its neighbourhood, parts with much heat by radiation. Rays of heat pass away from the hot body till it has reached the temperature of the air or surrounding medium. In proof of this, it is only necessary to hang a hot body in the vacuum of the air-pump, when it rapidly cools, although it does not lose heat by either conduction or convection.

265. The rate of cooling of a hot solid body, so far as radiation is concerned, is remarkably influenced by the state of its surface, and in the case of liquids and gases, by the state of the surface of the vessels containing them. Thus hot water placed in a tin vessel coated externally with lampblack, cools twice as fast as it does in a bright tin vessel. Similarly, if two

metallic vessels be taken, the one left bright, and the other covered with linen, hot water will be found to cool much faster in the covered than in the naked vessel.

266. From these observations, it appears that a kettle covered with soot is much less suited for retaining water warm, than if it had a polished metallic surface. So, also, bright metallic covers are the best at table, and metallic teapots and coffeepots are preferable to those of porcelain and stoneware.

267. The heat of the sun, in radiating towards the earth, passes through the atmosphere without raising it in temperature, except to a very small extent. In consequence of this, the higher regions of the atmosphere, though nearer the sun, are much colder than the lower, which are raised in temperature by the transference to them of heat from the warm earth.

LATENT HEAT.

268. The word fluid, we have already stated, includes two species—*liquid* fluids, or liquids, and *elastic* fluids, or gases. Each of these conditions, liquidity and gasëity, is determined by a very remarkable addition of heat to the solid which it converts into a liquid, and to the liquid which it converts into a gas. The subject, therefore, divides itself into two sections—heat of liquidity, and heat of gasëity.

Heat of Liquidity.

269. When a solid body, such as ice, is watched whilst melting, a large quantity of heat is observed to enter it without raising its temperature in the slightest degree.

270. This heat which enters the body serves only to melt or liquefy it, without rendering the liquid the least hotter than the solid was which yielded it. The water which flows from the melting ice is no warmer than the ice.

271. The heat which thus renders a body liquid without warming it, is called *latent*, or *insensible* heat, because it does not affect our sensations, and does not raise the thermometer.

272. It is, as it were, so completely occupied in maintaining liquidity, that it is unable to exhibit its otherwise characteristic properties of exciting in our bodies the sensation of warmth, and of elevating the thermometer. In illustration of the truth of this, the following experiments may be tried:—

273. If a piece of ice be hung up in a warm room, it will be found to melt very slowly, which would not be the case if

the addition of a small quantity of heat to frozen water served to convert it into liquid water. And that the slowness of its melting is owing to the large quantity of heat which it is under the necessity of gathering from the bodies around it, and which is totally expended in liquefying it, may be proved by holding the hand, or placing a thermometer, below the piece of melting ice, when a stream of cold air will be found constantly descending from it.

274. Another striking mode of proving the absorption and apparent disappearance of heat during liquefaction is the following:—Let a piece of ice be taken, and, in addition, a quantity of water equal to it in volume or bulk. The temperature of the water is then to be lowered to 32°, and the ice and water removed to a warm room, whilst a thermometer is placed in the water, so as to observe how many degrees it rises during a given portion of time, say half an hour. Let us suppose that the warmth of the room is such, that in this period the thermometer rises 7 degrees, and that the temperature of the room is kept the same as it was at the beginning of the experiment, till the whole of the ice is melted. This will require some hours; and as the ice, like the water, has been gaining 14 degrees of heat each hour, we shall be able to ascertain both that heat disappears, and how much of it becomes latent, during the melting of the ice.

275. In a trial of this kind made by Dr Black, the discoverer of latent heat, ten hours and a-half elapsed before the ice, originally at 32°, had melted. The temperature of the ice-water was then 40°, or 8 degrees above the freezing-point. During the period mentioned, the ice had been receiving heat at the rate previously mentioned (7 degrees every half-hour), so that if we multiply 7° by 21 (the number of half-hours), it will give us 147°, which should have been the temperature of the ice-water, if none of the heat which entered it had become latent. Its temperature, however, was only 40°, and it had risen 8 of these degrees after it had undergone complete liquefaction. If we subtract 8 from 147, it will leave 139, the number of degrees of heat which had been absorbed by the melting ice without raising its temperature. In other words, before ice can become water, as much heat must be absorbed by it, and become latent, as would, if free, expand the thermometer through 139, or, more accurately, 140 degrees.

276. The most decisive, however, of all ways of demonstrating the latency of heat, is to mix a certain quantity, say an ounce by weight, of ice, or still better, from its state of division, of snow at 32°, with an ounce of water at 172°. The result will be found to be that the snow is all melted, and two

ounces of water are procured at the temperature of 32°. The hot water, in cooling from 172° to 32°, has lost 140° of heat, which changes the snow into water, but does not raise its temperature above that originally possessed by the snow.

277. The striking nature of the last experiment will be rendered more apparent if it be contrasted with the effect of mixing an ounce of *water* at 32° with an ounce at 172°. The temperature now, instead of being only 32°, will be the mean of the two temperatures, or 102°.

278. What we have illustrated here with ice holds good for all solids. Each one of them renders latent a certain quantity of heat in becoming liquid, and retains that heat so long as it remains liquid. The following table shows the amount of heat which disappears during the liquefaction of several solids, and which is distinguished as their latent heat:—

	Latent Heat.
Water, ...	140 degrees
Sulphur, ...	145 ...
Lead, ...	162 ...
Bees' Wax, ...	175 ...
Tin, ...	500 ...

279. Every liquid may be spoken of as a combination of a solid and so much heat, and may thus be compared to a chemical compound. In the last, the elements cease to present the properties which they exhibited before combination; and in like manner we can detect in the liquid neither the solid nor the heat, which by their union have produced it.

280. As the elements, moreover, of a chemical compound may be separated from their state of combination, and then present all the characters which they exhibited before union, so the heat which is latent in a liquid has not in reality disappeared or become extinct, but, on the other hand, may be recovered, with its power to communicate warmth, and to affect the thermometer, unchanged. Thus, when water freezes, the 140 degrees of latent heat all abandon it, and manifest themselves as sensible heat, before the water solidifies.

281. The slowness with which water generally freezes, makes it more difficult to demonstrate the evolution of heat during congelation than the disappearance of it during liquefaction. By the following experiment, however, in which a different substance than water is made to solidify, the fact may be proved very strikingly:—

282. A flask full of water is to be placed over a lamp till the water boils. Sulphate of soda is then to be added in small successive quantities, as long as the water will dissolve it, and

when the boiling liquid is thus saturated, it is to be rapidly corked whilst the vapour is still issuing, and the light withdrawn. The flask is then to be set aside, and left perfectly undisturbed for several hours, so that it may slowly cool to the temperature of the air.

283. If such a solution as we have described were exposed in an open vessel, and especially if agitated, it would begin to deposit crystals soon after it was set aside, for boiling water dissolves a much greater amount of Glauber's salt than cold water can retain in solution; and accordingly, as the temperature of the liquid falls, the sulphate of soda gradually separates, and adheres in crystals to the bottom and sides of the vessel. If the corked flask, however, be not disturbed, the solution may be cooled even to 60° without a single crystal separating. If, then, the cork be withdrawn, and the liquid shaken, or, still better, if any rough body be dropped in, the whole amount of sulphate of soda, which water at 60° cannot dissolve, suddenly becomes insoluble and solid, and the liquid appears in a moment to freeze or congeal so completely, that the flask may be turned upside down without a drop of fluid escaping. This sudden conversion of liquid sulphate of soda into solid sulphate of soda, is a phenomenon of exactly the same kind as the sudden freezing of water would be, and is accompanied by the evolution, in a sensible form, of all the heat which, whilst in a latent state, kept the salt liquid, or in solution. Accordingly, if the flask be grasped in the hand at the moment when the cork is withdrawn, and crystallisation is occurring, it will be felt to grow warm; or, still better, if a thermometer be quickly introduced, it will be seen to rise through 30 or 40 degrees.

284. The experiment just recorded is a striking illustration of the general law, that as all solids, in becoming liquids, render a large amount of heat latent, so all liquids, in becoming solids, evolve or render free a large amount of heat previously latent.

285. A variety of simple but instructive experiments may likewise be made in illustration of the fact, that when a solid is compelled to liquefy rapidly, without heat being freely supplied to it, so as to confer on it liquidity, it lowers the temperature of surrounding objects by depriving them of their caloric. Thus there is scarcely one of the salts, such as common salt, Glauber's salt, nitre, and the like, which does not lower the temperature of water when dissolved in it, in consequence of the water compelling the liquefaction of the salt, which in its turn forces the water to part with heat, in order to melt it. Thus a handful of nitre thrown into

water causes its temperature to fall about 16 degrees; sulphate of soda, dissolved in muriatic acid, lowers the thermometer 50 degrees; when snow is mingled with salt, the former melts with such rapidity, in consequence of its affinity for the salt, that the temperature sinks to 0°.

286. Such combinations go generally by the name of freezing mixtures, and are employed in summer to produce ices for the table.

287. The salt called the chloride of calcium, when mixed with snow, produces, whilst melting the latter, a cold sufficient to freeze mercury, which requires, before it congeals, to be reduced to the temperature of *minus* 40°.

Latent Heat of Gasëity—Vaporisation.

288. It is matter of familiar observation that most liquids, such as water, when exposed to heat, steadily rise in temperature till they reach a certain point, when the phenomenon of ebullition or boiling occurs, and the liquid passes away abundantly as an invisible gas or vapour.

289. It is not essential to the production of vapour that the liquid should boil. No phenomenon is more familiar than the drying up of even large pools of water by silent conversion into vapour. The phenomena, however, we are about to explain, are best observed with boiling liquids.

290. We have already referred, whilst describing the thermometer, to the fact, that so long as water exposed to heat continues boiling, a thermometer plunged in it stands at the same point—that, namely, marked on our thermometers as 212°. We now add the statement, that the steam issuing from the boiling water has also the temperature of 212°, as we saw formerly that the water flowing from melting ice has the same temperature as the unmelted ice.

291. As the steam, then, is no hotter than the water, we may be tempted at first to imagine that nothing more is necessary, in order to convert water into vapour, than to raise it to the temperature of 212°. If this were all, however, that were requisite, the boiling of water would be a most perilous experiment; for the moment the liquid rose to 212°, it would explode into steam with a violence exceeding that of ignited gunpowder. That this would be the case is certain, from the fact that a given volume of water, when it changes into steam, occupies a space 1694 times greater than it does when liquid. In other words, one cubic inch of water yields 1694 cubic inches of steam. The strongest engine-boiler would be shattered to fragments by the instantaneous dilatation within it of even a small quantity of water.

292. Again, if vapours contained no more heat than the liquids which yielded them, they could not retain for a moment the condition of invisible gases, but would condense into liquids the instant they came in contact with any body lower in temperature than themselves. So far, on the other hand, are they from readily condensing, that in steam-engines, distilleries, and other places where it is essential to condense vapours, it is found necessary to expose them to a great amount of cold, otherwise they retain their condition as gases.

293. The explanation of these phenomena is furnished by the fact, that as ice, in becoming water, renders latent a large amount of heat, water does the same in becoming steam. What occurs with water occurs with every other liquid, so that as a liquid was spoken of as a compound of heat and a solid, a vapour may be called a compound of heat and a liquid.

294. A few experiments will suffice to demonstrate the disappearance of heat during the conversion of liquids into vapours. If a vessel of ice-cold water be placed over a steady source of heat, and the time be observed which elapses before the liquid rises from 32° to 212°, it will be found that a period about five times longer transpires before the water is entirely boiled away. Now the water acquired 180° of heat (212° minus 32°) during the first space of time, which we may suppose to be half an hour, and during each of the five succeeding half-hours it must have been receiving the same amount of heat, or altogether five times 180—that is, 900° of heat; yet its temperature has never been higher than 212°, so that the heat must have been expended in some other way than in elevating the temperature. That it has entered into the steam, and become latent there, is demonstrated by condensing the vapour, and observing how much sensible heat it evolves; for as the heat which was latent in the liquid becomes sensible when it returns to the solid state, so the heat which apparently disappears when water becomes steam, recovers its power to communicate warmth, and to expand the thermometer, when the steam returns to the state of water.

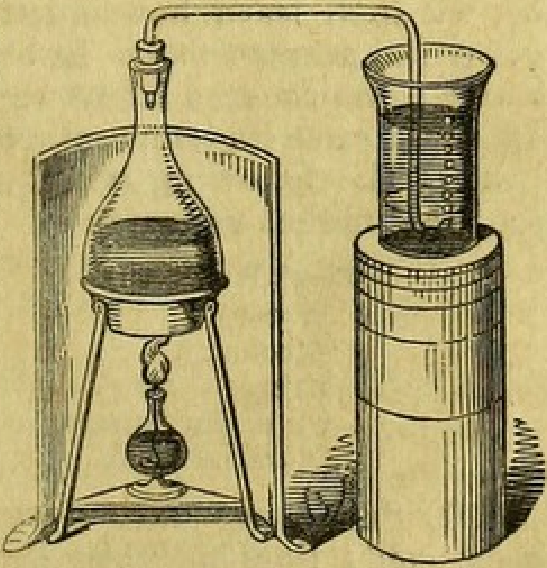
Fig. 9.

295. The most convincing way of illustrating this is the following:—Let a tube from the mouth of a kettle or glass flask (see fig. 9), containing water kept boiling, be made to dip below the surface of ice-cold water, so that the latter shall condense the steam; the steam, in passing through, will elevate the temperature of the water as it condenses in it, and speedily raise it to the boiling-point.

296. If eleven measures (ounces, half-ounces, or cubic inches) of water at 32° be raised in this way to 212°, its volume will be found increased to thirteen measures, in consequence of the condensation of the steam.

297. Two measures, then, of water in the form of steam, have raised eleven measures of liquid water from 32° to 212°, so that each measure of the liquid has received 180° of heat, and yet the (condensed) steam has not decreased in warmth, for it still retains the temperature of 212°, only it has ceased to be steam, and become water.

298. Let a similar experiment now be made with eleven measures of ice-cold water, and two measures of water (instead of steam) at 212°. On mixing the hot and cold water, the temperature will be found to rise about 28°. Hot steam, then, contains much more heat than equally hot water, and the former, in consequence, gives a much more severe scald than the latter.

299. In the first experiment, two measures of water in the form of steam heated eleven measures of water through 180°, so that one measure of steam would raise to that temperature five and a-half of water. If we multiply, therefore, 180 by $5\frac{1}{2}$, we shall learn how much heat is latent in steam. This gives the number 990. In other words, the steam of boiling water contains, in a latent condition within it, as much heat as would raise its temperature 990°, if it were sensible.

300. The following is a short table of the latent heat present in different vapours:—

Equal Weights.	Latent Heat of Vapour.
Water,	990
Alcohol,	385·2
Ether,	162
Oil of Turpentine,	133·2
Oil of Lemons,	144

301. Solids, we have seen, when suddenly liquefied, produce cold; liquids, when suddenly vaporised, do the same, and for a similar reason. Thus, if a readily-vaporisable liquid, such as sulphuric ether or alcohol, be poured upon the hand, a sensation of cold is produced, in consequence of the liquid, compelled as it is to become vapour, robbing the hand of the

heat it requires to render latent, before it can assume the gaseous form.

302. Water is sufficiently volatile to exhibit this phenomenon, as every bather must have experienced; and many curious experiments can be shown in illustration of this property. Thus, a small portion of water may be frozen by immersing a tube containing it in a wider vessel holding sulphuric ether, and compelling the ether to vaporise rapidly by placing it under a bell-jar on the plate of the air-pump, and withdrawing the vapour as fast as it forms by working the pump.

303. Water may even be frozen by its own evaporation. For this purpose it is placed in a shallow, porous vessel, in the air-pump vacuum, above a wide basin containing strong oil of vitriol. The air is then withdrawn, and the whole left at rest. A portion of vapour instantly rises from the water, and fills the empty bell-jar standing on the air-pump plate. This volume of vapour, however, is immediately condensed by the oil of vitriol, which has a great affinity for water. Successive volumes of water-vapour rise in like manner, and are in turn condensed; but the process does not proceed long before a cake of ice is seen in the porous vessel. The explanation is simple. The water having had nothing else to take heat from, takes it from itself, at least in part. It contains heat enough to maintain it all as a liquid, or to convert a portion of it into vapour, whilst the rest becomes solid. The oil of vitriol compels water-vapour to rise, and the vapour compels the unvaporised water to part with its heat to it; but in so doing, the residual liquid of necessity becomes solid.

304. We have stated already that there is no essential distinction between a gas and a vapour. The statement will be better understood now, after the exposition of latent heat. Our air is in greater part a mixture of two gases, oxygen and nitrogen, which we do not see condense under any circumstances, only, however, because we are not able, by any reduction of temperature, to deprive them of their latent heat.

305. Other gases, however, which were long reputed to be as little liable to alteration in condition, have been condensed into liquids and frozen into solids. Carbonic acid presents the best example of this curious fact. It may be reduced to the liquid form in two ways: by compressing it into a very small space, it may be compelled to abandon its latent heat, which becomes sensible—the gas at the same time liquefying; or it may be exposed in suitable vessels to great cold, which in actual practice is a much less convenient plan; or com-

pression and reduction of temperature may be simultaneously had recourse to, which is the process generally followed for the condensation of gases.

306. A liquefied gas is always a very volatile body, and may often be in part solidified or *frozen* by permitting the liquid to evaporate spontaneously. Thus liquid carbonic acid, if allowed to evaporate rapidly, acts exactly like water confined in the air-pump vacuum along with oil of vitriol. One portion of the liquid becomes gas, the other changes into solid carbonic acid, a substance scarcely distinguishable in external characters from snow.

307. Some gases do not require this process, but, by mere reduction in temperature, may be frozen like water. In short, the great majority of the gases comport themselves exactly as the vapours evolved by liquids do—the difference between them being only one of degree, so that a greater amount of cold is required to condense the gas than to condense the vapour. This, however, implies no greater difference between a gas and a vapour than between two vapours, no one of which contains the same amount of latent heat as another, or requires the same reduction of temperature to render it liquid.

308. Some gases, such as oxygen, nitrogen, and hydrogen, have as yet resisted every attempt to liquefy them; but we do not doubt that this is only because they are the vapours of bodies so highly volatile, that we are not able to command a temperature low enough, or a pressure sufficient to induce them to part with their latent heat.

Richard McNeown

R. Purcell Esqre
Clongowes

CRYSTALLISATION AND CRYSTALLOGRAPHY.

309. A large number of substances, both simple and compound, are susceptible of existence as solids in regular geometrical forms which have generally plane surfaces, bounded by angles which are constant. These geometrical solids are termed *crystals*, and the process by which they are produced is called *crystallisation*. Crystallisation is generally determined by conferring fluidity upon the substance to be crystallised, so as to give its particles freedom of motion on each other, and then leaving the fluid undisturbed, so that the molecules may slowly return to the solid state.

310. A crystallisable body is rendered fluid by heating it till—1, it melts into a liquid; or, 2, sublimes as a vapour; or, 3, it may be dissolved in a liquid which is afterwards caused to evaporate slowly. Some substances, such as sulphur, can be crystallised in all the three ways—that is, by fusion, vaporisation, or solution; the greater number of the metals chiefly by fusion, the majority of salts and crystallisable organic bodies by solution. It is also possible, by decomposing a compound liquid or gas, to obtain one or more of its constituents crystallised. The metals, for example, are readily crystallised by decomposing their solutions slowly by galvanic currents; and various compound gases, when passed through red-hot tubes, deposit certain of their constituents as crystals. Uncrystalline solids also, such as malleable iron, in certain circumstances have a crystalline structure developed in them, without becoming in the slightest degree fluid.

311. The same substance crystallises in a great variety of shapes; but when these are carefully examined, they are found to differ from each other only by slight modifications, so that in the majority of cases the crystalline forms of each single substance can be grouped together under one *crystallographic system*, as it is called, which includes a great variety of shapes, all of which a crystal exhibiting one of these forms may present; whilst, on the other hand, in the majority of cases it never occurs in any of the shapes belonging to a different system.

312. Numerous as crystalline forms are, they may all be included under six systems. Each of these contains a number of related, but dissimilar shapes, which agree in containing the same crystalline axes, as they are called. These axes are three straight lines passing through the same point, and terminating in the surfaces or angles of the crystal. Thus the first system is called the *octohedral*, or *regular* system of crystallisation. The three axes are at right angles to each other, and equal in length. The cube or hexahedron, which is one of the forms of this system, consists of six planes or squares, so arranged, that each is perpendicular to one axis, and parallel to the other two. The axes in this form terminate in the centre of each of the six faces of the crystal, as the figure will show. (See fig. 10, A, p. 89.)

313. In the octohedron, on the other hand, the axes terminate in the angles of the crystals, as the figure illustrates. (See fig. 10, B, p. 89.)

314. The other systems are named and characterised as follows:—2. The *square prismatic* has the axes at right angles to each other, but two only of them equal in length, the third being longer or shorter than the other two. 3. The *right prismatic* has the axes also at right angles, but all of different lengths. 4. The *rhombohedral* has the axes equal in length, and crossing at equal but not right angles. 5. The *oblique prismatic* has two of the axes intersecting each other obliquely, while the third is perpendicular to both, and unequal in length. 6. The *doubly-oblique prismatic* has all three axes intersecting each other obliquely, and unequal.

315. The crystalline systems are best understood by connecting together wires, wooden rods, or pieces of stiff pasteboard, so as to represent the several axes, and then constructing around these some of the more common crystalline forms of each system. Rods of wood are most convenient, dovetailed into each other, where they cross or intersect. Six of these will be requisite, if all the systems are to be illustrated, but fewer will suffice to make plain the scheme of crystalline systems.

316. By passing white cords or threads across the ends of the several rods, so as to connect them together, each set of axes (except that of the rhombohedral system) becomes changed into one of the octohedrons of its system.

317. Square-faced, rectangular, or rhombic forms, such as the cube, the different prisms, and the rhombohedron, may be represented by means of wires.

318. The following figures represent two of the principal forms of four of the systems. The thick black lines correspond to the wooden rods or axes; the thin continuous lines

are threads in the case of the octohedrons, and stout wires in the cube and prisms. The dotted lines in the figures of the latter are thin iron wires to receive and support the ends of the wooden rods. The same set of rods serves for two figures, A and B.

Fig. 10. Regular System. —A, skeleton cube. B, skeleton regular octohedron; all the faces being equilateral triangles.

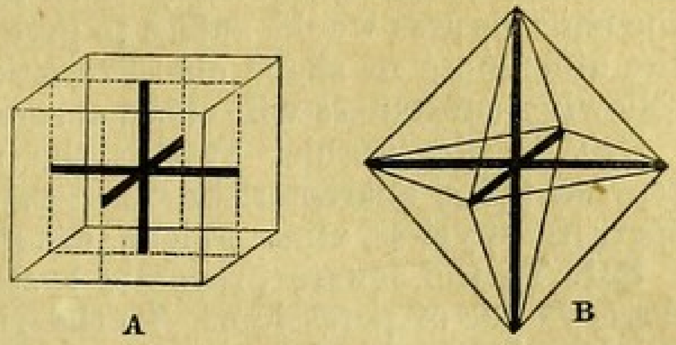

Fig. 10.

Fig. 11. Square Prismatic System.—A, a square prism. B, an octohedron with a square base; all the faces isosceles triangles.

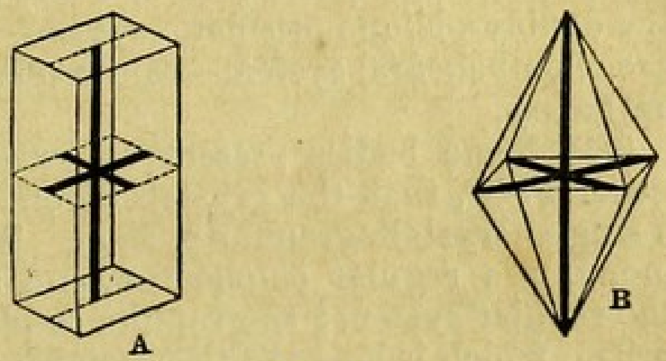

Fig. 11.

Fig. 12. Right Prismatic System.—A, right prism. B, an octohedron with a rhombic base; all the faces scalene triangles.

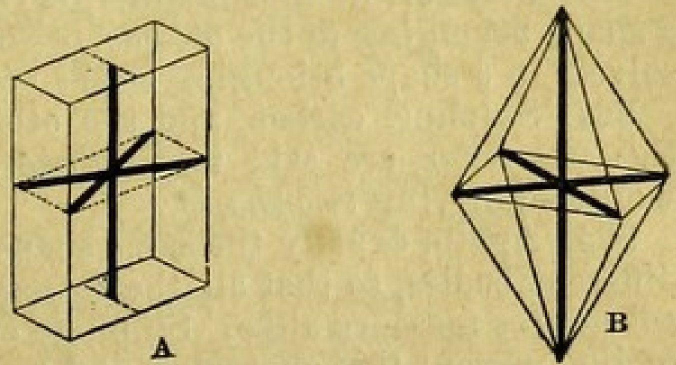

Fig. 12.

Fig. 13. Oblique Prismatic System.—A, oblique rhombic prism. B, octohedron of the same system.

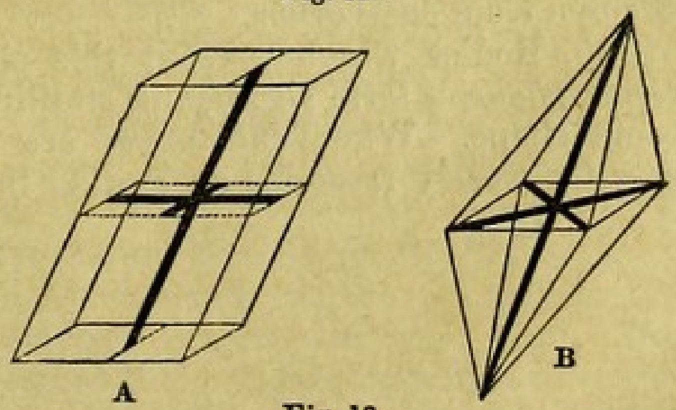

Fig. 13.

319. Without an extensive series of models, specimens, and drawings, the various crystalline secondary or derivative forms cannot be understood. Two models in each system of the chief figures would suffice to give a general conception of the differences in shape characteristic of each system. The following substances will afford specimens:—

320. In the regular system the majority of the metals represent the characteristic figures, also the diamond, fluor spar, iron-pyrites, alum, galena, the garnet, &c.

321. To the square prismatic system belong tinstone and ferrocyanide of potassium. To the right prismatic system—sulphur, iodine, sulphate of potass. To the oblique prismatic—carbonate and phosphate of soda, borax, green vitriol. To the doubly-oblique prismatic system—sulphate of copper. To the rhombohedral system—calcareous spar, quartz, ice, arsenic, antimony.

322. Some bodies present an exception to the otherwise general law, that the crystals of one substance belong all to a single crystallographic system. Thus carbon as the diamond, is a regular octohedron, and a member, therefore, of the regular system; as graphite or plumbago, it is a six-sided prism, which belongs to the rhombohedral system.

323. Sulphur, in like manner, crystallises when melted, in a shape belonging to the *oblique* prismatic system; when dissolved, in a shape belonging to the *right* prismatic system.

324. Sulphur, carbon, and the other bodies which present this character, are said to be *dimorphous*, from two Greek words signifying *two-shaped.*

325. Again, exactly the same shape is found to characterise different bodies, so that all the corresponding angles of these substances measure alike. Sulphate of magnesia and sulphate of zinc present this character, and cannot be distinguished by the eye from each other.

326. Bodies which present this character are said to be *isomorphous,* a term signifying similiform, or possessed of the same shape. When substances are isomorphous, they frequently closely resemble each other in chemical properties.

INORGANIC CHEMISTRY.

327. The discussion of the laws of chemistry is followed by a consideration of each of the more important elements in turn, and of its chief compounds.

328. The latter are arranged in two great divisions—that, namely, of organic, and that of inorganic chemistry.

329. Organic chemistry may in the meanwhile be defined to be the chemistry of plants and animals, and of the substances directly and indirectly derived from them. A fuller definition is given in the section which treats of this department of the science.

330. Inorganic chemistry is best defined negatively, as that section of the science which considers the properties of those substances which are not solely of vegetable or animal origin.

331. We commence with inorganic chemistry, in connection with the discussion of the elements.

OXYGEN.

Equivalent, 8; *symbol*, O; *density*, 1105 (*air*, 1000);
combining measure or atomic volume, □

332. At all observed temperatures, oxygen, when uncombined, is a gas. It is the most widely-diffused body in nature, forming one-fifth part of atmospheric air by volume, and eight-ninths of water by weight, besides being a constituent of nearly all the earths and rocks of the globe. It is estimated to form nearly one-half of our planet, and more than one-half of living plants and animals.

333. Its name is derived from the Greek ὀξὺς (oxys), acid, and γενναω (gennao)—I call into being, or give rise to—in allusion to its property of forming acids, by combining with other elementary bodies. The word oxygen thus signifies the *acid-producer*, and was given to this element at a time when all acids were believed to contain oxygen, and to owe their acidity to its presence. We now know many acids, such as hydrochloric, which contain no oxygen, and we do not impute

the acidity of those which possess it, to its occurrence in them. We retain the name, therefore, simply as a convenient appellation for this important substance.

334. *Preparation.*—Oxygen is generally disengaged from some oxide or salt containing it, by the application of heat. On the small scale, the only oxide made use of is the red oxide of mercury. To prepare oxygen from it, let a few grains be placed in a test-tube, and the tube held in the hand, or in a convenient tube-holder (fig. 14), exposed to the heat of a spirit-lamp. The oxide rapidly darkens in colour, and finally becomes nearly black; it then begins to separate into its two constituents, quicksilver and oxygen. The former rises in the tube as vapour, till it reaches a cool portion of it, where it condenses in its characteristic form of brilliant silvery globules. The oxygen passes away as a colourless, invisible gas, but its presence may be proved by thrusting into the tube a wooden match with a red-hot tip, which will immediately burst into full flame.

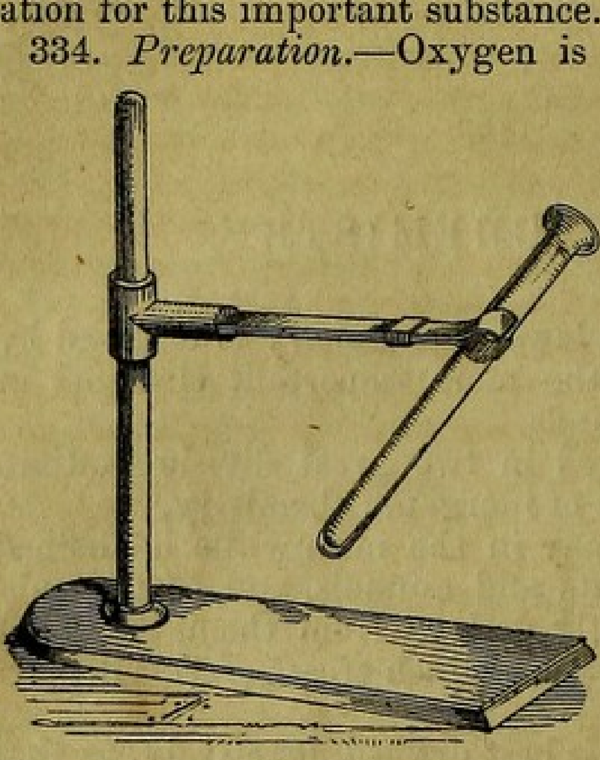

Fig. 14.

335. This method of preparing oxygen is never practised in the laboratory, in consequence of the costliness of the oxide of mercury, when used in considerable quantity; but it deserves the student's special attention, owing to the simplicity of the decomposition which leads to the evolution of the gas, and because it is the first substance from which oxygen was obtained—namely, in 1774, by Dr Priestley.

336. The salt most suitable for the preparation of oxygen is the chlorate of potass, a substance largely consumed in the arts, and therefore easily procured. To prepare oxygen from it, a few grains may be placed at the bottom of a test-tube, and the flame of a spirit-lamp applied. The salt quickly melts, and becomes, although quite free from water, a clear liquid. It then begins to effervesce, in consequence of the bubbling through it of multitudes of bells of oxygen, and this effervescence continues till the whole of the gas which the salt contains has been disengaged. If a red-hot match be plunged into the tube whilst the melted chlorate of potass is

effervescing briskly, it will burst into full flame, and burn much more brilliantly than it did in the similar experiment with the oxide of mercury.

337. When oxygen is wished in large quantity, a retort is substituted for the test-tube, and the gas is collected in jars at the pneumatic trough. The chlorate of potass is employed as the source of the oxygen, but it is previously mixed with from one-third to one-fifth of its weight of the black oxide of manganese, or red oxide of iron, which have a remarkable power of increasing (in a way not easily explained) the rapidity with which chlorate of potass evolves oxygen.

338. The pneumatic trough referred to above is a box made of wood or tin-plate, generally about two feet long, a foot and a-half in breadth, and a foot in depth; but it may be made of any size. At one side, parallel to the length of the trough, a shelf is fixed about three inches below the edge of the box. Holes are bored in this shelf at short distances, in order to allow gas to be passed into jars, standing on it with their mouths over the apertures. A moveable stool stands within the trough, of such breadth as nearly to fill the space between the free edge of the shelf at the one side, and the wall of the trough on the other, and of such height, that its upper surface is exactly on a level with that of the shelf. This stool has an aperture in the centre of its upper surface, which forms the termination of a funnel-shaped cavity hollowed out in the wood, so that its wider mouth looks downwards, and the aperture already referred to corresponds to the end of the pipe of the funnel, and points upwards. A spout projects from one extremity of the trough about two inches above the level of the shelf. It serves to carry off the excess of water discharged from the jars as they are filled with gas. A smaller trough is placed permanently to receive the water which runs off. Such an arrangement is rendered necessary

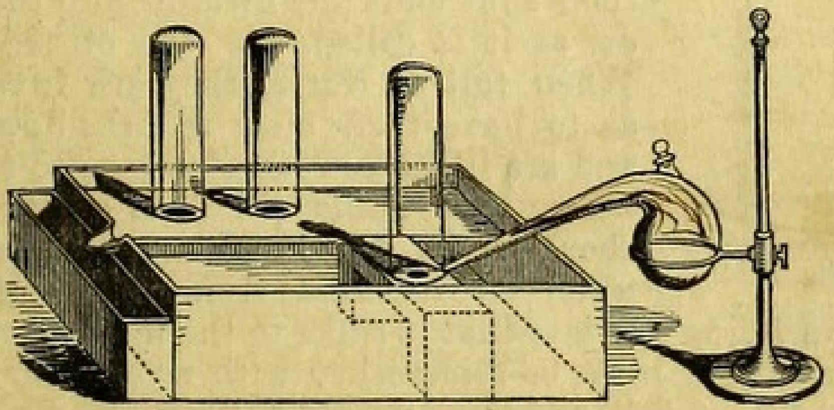

Fig. 15.

by the fact, that at the beginning of any process for collecting gas at the pneumatic trough, all, or the greater number of the jars which are to be filled with the elastic fluid must be arranged full of water on the shelf, whilst at the end of the process the whole of the jars are emptied of water, and the trough which receives it would run over, if the spout and smaller reservoir were not provided for its reception.

339. In using the pneumatic trough, water is poured in till it reaches the level of the spout, and begins to flow over; it should then stand some two inches above the level of the shelf and stool. The jars in which the gas is to be collected are filled with water by plunging them obliquely with their shut ends downwards into the cavity, or, as it is called, the well of the trough. When full of water, they are inverted, so as to have their open mouths downwards, and are lifted, or rather slid, on to the shelf, where they stand till each in its turn is about to be filled with gas. If so much water be removed from the well of the trough in filling the jars that it sinks to the level of the shelf, then the trough must be replenished with water; for the jars cannot be kept full of liquid unless their mouths are below the surface of the liquid, and a column more than an inch in height is left above the shelf. If this be neglected, in the rapid transference of jars to and from the shelf, air will certainly be allowed to enter, and the collection of gas arrested till the jar is filled with water anew.

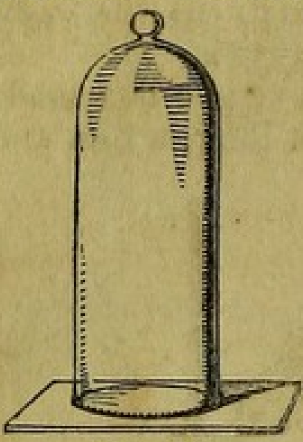
Fig. 16.

340. The further use of the trough will be best illustrated by continuing the description of the preparation of oxygen. The mixture of chlorate of potass and metallic oxide having been placed in a retort (fig. 17), the stopper is to be tightly fixed in, and the beak or extremity of the long tube of the retort plunged below the surface of the water in the trough. Instead of a retort, a flask (fig. 18) may be used, furnished with a bent tube, passed through a cork, which fits the neck of the flask. The moveable stool is then pushed along till it stands over the beak of the retort. Heat is now applied to the retort or flask by means of a spirit-lamp (fig. 19), a gas flame, or a small furnace or choffer containing coal or charcoal, the retort or flask being supported in one of the rings of a retort-stand (fig. 20). The first effect of the application of heat is to ex-

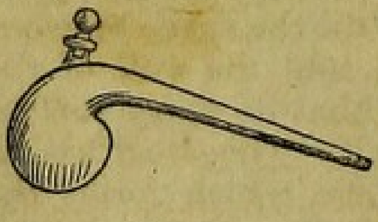
Fig. 17.

pand and expel the air in the retort, which comes bubbling up through the aperture in the stool, and is allowed to escape. When the pure gas succeeds it, one of the jars full of water standing on the shelf is transferred from it to the stool, its mouth being kept under water during the transference. The gas now rises into the jar, causing the water to descend till it has expelled the whole of it. The jar, when filled, is slid back again to the shelf, and another full of water removed to the stool, and this manipulation is repeated till all the jars are filled with gas, or the latter ceases to be evolved.

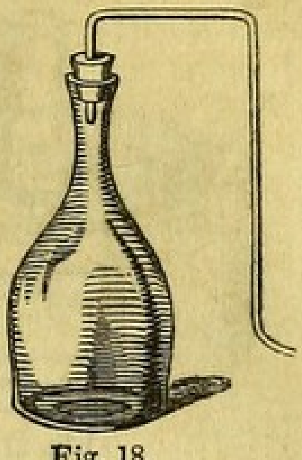
Fig. 18.

341. When the contents of a jar are to be examined, it is removed altogether from the trough, by sliding it off the shelf on to a gas-tray, as it is called. This consists of japanned tin plate, or sheet-zinc, and exactly corresponds in shape to the cover of a cylindrical canister or the lid of a round snuff-box. This tray is filled with water, and the jar, with its mouth down, being transferred to it, the two are lifted off together, the tray being held in one hand, and the other laid on the shut end of the jar to keep it from falling over. A jar of gas may be kept apart for any length of time, provided only the tray be kept full of water. If the mouths of the jars are ground, squares or disks of plate-glass which fit air-tight will be found still more convenient than the gas-trays.


Fig. 19.

342. When the gas is to be examined, as, for example, by plunging a lighted candle into it, the jar is quickly inverted, and the tray lifted off. In doing this, the jar should be held above the pneumatic trough, so as to allow the water which runs out of the tray to be received by it, and prevent it wetting surrounding objects.

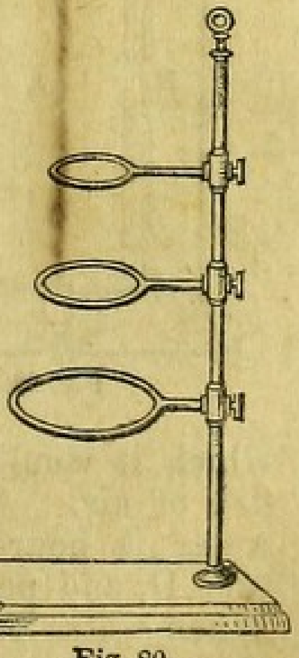
Fig. 20.

343. Other gases are collected at the pneumatic trough in the same way as oxygen. If, however, a gas be very soluble in water, that liquid must be dispensed with, and mercury employed in its place. We accordingly distinguish two varieties of the

[redacted]

pneumatic trough—the water and mercurial. Troughs are also constructed of stoneware, and have the advantage of being cleanly and water-tight. The accompanying figure (fig. 21) represents one, with a stoneware stand for the jars, and a lateral aperture for the beak of the retort or tube delivering the gas. A tub, a wash-hand basin, a foot-pail, a leaden cistern or sink, or any other water-tight box, may be used as a pneumatic trough, with a couple of bricks or flat stones to support the jars.

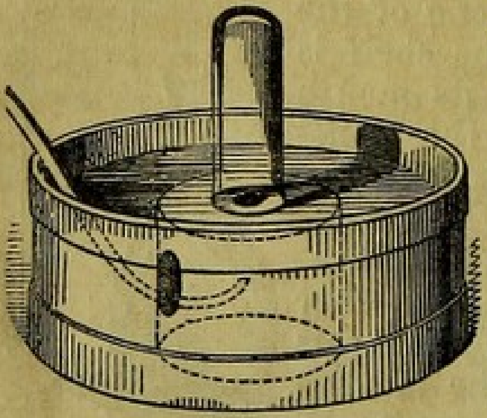
Fig. 21.

344. Besides the pneumatic trough, with its glass jars, it is desirable to have vessels of larger capacity, in which considerable quantities of gas can be collected, and from which it can be drawn off at pleasure. Such vessels are called gasholders, or gasometers, and are constructed of tin plate, or better of zinc or copper. The figure (fig. 22) represents one of the most convenient, distinguished by its inventor's name, as Pepys' gasholder. A is a metallic drum or cylinder; B a large funnel, communicating with A by a small tube C, which terminates in the roof of the cylinder, and a large one, D, which descends to nearly the bottom; E is a pillar of support to the funnel; F is a tube placed at an angle with the cylinder, and provided with a nut which screws into its mouth, and fits it air-tight; G is a stopcock, projecting laterally from the top of the cylinder.

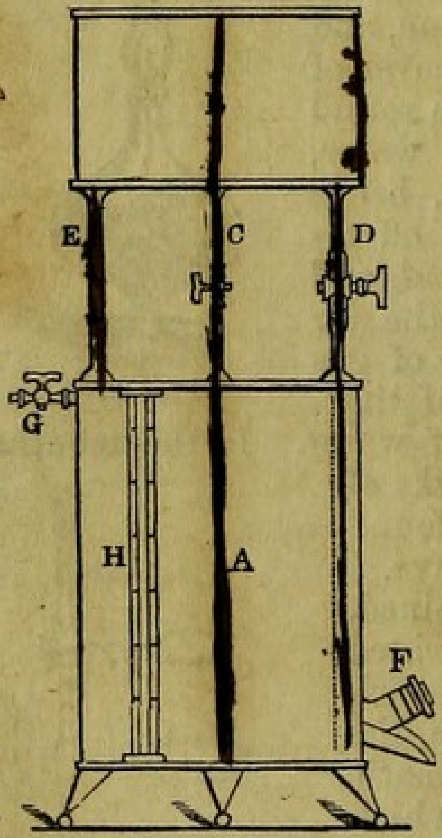

Fig. 22.

345. In the figure the gasholder is represented in the condition in which it would ordinarily be called empty—in other words, full of air. As a preliminary step to filling it with gas, water is poured into the funnel B. It descends by the tube D, and partly by C, whilst the air escapes by C and G. When water runs out at G, the cylinder is full, and all the stopcocks are shut. The nut of the oblique tube F is then unscrewed, and the beak of the retort, or exit tube of the flask,

Thomas [illegible] own

from which the gas is issuing, is inserted through F, and pushed in till its end is fairly within the cylinder. The gas rising vertically, accumulates in A, whilst the water it displaces flows out at F, past the neck of the retort or tube of the flask. When the water is all expelled, the retort or flask is withdrawn, and F closed again with the nut. A glass tube or gauge, H, communicating at each end with the cylinder, and in which the water stands at the same level as in A, allows the amount of gas in the latter to be readily observed.

346. The gas is drawn off either by C or by G. If a jar is to be filled, water is poured into B, and the jar full of water is placed mouth downwards over C. C and D are then opened, and the water which descends by D expels the gas by C. If a current of gas is wished, as for the lime-ball light or the oxyhydrogen blowpipe, the tube to convey it is attached to the end of G. B is kept full of water, and when D and G are opened, the gas rushes out by the latter. The stopcocks at D and G admit of the current being very nicely regulated.

347. Fig. 23 represents another and cheaper gasholder, made of stoneware.

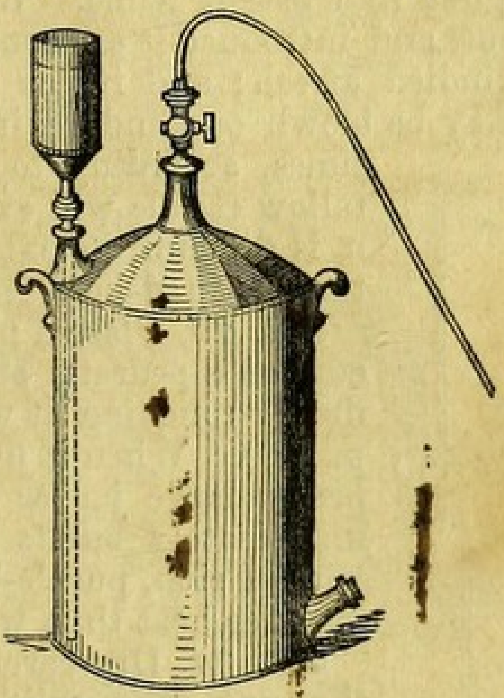

Fig. 23.

348. Chlorate of potass, KO,ClO_5, contains, in addition to oxygen, chlorine and potassium; namely, one atom or equivalent of each of the latter, to six atoms of oxygen. When it is heated, the six equivalents of oxygen are evolved, and the chlorine and potassium unite, forming a white salt, resembling in appearance and properties the corresponding chloride of sodium (common salt). Half an ounce of chlorate of potass yields 270 cubic inches, or nearly a gallon of pure oxygen gas.

349. *Properties.*—Oxygen has no colour, odour, or taste. It is heavier than air, in the proportion of about 11 to 10. It cannot be liquefied or solidified when uncombined. It is soluble in water to the extent of 3½, or, according to others, 6½ cubic inches of the gas in 100 of water. This is, comparatively speaking, a slight solubility; nevertheless, it is a property of oxygen of great importance in relation to plants, but still more to water-animals, the greater number of which are

dependent on this dissolved oxygen for the support of respiration and life. Fishes die at once if placed in water which contains no oxygen in solution. The sea and other natural beds of water are constantly dissolving this gas from the atmosphere above them.

350. The most striking property of oxygen is its power of supporting and enlivening combustion. In illustration of this, the following experiments may be tried:—

351. 1*st*, Kindle a match of wood, and blow it out, leaving the end red-hot. Plunge it into a jar of oxygen, when it will burst into bright flame. Withdraw it immediately, blow it out, and introduce it a second time into the gas. It will be kindled afresh; and if the gas be pure, a splinter of wood may be blown out and rekindled twelve, fourteen, or twenty times, according to the size of the jar. A wax or tallow candle will exhibit the same phenomenon, but it is difficult, in extinguishing a wax light, to retain the wick red-hot.

Fig. 24.

352. 2*d*, Place a piece of roll sulphur in a small tin cup, on a pedestal standing on a plate, and set it on fire by touching it with a red-hot wire. (See fig. 36, p. 110). When it has begun to burn, invert over it a pretty large jar or globe of oxygen. The sulphur immediately bursts into fuller combustion, burning with a rich, purple-blue flame, and evolving a much intenser heat than when burned in common air.

353. 3*d*, Dry carefully a piece of phosphorus about the size of a split pea. It is to be deprived of adhering moisture by gently pressing it between folds of blotting-paper, friction being as much as possible avoided, as it may kindle the phosphorus, and occasion a severe burn to the experimenter. The phosphorus is then to be placed in a small metallic cup attached to a wire (fig. 24), and after it has been inflamed by touching it with a hot wire, it is to be introduced into a glass globe, or other convenient jar, filled with oxygen (fig. 25). It burns with a brilliancy so intense, that the eye cannot bear it. The heat evolved is also very great, and frequently occasions fracture of the vessel in which the experiment is made. To guard against this, care should be taken that the phosphorus is dry, otherwise it spirts, and portions of it, in a state of combustion, are projected against the sides of the vessel, and occasion its destruction. Some water should always be left, or placed at the

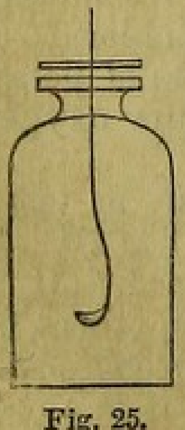

Fig. 25.

bottom of the glass vessel, to receive any phosphorus which may boil over, and the vessel itself should be of considerable dimensions, so that the burning combustible may be at some distance from its sides. An experiment similar to that recorded above may be made with wood-charcoal, a fragment of which, after being well kindled, is to be suspended by a wire in a jar of oxygen. A charred cork burns in these circumstances very prettily.

354. *4th*, The most brilliant of all the experiments on combustion in oxygen is that with iron wire. For its performance a glass vessel is needed resembling a large stoppered bottle without a bottom. A stopper is placed in the neck of the bottomless jar, and it is filled at the pneumatic trough with oxygen in the usual manner, and removed from it on a gas tray. A bundle of the thinnest iron wire, such as is sold under the name of harpsichord wire, is formed into a spiral, as large in diameter as the neck of the jar will allow to enter easily. This is done by coiling the wire round a cylinder of the proper dimensions. The thickness of the spiral must be varied according to the size of the jar. For one which will contain 200 cubic inches of gas, it may be of the thickness of the cord used for wrapping quills. One end of the spiral is tipped with brimstone, by heating it, and immersing it in flowers of sulphur till a small portion of the latter adheres to it. The other end of the spiral is fixed into a cork, which fits the neck of the bottomless jar. The sulphur having been kindled, the stopper of the jar is quickly withdrawn, and the spiral inserted, the cork to which it is fixed being firmly pressed down, so as to close the mouth of the jar. The sulphur bursts into full flame, and kindles the iron, which in its turn burns with great brilliancy, evolving a bright light, and letting white-hot drops of fused oxide of iron fall from it as it burns away. This, and the other experiments on combustion described, are seen to greatest advantage when performed in a dark room.

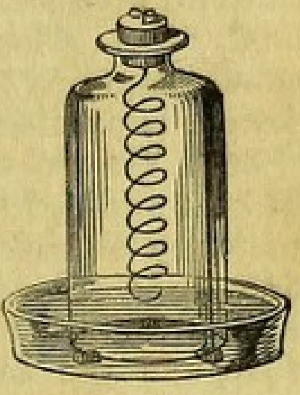
Fig. 26.

355. Combustion in oxygen and in atmospheric air is essentially the same phenomenon—air consisting of oxygen diluted by four times its volume of the negative gas nitrogen. Combustion, however, as might be expected, is much slower, and less brilliant, in atmospheric air, one-fifth part of which only is oxygen. Otherwise, the phenomena presented by bodies burning in air, and in oxygen, differ only in degree, and not in kind. A combustible gives out an intenser heat

and light in the pure gas than in the diluted one, but it evolves the same *quantity*, at least of heat, in both cases—that is, the same weight of ice will be melted during the combustion of six pounds of charcoal and sixteen pounds of oxygen, whether the oxygen be supplied pure, or be furnished in the state of dilution in which it occurs in atmospheric air. In the first case, however, the charcoal will burn a great deal more rapidly, and in so doing will produce a much higher temperature than when burning more slowly in air. The quantity of heat evolved will be exactly the same; for although the charcoal burned in oxygen will melt ice much more rapidly than the charcoal burned in air, the former will not melt a greater weight of ice than the latter.

356. During combustion, an oxide of the combustible is invariably formed. Thus the iron wire in the last experiment unites with the oxygen to form the black or magnetic oxide of iron Fe_3O_4. Phosphorus forms phosphoric acid, PO_5. Sulphur produces, by combustion with the oxygen, sulphurous acid, SO_2. Charcoal forms carbonic acid, CO_2. A match or candle contains two combustibles—carbon and hydrogen; the former is oxidised into carbonic acid, the latter into water.

357. We are unable to explain the cause of the evolution of heat and light which accompanies oxidation. In the great majority of cases where chemical combination occurs, heat and light are evolved, whether oxygen be one of the combining bodies or not; so that production of a high temperature, and the development of light, appear to accompany all cases of intense chemical combination. There is nothing, therefore, peculiar, so far as theory is concerned, in the combustion of bodies in oxygen; but as it is the substance by means of which we burn the fuel occurring at the earth's surface, and thereby provide ourselves at will with artificial heat and light, the relation of oxygen to combustion is more important than that of any other body.

358. Substances which, by combination with the marked combustibles—such as charcoal, sulphur, phosphorus, and the metals—cause the evolution of heat and light, are called *supporters of combustion*. Thus in our ordinary fireplaces, carbon and hydrogen are the combustibles, and the oxygen of atmospheric air supports their combustion.

359. The compounds of oxygen are divided into three classes:—1*st*, *Neutral oxides*—such as water, HO; carbonic oxide, CO; nitrous oxide, NO—which do not possess a sour taste; do not change the tints of colouring matters; and do not combine with acids, or with bases to form salts. The student can verify those properties with water. 2*d*, *Acid*

oxides, which have a sour taste; change vegetable blues to red, and vegetable browns to yellow; and form salts by combining with bases. To observe those properties, nitric or sulphuric acid may be taken, but the acid must be greatly diluted before it is tasted. To make manifest its action on colouring matter, an infusion must be made of the purple cabbage, or of the colouring matter *litmus*, which can easily be procured from any druggist. The purple-blue liquids so prepared are at once changed to red by a very small addition of the acids referred to. Solutions of brown colouring matter are prepared by pouring hot water on powdered turmeric, or medicinal rhubarb, and adding to the yellow liquid so procured a little carbonate of soda, which renders it brown. The acid will then change it back to yellow. To observe the third character, soda, one of the most powerful bases, may be added to sulphuric acid, or potass to nitric, till in either case the acid loses its sour taste. The liquid is then to be gently evaporated, and crystals of Glauber's salt—the sulphate of soda in the one case, of saltpetre, the nitrate of potass, in the other—will be procured. 3*d*, *Basic oxides*, which in the best-marked examples have a soapy taste, as seen in potass and soda; change vegetable reds to blue or to green, and yellows to brown, exactly reversing the effects of acids; and form salts by combining with acids. Only a few of the bases have a taste, or action upon colouring matter; all of them, however, possess the third character. Their action on colouring matter may be observed by adding a solution of potass, soda, or lime-water to an acidified, and therefore red, infusion of cabbage or litmus; when its colour changes to green in the first case, and to blue in the second. If these basic oxides are added to infusion of turmeric or rhubarb, it is at once changed from yellow to brown.*

HYDROGEN.

Equivalent, 1; *symbol*, H; *density*, 69·26; *combining measure, two volumes*, 

360. *Distribution.*—Hydrogen does not exist uncombined in nature, but is one of the elements of water, and is a constituent of all plants and animals, of nearly every compound combustible, and of the great majority of organic bodies.

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* Several of the acid oxides, such as silicic acid, SiO_3, and the majority of the basic oxides, as oxide of iron, Fe_2O_3, are tasteless, and without action on colouring matter. The only essential character of an acid oxide is, that it neutralises a basic oxide, and of a basic oxide, that it neutralises an acid oxide, so as to form a salt.

361. *Name.*—Its name is derived from ὑδωϱ (hydor), 'water,' and γενναω, 'I generate,' so that it signifies the 'water-producer.'

362. *Preparation.*—Hydrogen is generally obtained from water, its oxide, HO; but frequently also from hydrochloric acid, its chloride, HCl.

363. The simplest mode of preparing hydrogen is by sending a galvanic current through water, when it suffers resolution into its two constituent gases, which may be collected separately.

364. Another method—interesting from the simplicity of the change which occurs, but much too costly to be employed in practice on the large scale—is to fold up a fragment, about the size of a pea, of the metal potassium in blotting-paper, and pass it rapidly under the edge of a gas jar standing full of water on the shelf of the pneumatic trough. The potassium, which is lighter than water, ascends within the jar; and as soon as the paper becomes soaked, decomposes the water with great rapidity. This metal has a greater affinity for oxygen than hydrogen has. It is able, accordingly, to decompose water by uniting with its oxygen, and letting its hydrogen go free. The latter gas collects at the upper shut end of the gas jar, whilst the oxygen combines with the potassium, forming the oxide of potassium, or potass, KO. If the jar be filled at the beginning of the experiment with infusion of purple cabbage instead of pure water, the conversion of the potassium into potass will be rendered manifest by the liquid changing in colour from purple to green. This decomposition may be illustrated in symbols thus:—

Before decomposition, HO and K.
After decomposition, KO and H.

365. Iron cannot decompose water at ordinary temperatures, such as 60° Fahrenheit; but if heated red-hot, it acts exactly like potassium. This property of iron is generally illustrated by sending steam through an iron tube like a gun-barrel, placed across a small furnace, when the iron unites with the oxygen of the water (steam), and the hydrogen is set free; but so complicated and troublesome an apparatus is not necessary for the purpose. If a bar of iron be raised to a full red heat, it will be found to decompose water when plunged below its surface. To prove this, all that is needed is to thrust the red-hot bar below the mouth of a gas jar filled with water, when bells, apparently of air, will be seen to rise from the iron, and collect in the upper end of the jar. These bells con-

sist of hydrogen gas mixed with a little air. The decomposition is the same as in the case of potassium:—

Before decomposition, HO and Fe.
After decomposition, FeO and H.

Zinc also decomposes water at a red heat.

366. If sulphuric acid (SO_3), or certain other acids, be added to water, iron or zinc will decompose it without being raised to a red heat. This is the method generally followed. Zinc is preferred to iron on account of its greater purity, and is taken in small pieces, with a view to quicken the evolution of the gas. A retort (fig. 17) may be used for its preparation; but a bottle of any kind will suffice, if furnished with a bent tube passed through a cork which fits the bottle (fig. 18), and serves to conduct the gas. The most convenient piece of apparatus, however, is a double-necked bottle, into the one neck of which a funnel passing through a cork is fixed, and into the other a bent tube (fig. 27). When this arrangement is made use of, zinc and water are introduced into the bottle by one of the necks, before the delivery or exit-tube is fixed in, and sulphuric acid (oil of vitriol) is then added by means of the funnel. The gas is collected at the pneumatic trough exactly in the same way as oxygen is; and special care must be taken not to begin filling the jars till the whole of the air is expelled from the generating vessel, as hydrogen forms an explosive mixture with atmospheric air.

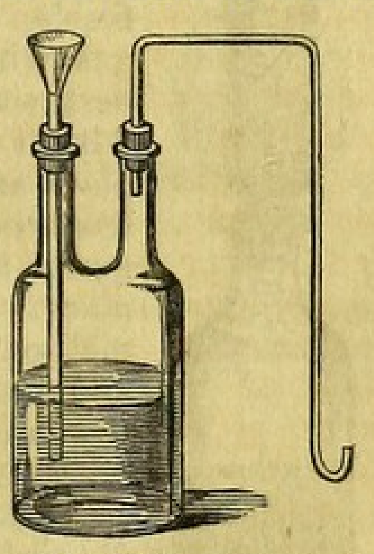
Fig. 27.

367. In the process just described, the action of the zinc and sulphuric acid is as follows:—The zinc combines with the oxygen of the water, forming oxide of zinc, liberating the hydrogen. The oxide thereafter unites with the sulphuric acid, forming the sulphate of the oxide of zinc. It may be expressed thus in symbols:—

First stage, $HO + Zn = ZnO$ and H.
Second stage, $ZnO + SO_3 = ZnO,SO_3$.

368. *Properties.*—Hydrogen is the lightest body in nature, being fourteen and a-half times lighter than air, and sixteen times lighter than oxygen. Fifty cubic inches weigh only a grain. Its lightness may be demonstrated by filling a bladder, or waterproof-cloth bag, with hydrogen, and employing this, by attaching it to a tobacco pipe, to blow soap bubbles with the gas. These ascend with great rapidity. A better method is to fill a small balloon with hydrogen, which

can easily be done by fixing in the neck of a bottle containing zinc and diluted sulphuric acid a vertical tube, over which the mouth of the balloon, previously well compressed, to empty it of air, is passed, and held till the balloon is filled with gas. A thread is then tied round the neck of the balloon, and it is allowed to ascend. When the balloon is small, the vertical tube should be some inches in length, and filled loosely with fragments of quicklime, which retains the sulphuric acid spirted up, and prevents it corroding the balloon, as well as arrests the moisture which accompanies the gas, and may render it so heavy that it cannot raise its envelope (fig. 28).

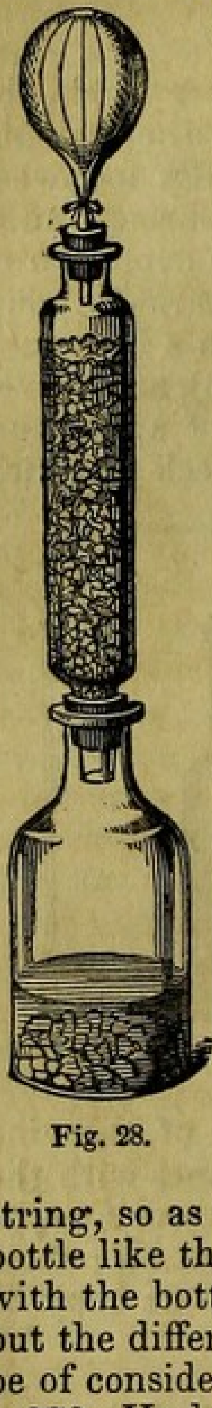
Fig. 28.

369. Sounds produced in hydrogen are very feeble, owing to a remarkable property of the gas which has not been fully explained. The best way of illustrating this is to ring a bell within a large jar standing on the air-pump plate and filled with hydrogen. After the ear has become accustomed to the sound, the hydrogen is allowed to escape, and air admitted in its place. The sound now is much louder. This method, however, requires a somewhat costly and complicated arrangement. A simpler plan is to sound an organ-pipe, flageolet, or whistle, first with air, and then with hydrogen, which may be sent through the musical instrument from an air-tight bag, or gasholder. Another very simple method is to fill a bottle with hydrogen, and then to close it by a cork, to the lower end of which a piece of metal or glass is attached by a piece of string, so as to admit of its striking against the sides of the bottle like the clapper of a bell. The experiment is to be made with the bottle alternately filled with air and with hydrogen; but the difference will not be observed unless the glass vessel be of considerable dimensions, and its walls tolerably thin.

370. Hydrogen has a high refracting power for light, like other transparent combustibles.

371. All the properties, however, of the gas we have hitherto mentioned are of secondary importance compared with its relation to flame. Hydrogen is strikingly combustible in air, but does not itself support combustion. Both these properties may be seen at once by introducing a lighted candle into a jar of hydrogen, held with its mouth downwards. The hydrogen burns at the mouth of the jar, where there is air

to support its combustion; whilst the candle, if thrust up so as to be enveloped by the gas, is extinguished. If a jar of hydrogen be held with the mouth upwards, and a light applied, the gas burns with great rapidity, its lightness enabling it to ascend swiftly.

372. The light evolved by burning hydrogen is pale yellow, and has very little illuminating power. It gives out, however, an intense heat. When it burns in air or in oxygen, it forms water by combining with eight times its weight of the latter gas, as we have frequently mentioned. The production of water in this way is best illustrated by using the arrangement already described for filling a balloon, where the gas is dried by passing through quicklime, and may be kindled at the upper extremity of the drying tube. If a white saucer, or dry glass vessel, be held over the burning jet of gas (fig. 29), it becomes rapidly covered by drops of water; and it is easy, by maintaining the combustion within a two-necked globe, which allows a current of air to pass through it, and can be kept cool, to collect the water produced. For every grain, or fifty cubic inches, of hydrogen burned, nine grains of water will be obtained. Fig. 30 represents a glass jet of the proper shape. It may be of any length, and only requires to be passed through a perforated cork fitting the neck of the bottle from which hydrogen is issuing.

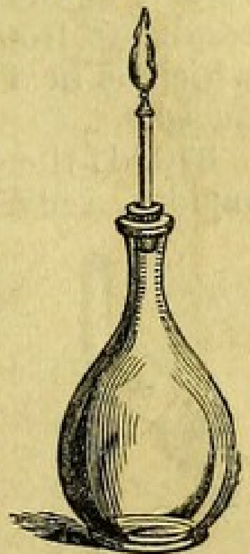
Fig. 29.

373. If hydrogen, instead of being burned at a jet, or at the mouth of a jar, be mingled with air, or oxygen, before a light is applied, the combustion of the entire volume of inflammable gas is instantaneous (or nearly so), and is attended by a loud explosion. We have already seen that the combining measure of hydrogen is twice as great as that of oxygen. When, therefore, we wish to explode the gases together, we fill a vessel two-thirds full of hydrogen, and one-third full of oxygen. If we employ air, one-fifth of which only is oxygen, we must take five volumes to two of hydrogen, or two and a-half of air to one of the combustible gas.


Fig. 30.

374. Wide-mouthed vessels much thicker and stronger than the ordinary gas jars must be used in these experiments; and it is well to wrap the vessel in a towel before applying a light, so that, if the glass should break, the

hands may escape injury. The fact that hydrogen forms an explosive mixture with air, should be kept in recollection whenever experiments are made with the gas, as many accidents have occurred from ignorance or forgetfulness of the fact.

375. The sound in such explosions is occasioned by the concussion of the air, from the propulsion against it of the steam resulting from the combination of hydrogen and oxygen, which is in a highly-expanded state, owing to the heat produced.

376. If the detonations are made to succeed each other very rapidly, a musical note is produced. To observe this, a jet of hydrogen should be kindled, and a glass tube, open at each end, about two feet long, placed over it like a chimney (fig. 31). The flame elongates, and begins to flicker, an effect which is owing to the tube preventing a large volume of air reaching the jet. The gas, in consequence, has to mix *comparatively* slowly with a volume of air sufficient to burn it, and combustion then happens with a slight detonation. This process of mixture with air, followed by explosion, proceeds with great rapidity, so that the detonations succeed each other with such swiftness, as to prevent the ear observing the intervals between them. A continuous sound, or musical note, is thus produced, which varies according to the size of the jet, and the length and diameter of the glass chimney placed over it. This arrangement has been called the hydrogen harmonicon; but any of the combustible gases will produce musical notes if burned in the same way.

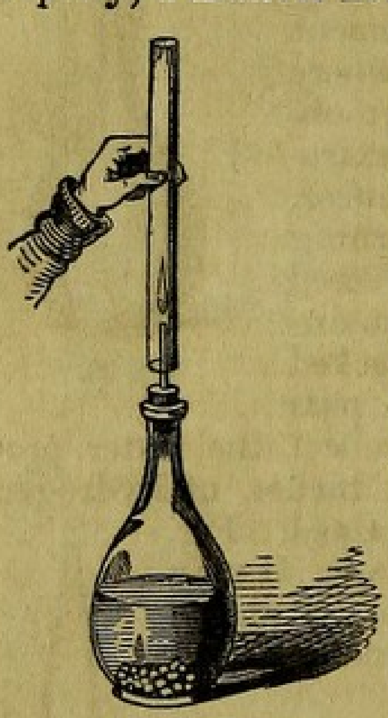

Fig. 31.

377. Hydrogen and oxygen may be preserved mixed for any length of time without combining. Combination is determined in a moment by the introduction of any body at a red heat, by the application of flame, or the passage of an electric spark. Another very interesting method of determining the union of the gases, is the introduction into a mixture of them of a piece of the metal platina perfectly clean, which, in a way not easily explained, causes their rapid union, with the evolution of heat and light.

378. An instantaneous lamp has been devised, which takes advantage of this property of platina. It consists essentially of a

vessel in which hydrogen is generated and stored (fig. 32), with a stopcock *a*, by means of which a jet of the gas can be directed against some finely-powdered, or, as it is called, spongy platina, contained in a small brass cup *b*. The hydrogen mingles with air before reaching the platina, which at once inflames the mixture, and a match may be lighted at the flame. This ingenious apparatus is now superseded by the lucifer-match.

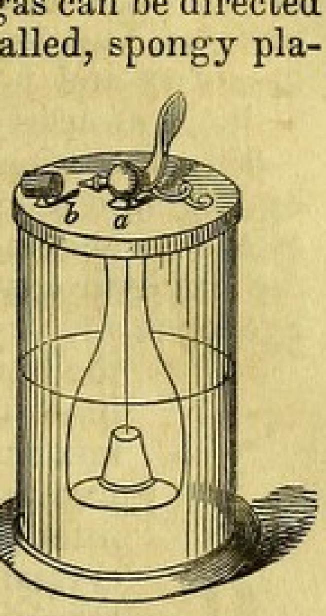

Fig. 32.

379. It has already been mentioned that the flame of hydrogen is very feebly luminous. The highest illuminating power, however, may be conferred upon it by introducing into its flame any infusible solid, which it may raise in temperature. The solid made use of for this purpose is generally quicklime, and the hydrogen is maintained in full combustion by mixing it with oxygen before kindling it. This is most easily and safely effected by conducting hydrogen through one tube, and oxygen through another, from separate gasholders containing them. These tubes terminate in a single canal, where they are allowed to mix, and from which they are conducted by curved jets or nozzles, which bend upwards like the arches of a royal crown. These nozzles permit the mixed gases to flow out against a piece of lime, which occupies the place filled in a crown by the cross-topped ball. The accompanying woodcut (fig. 33) will explain the arrangement. A, canal where the tubes conveying hydrogen and oxygen terminate; B, chamber from which the nozzles proceed; C C, curved tubes terminating in small apertures, by means of which the burning gases are directed against the lime; D, spindle to support lime; E, cylinder of quicklime or limestone.

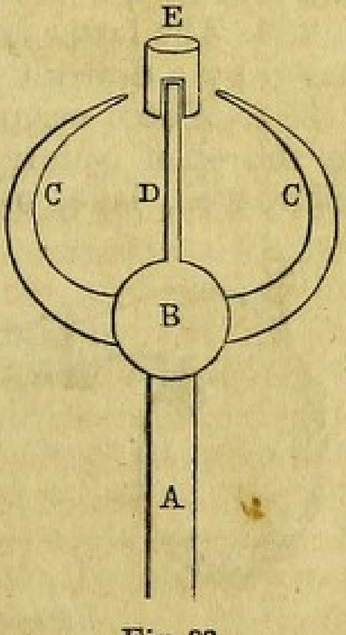

Fig. 33.

380. In using this arrangement, the hydrogen is first kindled, and allowed to heat the lime, which communicates to its flame a brick-red colour, owing to the combustion of the metal calcium, of which lime is the oxide. The oxygen is then turned on, when the flame becomes much smaller, and changes to a bright white light of the greatest intensity. It is the lime, in reality, however, which evolves the light,

the office of the burning gases being to maintain the solid at the high temperature essential to its exhibition of luminosity. This lime-ball light, as it is called, rivals sunlight in purity and brilliancy. It is visible on a clear night at a distance of nearly a hundred miles.

381. The intense heat evolved during the combustion of hydrogen in oxygen is turned to account in a modification of the arrangement just described, which is distinguished as the oxyhydrogen blowpipe. In it the tubes conveying the hydrogen and oxygen terminate in a canal, shaped exactly like the letter Y (fig. 34). The oxygen tube joins the one limb, the hydrogen tube the other, and the gases mix in the stalk of the Y, which terminates in a fine aperture like an ordinary gas jet. The most infusible substances, such as pipeclay and rock-crystal, are melted or even dissipated in vapour if exposed to the flame of the mixed gases. Steel, iron, antimony, copper, bismuth, and all the ordinary metals, burn with great brilliancy, and are most of them dissipated as oxides before this blowpipe flame. The heat it produces far exceeds in intensity or temperature that producible by our most powerful furnaces. It is employed in the arts to melt the refractory metal platina.

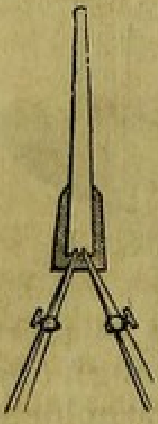

Fig. 34.

382. Hydrogen and oxygen form two compounds—namely, water, which is the protoxide, HO, and oxygenated water, the peroxide, deutoxide, or binoxide, HO_2.

383. The latter is a rare substance, which can only be prepared by a difficult process.

384. Water occurs tolerably pure in rain or snow collected in the open country, at a distance from dwellings. Spring, river, well, lake, mineral, and sea water, all contain various substances dissolved in them, which render them unsuitable for many purposes. It would be premature in this place to discuss the nature or properties of the substances which confer on ordinary water such characters as 'hardness,' 'softness,' medicinal virtues, and the like. These will be considered with more advantage under such bodies as sulphate and carbonate of lime, carbonic acid, sulphuretted hydrogen, &c. which

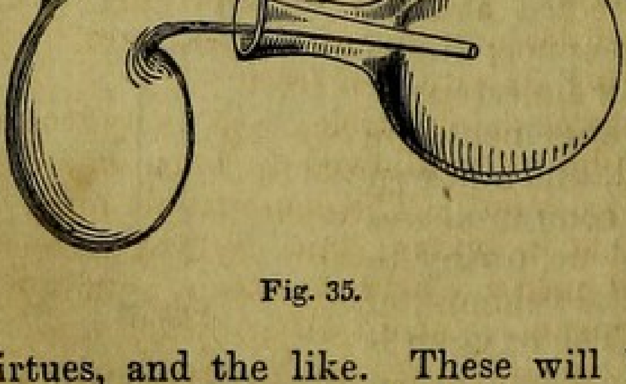

Fig. 35.

impregnate many natural waters, and give them peculiar properties.

385. Water is obtained pure for chemical purposes by distilling it in a copper still provided with a condenser. Instead of a still, a glass retort may be used (fig. 35), the neck of which passes into an empty flask, which is kept cool by placing it in a basin of cold water, or by surrounding it with cloths, or bibulous paper kept wet by a stream of water. The latter arrangement is called a retort and receiver.

NITROGEN.

Synonyme, Azote; equivalent, 14; *symbol,* N; *density,* 971·37, *or* 972; *combining measure,* □□

386. *Distribution.*—Nitrogen constitutes four-fifths, or 79 per cent., of air by volume. It is present in the native nitrates or nitres, saltpetre (nitrate of potass), and cubical nitre (nitrate of soda). It occurs also in coal, and in a few other minerals, and is a constant ingredient of plants and animals.

387. *Name.*—The term nitrogen signifies the nitre-producer, and was given to this substance in relation to its occurrence in the important substance saltpetre. Azote is derived from α, signifying, in combination, to deprive of, and ζωη (zoë), life, and was applied to this substance by the French chemists in consequence of animals dying when introduced into the gas. It is not, however, poisonous, as the name might imply, but destroys life, as water does when an animal is drowned in it, by excluding air, and so occasioning suffocation.

388. *Preparation.*—Nitrogen is prepared in two ways. The one, which consists in heating nitric acid on raw butcher-meat in a retort, does not readily yield it pure. The other, and more convenient method, consists in depriving atmospheric air of the oxygen, which forms a fifth part of its volume, and thereby leaving its nitrogen free.

389. For this purpose some combustible, such as hydrogen, sulphur, alcohol, or phosphorus, is allowed to burn in a confined portion of air till it goes out. The combustible must be one whose oxide is soluble in water; thus hydrogen forms water; alcohol, water and carbonic acid; sulphur, sulphurous acid; and phosphorus, phosphoric acid—all of which dissolve in water. The most convenient combustibles are alcohol and phosphorus. One or other of these is to be placed within a metallic cup, mounted on a pedestal, placed on the shelf or

[redacted] D.

stool of the pneumatic trough, or in a basin of water. The combustible is then to be kindled, and a jar full of air placed over it. If alcohol be employed, the carbon and hydrogen which it contains rapidly unite with the oxygen of the confined air, and form carbonic acid and water, which are immediately dissolved by the liquid in which the jar stands. If the experiment be made properly, as soon as the alcohol ceases to burn, the water begins to rise within the jar, and ascends till it occupies about one-fifth part of its capacity, replacing the oxygen, which has been converted into water and carbonic acid. The gas which remains is the nitrogen of the air. Alcohol has this advantage over most combustibles, that it leaves the nitrogen colourless, but it frequently ceases to burn before the whole of the oxygen is withdrawn from the air. Phosphorus, accordingly, which removes every trace of oxygen, is generally preferred; but when it is made use of, the nitrogen must be allowed to stand over water till the phosphoric acid, which spreads through it in white fumes, has been absorbed by the water.

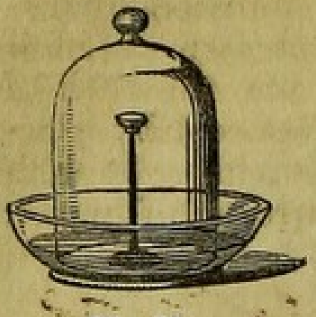

Fig. 36.

390. *Properties.*—Nitrogen is strikingly characterised by the absence of all positive properties. It has no taste, colour, or odour; no action upon colouring matter; it neither burns nor supports combustion; and it cannot maintain animal respiration.

391. The only experiment which can readily be tried with it is its action on flame. In relation to combustion, gases are divisible into three classes:—1. Those which support combustion, of which oxygen is the best example; 2. Those which are combustible, of which hydrogen is one; and 3. Those which neither burn nor support combustion, among which nitrogen ranks. A candle introduced into the gas (fig. 37) is at once extinguished without kindling the nitrogen.

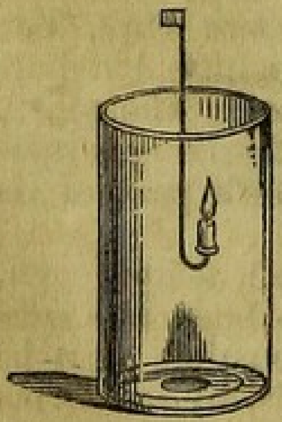

Fig. 37.

392. In reality, however, nitrogen is combustible. This may be proved by mingling it with hydrogen, and kindling the mixture as it issues from a jet into the air. The nitrogen burns to a small extent along with the hydrogen, so that whilst the latter combines with oxygen to form water, the former unites with the same gas to form nitric acid. Electric sparks or lightning discharges, when they pass through air,

[redacted]

determine in like manner the combustion of the nitrogen, and the production of nitric acid.

393. Negative as seem all the properties of nitrogen when uncombined, no substance forms compounds possessed of more marked properties, as nitric acid (NO_5) and ammonia (NH_3) may serve in the meanwhile to illustrate. Before discussing, however, any of the compounds of nitrogen, it is desirable to consider the constitution of atmospheric air, of which it forms so large a [redacted]

THE ATMOSPHERE.

394. The air is not a chemical compound, but a mechanical mixture of several gases. The most abundant of these ~~is~~ are nitrogen. The next in quantity is oxygen, on which the positive chemical characters of the air, such as its power to support combustion and animal respiration, chiefly depend. Besides these gases, carbonic acid, CO_2, light carburetted hydrogen, CH_2, and ammonia, NH_3, are present in small quantity, as well as a varying amount of watery vapour. Minute quantities also of the different volatile compounds which are evolved at the earth's surface, find their way into the atmosphere, but do not permanently affect its constitution.

395. The gases first mentioned, on the other hand, are constantly present, and (with the exception of CH_2) are essential to the maintenance of animal and vegetable life on the surface of the globe. They occur in the following proportions in the atmosphere:—In 100 volumes of air there are present 79 volumes of nitrogen and 21 of oxygen.* In 100 parts by weight of air there are 77 by weight of nitrogen and 23 of oxygen. The one of these latter numbers is not a multiple of 14, the atomic weight of nitrogen, nor the other of 8, the atomic weight of oxygen, as they should be, if air were a chemical compound.

396. Of carbonic acid there are present from 4 to 6 measures in 10,000 of air; and the proportion of carburetted hydrogen is nearly the same.

397. The amount of aqueous vapour is dependent chiefly

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* Air varies slightly in composition, so that the proportion of oxygen found in it is sometimes a little less than 21, and the nitrogen a little more than 79, volumes per cent. Thus it may contain 20·9 oxygen, and 79·1 nitrogen. It may, however, with sufficient propriety be regarded as always presenting the composition stated in the text; and it will be found convenient to call the proportion of oxygen one-fifth, and that of nitrogen four-fifths, of the volume of air.

upon temperature, so that it varies with latitude, the season, region of the atmosphere, &c.

398. The quantity of ammonia is so small, that it has not hitherto been found possible to determine its relative quantity. It occurs in the atmosphere, combined with carbonic acid, as carbonate of ammonia; and with nitric acid, as nitrate of ammonia.

399. The presence of oxygen in the atmosphere is proved by combustible bodies becoming converted into oxides when made to burn in it. Thus hydrogen becomes water, the oxide of that gas.

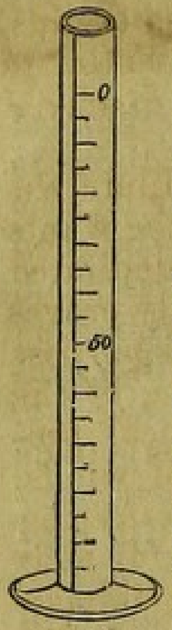


Fig. 38.

400. The presence of nitrogen is demonstrated by the result of combustion in confined portions of air, as we have mentioned whilst describing the method of obtaining free azote.

401. The relative quantity of these gases may be most simply ascertained by introducing into a tube, graduated into a hundred equal parts, the same number of measures of air. A piece of phosphorus attached to a wire is then to be passed up into the confined portion of air, the tube all the while being kept vertically in the pneumatic trough with its mouth downwards, and under water. The arrangement is to be left undisturbed for twelve hours, during which period the phosphorus, though not kindled, slowly combines with the oxygen of the air, forming an acid which the water dissolves. At the end of the time specified, the phosphorus may be withdrawn, and the volume of gas which remains observed. The water should rise through 21 spaces, replacing the oxygen withdrawn, and leave 79 volumes of nitrogen.

402. The presence of carbonic acid in the atmosphere is demonstrated by leaving a shallow vessel containing lime-water in the open air. The lime-water rapidly becomes turbid, owing to the combination of the carbonic acid with the lime to form the insoluble carbonate of lime, chalk (CaO,CO_2).

403. To detect ammonia, air must not be taken, but rain-water or snow, both of which, in falling through the atmosphere, carry with them the ammonia diffused through it. Several gallons of rain-water must be employed, or many pounds of snow. The rain, or melted snow, is placed in a still, and a fourth part of it distilled over. The ammonia (or rather its carbonate), which is volatile, accompanies the water, which first rises in vapour. To this, after its condensation, a little muriatic acid is added, which combines with the am-

monia to form sal-ammoniac (NH_3HCl), which is not volatile at 212° F. The acidulated liquid is then evaporated to dryness, and leaves a slight residue of ammoniacal salt, which, when mixed with quicklime, gives off its ammonia. This is easily recognised by its characteristic odour of hartshorn.

404. The uses of the several gases and vapours mentioned, are now pretty well ascertained. The importance of water-vapour to animal and vegetable life does not call for lengthened illustration. The oxygen supports the respiration of animals, entering their bodies by their lungs or other breathing organs, and effecting changes on the fluids and tissues, essential to the maintenance of life. Oxygen also enters plants, dissolved in the water which they absorb by their roots.

405. The nitrogen of the atmosphere serves to dilute the oxygen to the point, or strength most suitable for the wants of living beings. Animals made to breathe pure or undiluted oxygen are thrown into a state of fever, which quickly proves fatal. Nitrogen, however, also serves an important purpose in the economy of nature, by increasing the volume of the atmosphere without conferring upon it active chemical properties. Provision is thus made for the occurrence of winds, the tempering of climate, the diffusion of heat, the scattering of the sun's light, and the realisation of other useful ends essential to the welfare of man and the other living inhabitants of the globe.

406. The carbonic acid supplies plants with their most abundant element, which they obtain from it by decomposing it into its constituents, carbon and oxygen; the former they retain, the latter they restore to the atmosphere. This decomposition is effected chiefly by the leaves, but also by the other green parts of plants. It occurs only during the day; and to the greatest extent when the sun is shining most brightly. During darkness, plants totally lose the power of decomposing carbonic acid. This remarkable action of living vegetables will be referred to again under the head of carbonic acid.

407. The ammonia which is constantly reaching the air, as a product of the decomposition of animal and vegetable matters, is brought down to the earth, as we have seen, by each shower that falls; and entering the roots of plants along with the rain-water, supplies them with nitrogen, an element essential to their growth. This will be referred to again under the head of ammonia.

408. The physical properties of the atmosphere are of as much interest as the chemical, but cannot be discussed at length here. The height of the atmosphere is about forty-

five miles—that is to say, it spreads from the earth in every direction to that extent, so that our globe may be compared to a cannon-ball enclosed in a sphere of glass. The density of the atmosphere, however, is not the same throughout, but rapidly diminishes as we recede from the earth, its lower strata being compressed by those above them, so as to contain within the same volume a much greater weight of air. Were the atmosphere of uniform density throughout, and its density the same as it is at the surface of the sea, its height above the earth would be only five, instead of forty-five miles, as it actually is.

409. The density of air, as we have already mentioned, when treating of specific gravity, is estimated at 1000, and it is the standard of comparison for the specific gravities of gases and vapours. It is 810 times lighter than water, and 11,000 times lighter than mercury. Nevertheless its quantity is so considerable, that it exerts a great pressure on objects at the surface of the earth. This pressure, at the level of the sea, is equal in amount to fifteen pounds on each square inch, or to the weight of a column of mercury thirty inches in height, or one of water nearly thirty-four feet. This pressure is constantly varying, however, even at the same level, as the risings and fallings of the barometer enable us to mark and to measure.

410. The air, as we have particularly mentioned, is a mechanical mixture, not a chemical compound; nevertheless it is exceedingly uniform in constitution. No difference has been detected in the composition of air in one part of the world as compared with another; nor does air brought from the summits of high mountains, or the greatest elevations accessible to balloons, appreciably differ from that in the lowest valley or the deepest mine. The atmosphere, moreover, of unhealthy districts, such as the Campagna of Rome, appears identical in chemical constitution with that from the most salubrious localities, or from above the sea. These remarks apply chiefly to the nitrogen, oxygen, and carbonic acid of the air; and they lead to the discussion of a very important law, which regulates the mixture of gases with each other.

DIFFUSION OF GASES.

411. If the gases of the atmosphere were combined chemically, its uniformity in composition would not surprise us; neither would this be remarkable if the gases had the same densities; but we have already seen that their specific gravi-

ties are very different. The following numbers illustrate this:—

Gas.	Specific Gravity.
Air,	1000
Nitrogen,	972
Oxygen,	1105
Carbonic acid,	1524

Where the densities are so different, we should expect that the gases would arrange themselves in the order of their densities; so that the lightest of the three, the nitrogen, should accumulate in the upper regions of the atmosphere; and the heaviest of them, the carbonic acid, be found preponderating at the surface of the earth; whilst the intermediate oxygen occupied the middle space between the nitrogen and carbonic acid. Liquids which do not act chemically on each other invariably arrange themselves in layers according to their densities: thus oil, water, and mercury, even if shaken together, would speedily dispose themselves in strata, with the oil highest, and the mercury at the bottom. No such separation of the atmospheric gases takes place. A long shut tube full of air, kept for many months in a vertical position, is found to contain the gases mixed in the same proportion throughout its whole length.

412. What is still more curious, gases differing much more in relative density than those of the atmosphere, will uniformly mix with each other, although the heaviest be placed lowest. In illustration of this, the following instructive experiment may be tried:—Fill one bottle at the pneumatic trough with carbonic acid, and another with hydrogen, closing their mouths afterwards with corks or stoppers. Place the carbonic acid bottle standing on a table, and fix into its mouth, by means of a perforated cork, a glass tube two or three inches long, having attached to its upper extremity a second cork, fitting the mouth of the hydrogen bottle, into which it is to be inserted, the hydrogen bottle having its mouth turned downwards. The bottles thus arranged, as in the accompanying figure (fig. 39), are to be left undisturbed for an hour or more. Carbonic acid is twenty-two times heavier than hydrogen, yet it ascends through it, the greatly lighter hydrogen simultaneously descending through the heavier gas, till ultimately an exactly uniform mixture of the gases is contained in the bottles, and this notwithstanding the narrowness of the tube which connected them. The presence of carbonic acid in

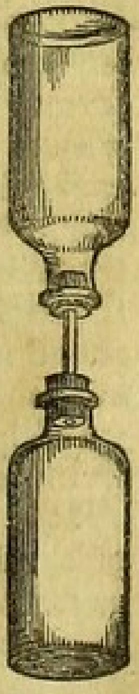


Fig. 39.

the upper bottle (originally filled only with hydrogen) may be shown by pouring into it lime-water, which will immediately become milk-white, owing to the production of carbonate of lime. The presence of hydrogen, in like manner, in the lower bottle (at the beginning of the experiment occupied solely by carbonic acid), may be demonstrated by transferring its contents at the pneumatic trough to a gas jar, and adding a little air or oxygen. The hydrogen will then burn on applying a flame. If oxygen be not added, the carbonic acid prevents the combustion of the hydrogen.

413. This simple experiment shows that gases are under the influence of a force powerful enough to resist the influence of gravitation, and to prevent its taking effect upon mixtures of gases as it does on mixtures of liquids. It has been named *the force of gaseous diffusion;* and the spreading of gases through each other, against the solicitation of gravity, is spoken of as their mutual *diffusion.*

414. It is this diffusive force which maintains the atmosphere uniform in constitution; both by retaining in a state of mixture gases which have once mingled, and by causing the uniform diffusion through the atmosphere of every gas and vapour which reaches it, whether it be light or heavy. Thus when hydrogen is allowed to escape from a balloon, it does not ascend to the upper regions of the atmosphere, but diffuses equally through it in all directions. In like manner the carbonic acid which the combustion of fuel on the earth is constantly throwing into the air, does not remain at the surface, or descend into pits and mines, but spreads quite uniformly through the whole mass of air. So also the oxygen, which, as we have seen, plants are constantly separating from carbonic acid during daylight, does not accumulate around them, but is uniformly mingled with the other constituents of the atmosphere. The air is thus maintained of equal purity throughout. A noxious gas like carbonic acid, which would prove injurious if confined to one spot, is thus rapidly diluted, and so rendered harmless; and a useful gas like oxygen is speedily diffused through the whole atmosphere, so that every living creature equally profits by it.

415. When gases exchange places with each other, in virtue of the force of diffusion, they do not, whilst diffusing, replace each other in equal volumes; but, on the other hand, a larger volume of a light gas passes in one direction than of a heavy gas in the opposite. This admits of being illustrated by a simple and very beautiful experiment. A glass tube or cylinder, open at both ends, from one to two feet in length, and from half an inch to two inches in diameter, is closed

at one extremity by a plug or plate of stucco, about half an inch in thickness, and well dried. Stucco, when dry, is traversed by a multitude of very fine pores or canals, through which gases pass readily. At the same time it affords a certain amount of obstruction to their passage, which enables the law regulating their diffusion through each other, when of different densities, to be observed.

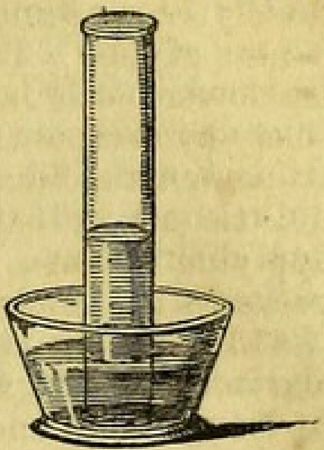


Fig. 40.

416. Such a cylinder as we have described is to be filled with hydrogen, but not at the water-pneumatic trough, as this would wet the stucco, which then becomes impervious to gases. The cylinder is most conveniently filled by holding it over a vertical tube proceeding from a gasholder; a large jar, or bag full of hydrogen. The tube from which the hydrogen is issuing, is passed up till it almost touches the stucco plate, over which a square of window or plate-glass is laid whilst the gas, which is supplied in a rapid stream, is displacing the air. When the cylinder is full of hydrogen, the tube is quickly withdrawn, and the mouth of the cylinder closed by a gas-tray. This is retained in its place by one hand, whilst a finger of the other is laid on the glass plate covering the stucco, till the cylinder has been transferred, with its open end downwards, to a basin of coloured water. The tray and glass plate are now removed, and the eye fixed on the surface of the liquid within the cylinder. The plate of stucco is now in the condition of a porous screen or partition, on the upper side of which there is one (complex) gas—namely, air, and on its lower side another—namely, hydrogen, which is more than fourteen times lighter. The gases immediately begin to exchange places through the stucco; but, in virtue of the law we have mentioned, a much larger volume of the lighter hydrogen ascends in the one direction, than of the heavier air descends in the other. Thus whilst nearly four cubic inches (3·83) of hydrogen leave the tube, only one cubic inch of air enters it. The water, accordingly, rapidly rises to fill the space previously occupied by the hydrogen, which has not been replaced by an equal volume of air. For every four cubic inches (or nearly so) which escape, the water rises three cubic inches, being forced upwards by the pressure of the air acting on the liquid in the basin.

417. If the cylinder, when filled with hydrogen, were covered by a large bell-jar full of oxygen, then exactly four

cubic inches of hydrogen would leave the tube for each cubic inch of oxygen that entered it. These numbers—namely, 4 in the case of hydrogen, and 1 in that of oxygen—are inversely as the square roots of the densities of these gases, for oxygen is exactly sixteen times heavier than hydrogen, or their relative densities are as 16 (O) to 1 (H), whilst the square root of 16 is 4, and that of 1 is 1. If the gases replaced each other in volumes, which were *as* the square roots of their densities, we should have four cubic inches of oxygen entering the stuccoed cylinder for one of hydrogen that left it; and the water, if originally standing at some height within the cylinder, would descend instead of ascending. Exactly the reverse of this we have seen to be the case. It is the hydrogen which gives four cubic inches, whilst the oxygen returns only one. Or the replacing volumes are not *as*, but *inversely as*, the square roots of their densities.

418. It is the same with other gases, so that it can be announced, as a general law, that the *diffusion-volumes* of gases—that is, the volumes in which they replace each other—are inversely as the square roots of the densities of the gases. If this particular law be forgotten, the more general one may be remembered, that when light and heavy gases are exchanging places, a larger volume of the light gas passes in the one direction than of the heavy gas in the other.

419. The spread of infectious diseases, the ventilation of apartments, the maintenance of animal respiration, and other important natural and artificial processes, are controlled by the law of gaseous diffusion, which belongs more strictly to physics than to chemistry, but cannot be omitted from any treatise on the latter.

COMPOUNDS OF NITROGEN AND OXYGEN.

420. Nitrogen forms several important compounds both with oxygen and hydrogen. Those containing the latter element will be discussed along with the fixed alkalies. Three of the oxides (of which altogether there are five, see page 36)—namely, nitric acid, nitrous oxide, and nitric oxide—are important substances, and possess striking properties. The remaining two—hyponitrous and nitrous acids—are less interesting bodies:—

Nitric Acid.

Synonyme, Azotic acid; symbol, NO_5; *equivalent,* 54.

421. This acid has been known from an early period, and still retains, as one of its titles, the appellation of aquafortis,

given to it by the alchemists. It consists of one atom (14) of nitrogen, and 5 atoms of oxygen (8), so that its atomic weight, when anhydrous, is 54. It is scarcely known, however, except in a state of combination. What is ordinarily called free nitric acid is in reality a hydrate of that substance, consisting, when strongest, of an equivalent of this acid, NO_5, united to an equivalent of water, HO, so that it is written HO,NO_5. Anhydrous nitric acid, NO_5, has only very recently been procured by passing a current of dry chlorine gas over dry nitrate of silver, AgO,NO_5, raised in temperature. The acid appears in white prismatic crystals, and has not yet been much examined.

422. *Distribution.*—Nitric acid occurs in nature chiefly as the nitrate of potass and nitrate of soda. It is found also in the atmosphere in small quantity, especially after thunderstorms. It is believed to be produced as a result of the lightning-discharges (as it can be produced on the small scale by sending electric sparks through air), and to unite, after its formation, with the ammonia present in the atmosphere, so that it is found in rain-water as the nitrate of ammonia.

423. *Preparation.*—On the small scale, nitric acid is most conveniently prepared by distilling together in a glass retort, connected with a receiver, oil of vitriol HO,SO_3, and nitrate of potass KO,NO_5 (see fig. 35). The accompanying figure (fig. 41) shows a more elaborate arrangement for the distillation of nitric acid. It is applicable to the distillation of other volatile liquids also. Equal weights of the two substances are placed in the retort, to which heat is then applied. Each of the acids exchanges the oxide or base with which it was united at the beginning of the experiment, for that in combination with the other acid. Thus the sulphuric acid, SO_3, abandons the water to unite with the potass, forming the sulphate of that base. KO,SO_3; whilst the nitric acid relinquishes the potass, and unites in preference with the water, forming the nitrate of water, or hydrated nitric acid, HO,NO_5. The latter distils over into the receiver, where it condenses; the sulphate of

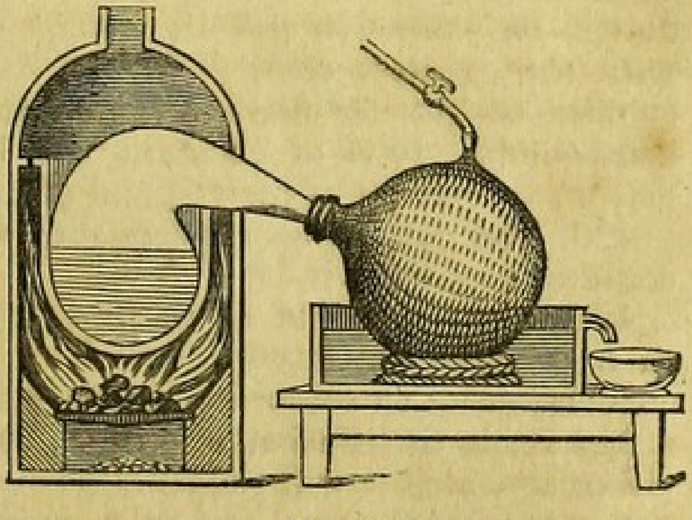


Fig. 41.

potass remains behind in the retort. The decomposition may be illustrated thus in symbols:—

Before decomposition, KO,NO_5 and HO,SO_3;
After decomposition, HO,NO_5 and KO,SO_3.

Or more fully thus:—

$$\begin{tikzcd} KO \arrow[r, dotted] \arrow[dr, no head] & NO_5 = HO,NO_5. \\ HO \arrow[r, dotted] \arrow[ur, no head] & SO_3 = KO,SO_3. \end{tikzcd}$$

Here the dotted horizontal lines indicate the bodies in combination at the beginning of the process, the oblique unbroken lines the exchange of acid and base that occurs *during* the decomposition, and the double horizontal lines $=$ (the algebraic sign of equal to) the bodies in combination at the end of the process.

424. All nitrates yield nitric acid when distilled with oil of vitriol. The nitrates of potass and soda, however, are the only ones sufficiently abundant and cheap to be used on the large scale.

425. *Properties.*—Nitric acid (HO,NO_5) is a colourless, transparent liquid when quite pure, but generally exhibits a straw or yellow tint. Its density, when strongest, is about 1520 (compared with water, 1000). It has a peculiar odour, a very sour taste, and is exceedingly corrosive. It dissolves nearly all the metals, except gold and platina; combines with all the basic oxides and other bases, forming, by so doing, an extensive and important series of salts; and acts with the greatest energy on the majority of organic substances, converting them into new and generally remarkable compounds. It is of constant use in the laboratory, especially as a solvent of metals, and of ores and other minerals.

426. The following experiments will exhibit all its more striking properties:—

1. Its odour should be noticed, and its taste, after it has been greatly diluted.

2. Its effect on colouring matter may be observed by adding a few drops to infusion of litmus, or of the purple cabbage, either of which it will redden.

3. It stains the skin and other animal substances yellow, as may be well seen by dipping white wool or worsted into the acid.

4. If iron, zinc, or copper, in filings or small fragments, be thrown into it, it evolves a dark brown or ruddy gas (nitrous acid, NO_4). This property is highly characteristic of nitric acid.

5. A grain or two of morphia (a crystalline substance pre-

pared from opium), or any of its salts, if added to this acid, give it a dark orange colour, soon fading into yellow.

6. A weak solution of indigo in sulphuric acid has its blue colour destroyed by nitric acid, especially if the liquid be heated.

7. Paper soaked in a solution of potass, when dipped into nitric acid, and dried, becomes converted into match-paper, owing to the production of nitrate of potass.

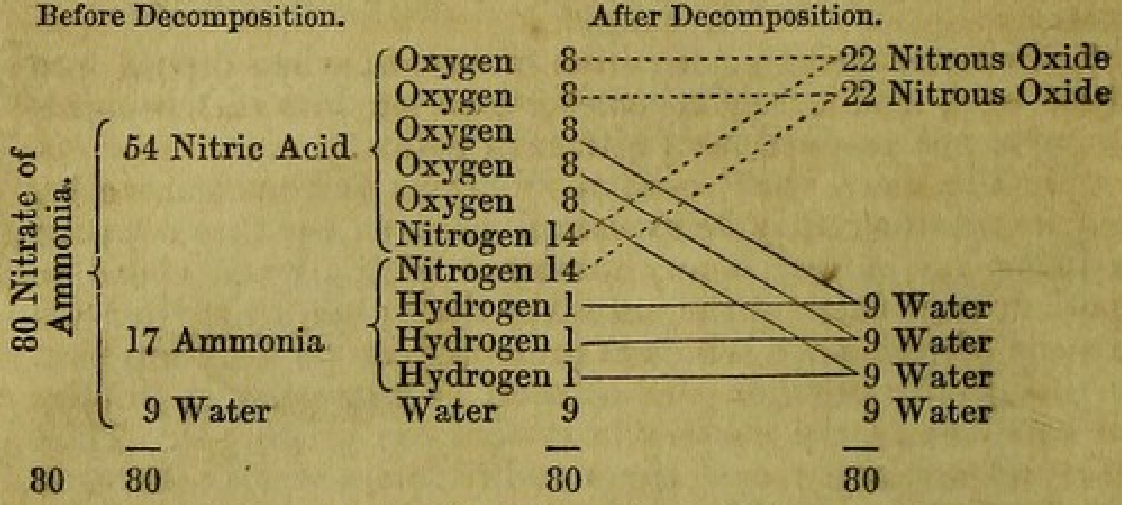
427. The word 'test' constantly occurs in chemical works, and its meaning may be explained here, on our first occasion of using it. A test is any substance which, when added to another, demonstrates the nature of that other, by giving rise to some phenomenon which is presented by no body but one, so that if the peculiar phenomenon be witnessed, it implies the existence of the solitary body that can produce it. Thus no liquid but nitric acid gives ruddy fumes when a metal is added to it; hence the metals, such as copper and zinc, are tests of nitric acid, which they identify by causing the evolution from it of nitrous acid.

Nitrous Oxide.

Synonyme, protoxide of nitrogen—laughing gas; equivalent, 22; *symbol,* NO; *density,* 1520; ☐☐

428. All the lower oxides of nitrogen are prepared, directly or indirectly, from nitric acid. To procure nitrous oxide, nitric acid is neutralised with ammonia, and thereby is converted into the nitrate of ammonia, a crystalline salt, very like nitrate of potass in appearance. The nitrate of ammonia is placed in a retort, and heat applied, when it is entirely resolved into nitrous oxide and water. The former may be collected in jars at the pneumatic trough whilst the water condenses. The change which occurs is the following:—Nitrate of ammonia consists of three things—nitric acid, ammonia, and water. Ammonia is a compound of one equivalent of nitrogen and three of hydrogen—NH_3. When heated, the water existing in the nitrate is given off; the three equivalents or atoms of hydrogen in the ammonia combine with three out of the five atoms of oxygen in the nitric acid, forming three atoms of water. There are thus left two atoms of oxygen and two of nitrogen; the one of the latter derived from the nitric acid, the other from the ammonia. Each equivalent of nitrogen becomes united to one equivalent of oxygen, and in this way two equivalents of nitrous oxide result.

429. As this process is an interesting and important one, we illustrate it by a detailed diagram from Professor Graham's Chemistry:—



Or in symbols, $NH_3,HO+NO_5 = 2NO$ and $4HO$.

430. *Properties*—A colourless invisible gas, possessing a faint, agreeable odour, and pleasant, sweetish taste. Water dissolves about three-fourths of its volume of the gas, and a solution so prepared has been sold as an exhilarating drink. It is only, however, when it enters the body by the lungs that this gas occasions that peculiar form of excitation which has made it so famous.

431. It supports combustion brilliantly; throws into full flame a red-hot match or paper; and detonates when exploded with an equal measure of hydrogen. It is distinguished from oxygen by its solubility in water, its odour, and its taste. Sulphur also, which burns in oxygen with a blue or dark-purple flame, exhibits in nitrous oxide a beautiful rose tint.

432. It is unnecessary to specify what experiments on combustion should be tried with this gas, as the directions under the head of oxygen apply exactly to it.

433. The most interesting property of nitrous oxide is its action on the living body. When rapidly respired, it produces a transient, but very pleasant form of excitement, resembling that occasioned by wine or opium. The sensations and emotions experienced during the respiration of this gas are generally pleasurable, and are not followed by depression or other unpleasant symptoms. It frequently, however, occasions violent muscular action; the party breathing it, especially if restrained, struggling powerfully, and striking out in every direction. The gas, accordingly, should never be administered unless in the presence of one or two persons strong enough to resist effectually the struggles of the party

under the influence of the nitrous oxide, otherwise he may injure himself and others.

434. In the great majority of cases no unpleasant result follows the respiration of this gas; but on some persons it acts injuriously, and it cannot be considered safe to administer nitrous oxide in any circumstances, unless in the presence of a medical man. Care, moreover, should be taken that the gas is pure; in particular, that the nitric acid employed to prepare the nitrate of ammonia contain no muriatic acid; and the salt should not be heated too strongly when collecting the nitrous oxide, otherwise the latter may be rendered irritating by the presence of fumes of nitrate of ammonia, and irrespirable products of its hasty decomposition.

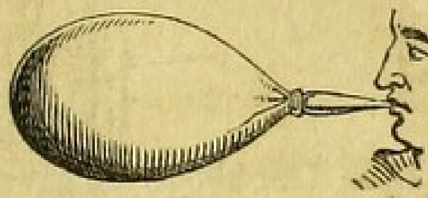


Fig. 42.

435. Nitrous oxide is breathed from a waterproof cloth bag large enough to contain two or three quarts, having a wooden tube or nozzle. It is replenished, as wanted, from a gasholder.

Nitric Oxide.

Synonyme, binoxide or deutoxide of nitrogen; symbol, NO_2;

equivalent, 30; *density,* 1038; ⊞

436. *Preparation.*—By pouring diluted nitric acid on copper clippings or filings. A retort, or any other of the pieces of apparatus employed in the case of hydrogen, will serve for the preparation of this gas. See fig. 27. It does not require the application of heat.

437. Nitric acid contains five equivalents of oxygen, nitric oxide two; if, therefore, we can remove three atoms of oxygen from the former, we shall convert it into the latter. The copper effects this separation of oxygen. One equivalent of nitric acid, HO,NO_5, is acted on by three equivalents of copper, each of which unites with one of oxygen, forming the protoxide of copper, CuO. This oxide then unites with undecomposed nitric acid, forming the nitrate of the oxide of copper, CuO,NO_5, whilst the nitric oxide escapes with effervescence. The change may be illustrated thus in symbols; each of which, it will be remembered, represents an atom or equivalent of the body taken:—

Before decomposition, $4HO,NO_5$ and $3Cu$.
First stage of decomposition, $HO,NO_5+3Cu=NO_2$ and $3CuO$.
Second stage of decomposition, $3CuO+3NO_5=3CuO,NO_5$.

438. One-fourth only, it will be observed, of all the nitric acid taken is reduced to the state of nitric oxide, the remaining three-fourths being spent in uniting with the oxide of copper resulting from the decomposition of the one-fourth. The change may be illustrated more fully in symbols—the nitric acid which is decomposed being represented as if anhydrous, and with each of its atoms of oxygen separately—thus:—

$$\left.\begin{matrix}\mathrm{N}\\\mathrm{O}\\\mathrm{O}\end{matrix}\right\} \quad = \quad \mathrm{NO_2}.$$

$$[\mathrm{Cu\ \ O}]+\mathrm{NO_5}=\mathrm{CuO,NO_5}.$$

$$[\mathrm{Cu\ \ O}]+\mathrm{NO_5}=\mathrm{CuO,NO_5}.$$

$$[\mathrm{Cu\ \ O}]+\mathrm{NO_5}=\mathrm{CuO,NO_5}.$$

439. The above is given as an example of the convenient way in which the symbols can be employed to illustrate chemical decompositions. The student should follow every chemical change in a similar way on his slate, and exercise himself in devising, instead of copying, diagrams. It will be found one of the most effectual methods of rapidly acquiring a knowledge of chemistry.*

440. *Properties.*—Nitric oxide is colourless and invisible, very sparingly soluble in water, incombustible, irrespirable, and not a supporter of ordinary combustion.

441. It possesses one remarkable and useful property: when it meets air, it gives rise to the production of a dark-brown or ruddy gas—nitrous acid, NO_4. This change is owing to its combining with the oxygen of the air, $NO_2 + O_2 = NO_4$; and, as may be expected, the change occurs still more markedly when oxygen instead of air mixes with nitric oxide.

442. The most striking way of exhibiting this property of

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* Symbols are much more expressive as used on a black board or slate than as they appear on a printed page, where they all stand at once before the reader, and the *stages* of a decomposition cannot be illustrated. In the present case, for example, the student should first put down N, with five Os below it, and observe that these letters represent anhydrous nitric acid. Cu is then to be marked against each of the three lowest Os, and the combination of these to produce oxide of copper considered. NO_5 is then to be put down opposite each Cu O, and the production of nitrate of copper studied; and lastly, the retention by the nitrogen (of the decomposed atom of nitric acid) of two atoms of oxygen, so as to form nitric oxide, is to be denoted by the bracket enclosing the N and the two upper Os, and the = sign pointing to NO_2. Chalks of different colours may be used in the case of very young pupils, to make the diagrams more manifest; but, on the whole, one colour is preferable, as it can be copied by the pupil with the slate or lead pencil, or pen.

the gas, is to fill a large jar with it at the pneumatic trough, and then suddenly turn its mouth upwards. If, whilst the ruddy fumes are in the jar, it be placed with its mouth downwards in a vessel of water, an additional phenomenon is observed: the water dissolves the nitrous acid, and rapidly ascends within the jar.

443. To observe the effect with oxygen, a jar half full of nitric oxide is placed upon the stool of the pneumatic trough, and oxygen gas rapidly added to it. This is effected by placing the mouth of the oxygen-jar between the limbs or supports of the stool; the mouth of the jar being held downwards till it is completely within the funnel-shaped cavity of the stool. The shut end of the jar is then rapidly depressed, so that the gas it contains is quickly poured up through the funnel, as liquids are familiarly poured down through such an apparatus. (See Fig. 43.) The trough-stool is omitted, for simplicity's sake, in the drawing.

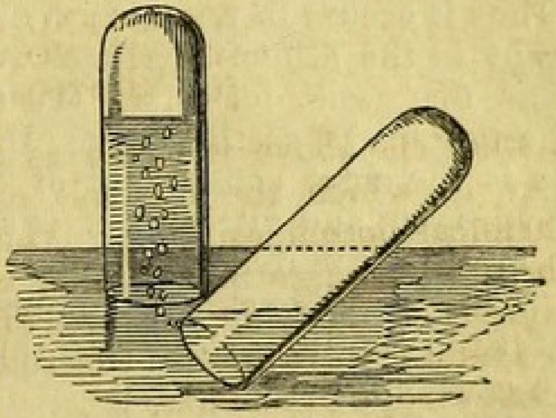


Fig. 43.

444. This experiment is a striking and beautiful one, from the instant development of the dark-coloured gas, and the rapid ascent of the water in the jar.

445. Nitric oxide thus supplies a very delicate test of the presence of oxygen in any gaseous mixture. It is only necessary to add to the latter, whilst standing over water, a small volume of the gas in question. If oxygen be present, the gas will instantly become coloured. A dark-brown tint will appear if there is much oyygen, a pale yellow if there is only a trace of it. A sheet of white paper held behind the glass vessel enables the eye to detect the slightest production of colour.

446. Hyponitrous acid, NO_3, eq. 38, is prepared by mixing 4 measures of nitric oxide with 1 measure of oxygen, both perfectly dry, and surrounding the vessel containing them by a freezing mixture. They condense into a volatile, green liquid.

447. Nitrous acid, NO_4, eq. 46, is prepared by mixing 4 measures of nitric oxide with 2 of oxygen; or, more conveniently, by heating nitrate of lead (PbO,NO_5), when the nitric acid separates from the oxide of lead, and immediately resolves itself into oxygen and nitrous acid, $NO_5 = NO_4$ and O. This acid forms the ruddy fumes which appear when

nitric oxide meets air or oxygen. It can be condensed into a very volatile liquid, which is nearly colourless below zero, but yellow or brown-red at higher temperatures.

CARBON.

Equivalent, 6; *symbol*, C.

448. *Distribution.*—Carbon occurs in nature uncombined, as the diamond, and as the mineral *graphite* or *plumbago*. It is much more abundant, however, in a state of combination. Thus it occurs in union with oxygen in the carbonic acid present in the atmosphere, and which, in combination with lime and magnesia, forms, in the shape of limestone, so large a portion of the earth's crust. In union mainly with hydrogen, it is the chief constituent of coal; and along with oxygen, hydrogen, and nitrogen, it is an abundant ingredient of animals, and still more of plants.

449. The diamond is the purest form of carbon, and admits of being entirely converted into carbonic acid by combustion in oxygen.

450. Graphite or plumbago is the substance so largely employed in the manufacture of pencils. It goes ordinarily by the name of *black-lead*, but it contains no lead. Iron is frequently present, but the purest specimens consist solely of carbon. It occurs in veins, generally in granite and the primitive rocks, in various parts of the world, but only a limited portion of it is soft enough to be used for pencils. The coarser varieties have a certain commercial value, being employed as a coating for iron.

451. Various important artificial varieties of carbon are made use of in the arts. They go generally by the name of charcoal. The four most important kinds are *wood-charcoal*, *coke*, *animal-charcoal*, and *lamp-black* :—

452. Wood-charcoal is prepared by heating wood in iron retorts as long as it evolves anything volatile. The water originally present in the wood, its hydrogen, oxygen, nitrogen, and a large part of its carbon, are expelled in the form of various gases and vapours, and the excess of carbon left behind constitutes the wood-charcoal of commerce. Charcoal may be made on the small scale by heating a piece of wood to a low red heat in a glass tube. Wood-charcoal is employed in the arts, and as a fuel. It is of much use in blowpipe experiments, and is largely consumed in the manufacture of gunpowder.

453. When coal is treated in the same way, as it is in the manufacture of coal-gas, the excess of carbon is, in like man-

ner, left behind, forming a hard, shining, light solid, highly valued as an economical and powerful fuel. This substance, which is literally charred coal, and therefore best deserves the title of charcoal, goes nevertheless by the name of *coke*, the word charcoal, when not qualified by some prefix, being generally understood to signify the carbon of wood.

454. Animal charcoal is obtained by heating any animal substance in retorts as long as volatile products are evolved. The variety of it best known as an article of commerce is that which goes by the name of ivory-black, or bone-black. It is not pure charcoal, but consists of that substance mixed with the non-volatile calcareous salts, chiefly combinations of lime with phosphoric and carbonic acids, which confer upon fresh bones their hardness and rigidity. These salts are left as a white earthy skeleton, when a bone is heated in an open fire so as to burn away its carbon. Animal charcoal, but especially bone-black, possesses in a remarkable degree a property not altogether wanting in wood-charcoal—that, namely, of removing colour from liquids which owe their tint to the presence of animal or vegetable colouring matters. This bleaching power of bone-black leads to its great consumption by the sugar-refiner, who deprives brown sugar of its colour by filtering it through a stratum of coarsely-powdered charcoal. It acts still more powerfully if heated with the liquid to be bleached, and it is largely used in this way by the manufacturing and scientific chemist in the purification of organic substances; such, for example, as morphia or quinine.

455. Animal, like wood-charcoal, possesses the power of destroying odour as well as colour. The latter is employed, accordingly, to purify tainted water on shipboard, and occasionally to lessen the odour of game which has been overkept. The decolorising power of animal charcoal may readily be demonstrated by boiling infusion of litmus or cabbage with powdered ivory-black, and then passing the liquid through a paper filter. (See fig. 44.) It is rendered perfectly colourless.

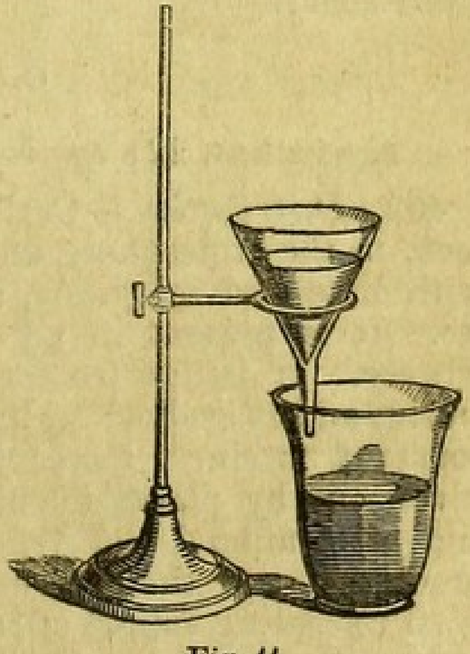


Fig. 44.

456. Lamp-black is the soot of imperfectly-burned combus-

tibles. It is prepared by burning tar, or any other inflammable body containing carbon and hydrogen, with a limited supply of air. In such circumstances the hydrogen of the combustible burns, but very little of the carbon is consumed. The greater part of it, on the other hand, is carried up in the state of a finely-divided powder in the current of warm air which rises from the burning body. When this warm current of gases impinges upon a cold surface, it deposits on it the carbon, which is allowed to accumulate, until it has formed a pretty thick layer, when it is scraped off, and forms the lamp-black of commerce.

457. This variety of carbon, which, it will be observed, is merely soot or condensed smoke, is very largely employed in the arts in the preparation of black pigments. China-ink is a kind of lamp-black made into cakes with gum-water.

458. Carbon, in all its forms, is an exceedingly unalterable substance at ordinary temperatures, so that stakes of wood are charred at their surfaces before being driven into the earth, as a precaution against their decay. If carbon, however, be raised in temperature, it combines with oxygen, as we have seen in speaking of that gas, and by so doing, forms carbonic acid CO_2, or carbonic oxide CO, according to the proportion of oxygen supplied to it. Both of these oxides of carbon are compounds of great interest; we begin with carbonic acid:—

Carbonic Acid.

Equivalent, 22; *symbol*, CO_2; *density*, 1524; □□

459. *Distribution.*—Carbonic acid occurs, as we have already seen, in the atmosphere, and in large quantity in combination with lime and magnesia, in limestone, marble, shells, corals, &c. It is present in all natural waters; in some of them largely. It issues from the earth in various parts of the world, and is evolved in large quantity by volcanoes. It is a constant product, moreover, of animal respiration, and is given out by plants during darkness. Fermenting liquids, and most animal and vegetable substances whilst decaying, produce it, and the combustion of fuel at the earth's surface is an unceasing source of carbonic acid.

460. *Preparation.*—Carbonic acid is prepared in the laboratory in two ways. The one is a synthetic process, and consists in burning charcoal in oxygen; the other is an analytic one—namely, the displacement of carbonic acid from one of its compounds, such as the carbonate of lime.

461. We have described, under the head of oxygen, the ar-

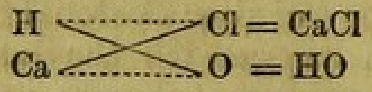
rangement required for burning charcoal in that gas. When charcoal is burned in oxygen till the latter is entirely converted into carbonic acid, no change in volume occurs, so that a cubic foot, for example, of oxygen, after it is saturated with carbon, forms exactly a cubic foot of carbonic acid. Although the oxygen is not increased in volume by its conversion into carbonic acid, we need scarcely say that it is altered in weight, so that for every sixteen parts of oxygen, we obtain, in virtue of its combination with six of carbon, twenty-two of carbonic acid.

462. The production of carbonic acid during the combustion of charcoal is easily demonstrated by adding lime-water to the jar originally full of oxygen in which the charcoal was burned. The lime-water at once becomes milky, from the production of carbonate of lime.

463. The analytic process for carbonic acid is the one generally followed. Fragments of broken marble are placed in such a vessel as was used in the preparation of hydrogen or nitric oxide (see fig. 27), and muriatic acid diluted with water is poured over the marble. Carbonic acid is evolved with great rapidity, and may be collected in the usual way at the pneumatic trough.

464. Any carbonate will yield carbonic acid if exposed to the action of the stronger acids, such as sulphuric, muriatic, nitric, or acetic. No carbonate, however, is so convenient as that of lime, in the form of fragments of white marble, and no acid is so suitable as hydrochloric.

465. The evolution of carbonic acid by the action of a stronger acid on a carbonate admits of a simple explanation. Marble consists of lime united to carbonic acid. Muriatic acid, however, has a much greater affinity for lime than carbonic acid has. The stronger acid, accordingly, unites with the lime, forming the hydrochlorate or muriate of lime, whilst the carbonic acid set free immediately assumes the gaseous form. The change may be expressed thus in symbols:—CaO,CO_2 and $HCl=CaO,HCl$ and CO_2. There is a further change, however. Muriatic acid consists, as its symbol HCl implies, of hydrogen and chlorine, whilst lime, CaO, consists of the metal calcium and oxygen. When the acid and the base meet, they do not simply unite, but exchange constituents, so that the hydrogen of the acid combines with the oxygen of the base to form water, whilst the chlorine of the acid combines with the calcium of the base to form the chloride of calcium, $CaCl$. This mutual or double decomposition, which is the type of a change of exceedingly frequent occurrence, may be represented as follows in symbols:—



In this, as in a similar diagram given before, the horizontal dotted lines show the bodies in combination at the beginning of the decomposition; the oblique unbroken lines, the interchange which occurs during the decomposition; and the symbols placed after =, the ultimate products.

466. The full decomposition may be represented thus:—

Before decomposition,	CaO,CO_2 and HCl
First stage of decomposition,	CaO,HCl and CO_2
Second stage of decomposition,	CaCl and HO

These diagrams are given more as examples of the mode of using symbols, than as referring to changes requiring to be studied with great minuteness.

467. *Properties.*—Carbonic acid is a colourless, invisible gas, having a peculiar sharp, but not sour odour and taste. Water dissolves more than its own volume of this gas, and acquires, in consequence, a sparkling appearance, and refreshing, slightly-stimulant taste, such as all are familiar with in soda water and other effervescing liquors.

468. Carbonic acid is about half as heavy again as air. Its specific gravity, according to some, is 1529, rather than 1524. It is uninflammable, extinguishes combustion, and cannot support animal respiration. It is distinguished from the other irrespirable and incombustible gases by the precipitate, already frequently referred to, which it produces in lime-water. Its properties may be demonstrated by the following experiments:—1. The odour of carbonic acid is best observed by holding the nostrils over soda water, or a dissolved seidlitz powder, from which the gas is effervescing. 2. Its taste is best noticed by taking a draught of pure water which has been saturated with it. 3. Such a solution is most easily prepared by half filling a bottle of water at the pneumatic trough with the gas, corking it, and shaking it briskly. The carbonic acid is immediately absorbed by the water, as may be proved by quickly withdrawing the cork, when the sound of air rushing in to fill the vacuum left by the absorbed gas will be heard. This experiment illustrates the solubility of carbonic acid in water, and one of the modes in which solutions of gases are prepared. 4. If a little infusion of litmus be poured into a jar of carbonic acid, it will be faintly reddened. If the liquid be then transferred to a flask or test-tube, and heated, it recovers its original blue tint, owing to the escape of the gas. 5. Carbonic acid does

not extinguish flame, for the same reason that nitrogen does —namely, by excluding oxygen—but exerts a positively prejudicial effect on combustion, so as to prevent its occurrence, even when there is as much oxygen present as would otherwise have supported flame. In illustration of this, a mixture may be made at the pneumatic trough of four volumes of carbonic acid with one of oxygen. If a lighted candle be plunged into this mixture, it will be at once extinguished, although the proportion of oxygen present is as great as that in atmospheric air. In like manner, if a lighted tallow candle with a long wick be introduced into carbonic acid, it will be totally extinguished, whereas in nitrogen the wick would have remained red-hot, and might have been fully kindled by being plunged into oxygen. 6. The density of carbonic acid admits of demonstration by a striking experiment. The weight of the gas is such, that it may be poured like a liquid from one vessel to another, and a candle may be extinguished by letting the gas fall on it. A jar quite full of the gas should be taken for this purpose, and slowly emptied by inclining it till it assumes a horizontal position close to a candle. The jar should not be emptied directly above the candle, which frequently makes the experiment fail, in consequence of allowance not being made for the impetus in a lateral or horizontal direction, communicated to the gas by the inversion of the jar. If the latter be held a little above, but at the same time to the one side of the flame, and then gently turned over, the candle will not fail to be extinguished.

469. The descent of the gas may be also followed by pouring it into a vessel containing a little lime-water, when the latter becomes chalky. 7. The influence of carbonic acid on respiration does not admit of illustration by experiment unless by the cruel one of introducing a living animal into the gas, when it becomes insensible, and in a short time, if not removed, dies.

470. Carbonic acid does not extinguish life by simply causing suffocation—that is, by cutting off oxygen, as nitrogen does, or water, when an animal is drowned in it. The first-mentioned gas is a positive poison, and occasions death though all the other conditions of life are fulfilled. Thus air containing a proportion of carbonic acid so comparatively small, that it does not extinguish flame, will nevertheless, if long breathed, extinguish life. This fact cannot be too carefully remembered, as fatal accidents are constantly occurring from ignorance or neglect of it. During the cold season of the year, persons are often tempted to introduce braziers or pans of red-hot charcoal into their apartments. Such con-

trivances have not chimneys communicating with the outer air, so that the carbonic acid produced of necessity escapes into the room, and rapidly vitiates its atmosphere. Fuel should never be burned in rooms, unless in fireplaces provided with chimneys, and well ventilated, so that the products of combustion do not accumulate within the apartment.

471. The following experiments, throwing light on important relations of carbonic acid, should also be tried. The vinous fermentation, as already mentioned, is attended by the production of carbonic acid. Those who can obtain access to a brewing-vat may have instructive evidence of this in several ways. A candle, let down into a tun containing fermenting beer, will be at once extinguished. A vessel containing lime-water, suspended within it, will soon exhibit the chalkiness characteristic of the action of carbonic acid. An infusion of litmus in the same circumstances will become faintly reddened.

472. On the small scale, a little brown sugar, water, and yeast, may be placed together into a gas-bottle, such as that used for preparing hydrogen. If this be put in a warm place, gas will soon be evolved, which may be conducted by means of the delivering tube through lime-water, so as to obtain proof that it is carbonic acid. Or a little fresh beer may be placed in a retort, the beak of which dips into lime-water, and heat applied to the liquid. Carbonic acid will soon be evolved.

473. During animal respiration, carbonic acid is given off abundantly. In proof of this, it is only necessary to blow, by means of a tube, through lime-water, so that the expired air from the lungs may act upon it. A few minutes' blowing will cause a copious precipitate of carbonate of lime.

474. Whilst discussing the atmosphere, reference was made to the power of living green plants to decompose carbonic acid when shone upon by the sun. In proof of this, a recently-cut branch, with healthy green leaves upon it, may be placed within a jar of carbonic acid standing over water, and the whole exposed to direct sunlight. After an interval, which will vary according to the brightness of the day, but may amount to one, two, or six hours, the gaseous contents of the jar, when examined, will be found to have lost all power to precipitate lime-water, and instead of extinguishing flame, will support it brilliantly. In short, the carbonic acid has been replaced by oxygen, in consequence of the plant resolving the former into its constituents, and retaining within itself the carbon, leaving the oxygen free.

475. Analysis shows that the proportion of carbonic acid in

the air varies very little from year to year, although it is constantly passing in large quantity into the atmosphere as a product of combustion, respiration, fermentation, volcanic action, &c. The carbonic acid is prevented from accumulating, so as to become fatal to animal life on the globe, by this remarkable action of plants, which not only withdraw the poisonous carbonic acid, but replace it by the vital oxygen.

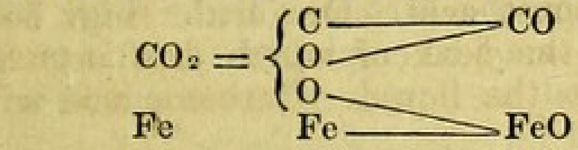
Carbonic Oxide.

Equivalent, 14; *density*, 972; *symbol*, CO; ☐☐

476. Carbonic oxide does not occur as a natural product, but is known only as produced artificially.

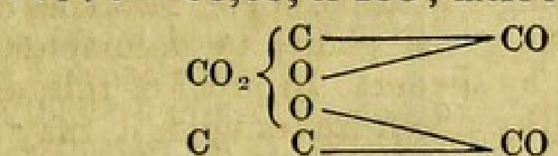
477. *Preparation.*—This gas, it will be observed, contains an atom less of oxygen than carbonic acid. If the latter, accordingly, be transmitted through a red-hot iron tube, the iron deprives the carbonic acid of half its oxygen, and thereby converts it into carbonic oxide. Thus twenty-two grains of carbonic acid will part with eight of oxygen to the iron, and become fourteen of carbonic oxide.

$CO_2 + Fe = CO$ and FeO; more fully thus:—



478. Carbonic acid may likewise be changed into carbonic oxide, by passing it through a porcelain tube containing red-hot charcoal. The carbonic acid combines with a second atom of carbon, and becomes carbonic oxide.

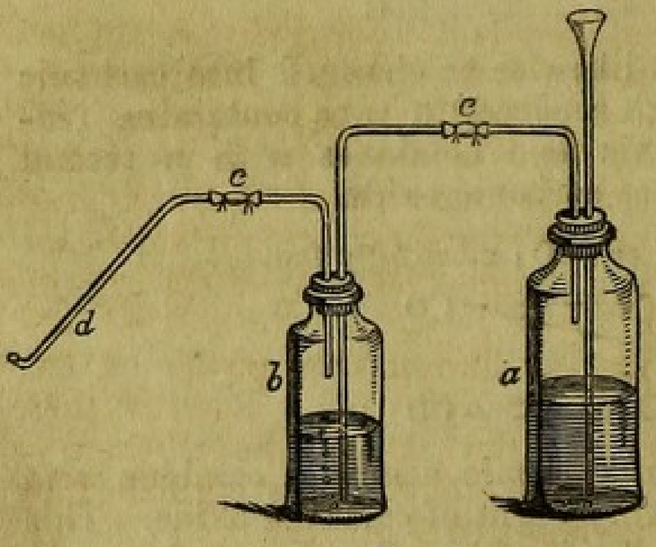
$CO_2 + C = CO, CO$, or $2CO$; more fully thus:—



Thus twenty-two grains of carbonic acid will combine with six of carbon, and form twenty-eight of carbonic oxide. This change is constantly occurring in charcoal and coke fires. At the lower and outer part of the choffer or fireplace, the hot charcoal, combining with the oxygen of the air, forms carbonic acid. Much of this ascends through the red-hot fuel in the body of the fireplace, and being thus exposed to a great excess of red-hot charcoal, combines with it, forming carbonic oxide: when this reaches the surface, it burns, producing carbonic acid. The flame of carbonic oxide is blue, but when seen against a ground of red-hot cinders, it appears purple. It is matter of popular observation that the appearance of such a flame in the fireplace is an indication of frosty weather. A low temperature, such as that of 32°, favours the production of carbonic oxide in the way mentioned, by condensing nearly all the moisture in the atmosphere, so that our fires are maintained at that temperature by almost dry air.

479. For experimental purposes, carbonic oxide is not prepared in either of the ways mentioned. The deadly poison oxalic acid, which is sold in the shape of small white crystals, when heated in a retort along with strong oil of vitriol, yields a mixture of this gas and carbonic acid. The process needs no particular attention. The gas is not evolved till the temperature of the oil of vitriol has been raised considerably; but when the gas begins to come off, it is evolved with great rapidity, so that the jars intended to receive it should be standing full of water from the beginning of the process.

480. In this way a mixture is obtained of carbonic acid and carbonic oxide. By pouring into the gas-jars a small quantity of lime-water or solution of caustic potass, the carbonic acid may be absorbed, and the carbonic oxide left; or the mixture of gases may be passed through a solution of caustic potass, which retains the carbonic acid. Fig. 45 shows an arrangement which may be employed for this purpose. But as the only property of carbonic oxide which readily admits of experimental observation is its combustibility, and as the carbonic acid does not interfere with this being seen, the mixture of the gases may be taken to represent pure carbonic oxide.



a, Flask containing oxalic acid and oil of vitriol.

b, Flask containing strong solution of potass.

c c, Tubes of caoutchouc, tied by threads to those of glass, and intended to give flexibility to the arrangement.

d, Tube passing to trough.

Fig. 45.

481. *Properties.*—Carbonic oxide is a colourless, invisible

gas, having a slight odour, and no taste. It does not support combustion nor respiration. It is, in truth, positively poisonous, and is one of the causes of the fatal result which attends prolonged exposure to the fumes of burning charcoal. Its most striking property is its combustibility. It burns with a very beautiful blue flame, combining with the oxygen of the air, and forming carbonic acid. $CO+O=CO_2$. The pure gas, if mixed with an equal volume of oxygen, and kindled, detonates sharply; and the production of carbonic acid may be proved in the usual way, by adding lime-water to the jar after the explosion.

482. The production of carbonic oxide from oxalic acid is easily explained. This acid consists of 2 atoms of carbon, 3 of oxygen, and 1 of water, C_2O_3HO, so that it contains the elements of one equivalent of carbonic acid, one of carbonic oxide, and one of water—thus, CO_2,CO,HO. When it is heated with oil of vitriol, the sulphuric acid combines with the water, for which it has a great affinity, and the carbonic oxide and carbonic acid are liberated, and come off together. The change may be represented thus in symbols:—

Before decomposition, CO_2CO,HO, and HO,SO_3.
After decomposition, CO_2,CO, and HO,SO_3+HO.

COMPOUNDS OF CARBON AND HYDROGEN.

483. The compounds of carbon and hydrogen are not less interesting than those of carbon and oxygen. They are very numerous, and occur alike as solids, liquids, and gases. We can refer, however, only to some of the more important of them, which are of more than ordinary theoretical and practical importance. They are, strictly speaking, organic compounds, but their consideration cannot be delayed till organic chemistry is discussed.

484. Coal-gas depends for its illuminating power on two gaseous compounds of carbon and hydrogen. Each of these is called *carburetted hydrogen;* but as the one of them is nearly twice as heavy as the other, they are distinguished by the names *light* and *heavy* carburetted hydrogen.

Heavy Carburetted Hydrogen.

Synonyme, olefiant gas; equivalent, 28; *symbol,* C_4H_4;
density, 985; ☐☐

485. Heavy carburetted hydrogen is generally called olefiant gas, a name which it derives from its property of form-

ing an oily liquid when it combines with chlorine. Though heavy as a compound of carbon and hydrogen, it is light when compared with other gases. Air being the standard of density, only those gases which are denser than it are called heavy. Olefiant gas, however, is lighter in the proportion of 985 to 1000.

486. This gas is obtained by placing in a retort one measure of spirits of wine and three measures of oil of vitriol. Heat is then applied, and in a short time the liquid grows dark, and evolves olefiant gas with great rapidity. It may be collected at the pneumatic trough in the usual way. Its production depends on the following change:—

487. Alcohol may be represented as consisting of one equivalent of olefiant gas and two equivalents of water. When heated with excess of oil of vitriol, the sulphuric acid separates the water from the olefiant gas, and the latter is evolved. Thus in symbols,

Alcohol is $C_4H_6O_2$; or C_4H_4+HO,HO (or $2HO$).

so that—

Before decomposition, $C_4H_4,2HO$ and HO,SO_3.
After decomposition, C_4H_4 and HO,SO_3+2HO.

488. *Properties.*—Olefiant gas is colourless and invisible, scarcely soluble in water, and does not support combustion or respiration. The most striking property of this gas is its combustibility. It burns with a dense bright flame, producing during its combustion carbonic acid and water, from the combination of its carbon and hydrogen with the oxygen of the air. The following experiments may be tried with it:—

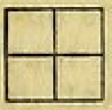
1. A jar of the gas kindled will enable its combustibility and the brightness of its flame to be witnessed. This is a point of interest, as the illuminating power of coal-gas is in great part dependent on the presence in it of heavy carburetted hydrogen.

2. A strong thick jar is to be filled one-fourth full of the gas, and the remaining three-fourths with oxygen. When a light is applied to this mixture, it occasions a loud and powerful explosion, accompanied by the evolution of much heat, but little light.

3. A jar half-full of chlorine gas (see page 169) is to be placed on the stool of the pneumatic trough, and filled up with olefiant gas. The gases will rapidly unite, combining to form a liquid, which will be seen collecting like drops of oil on the surface of the water which ascends within the jar. This experiment illustrates the origin of the name *olefiant*.

4. A similar mixture of one measure of olefiant gas and two of chlorine may have a light applied to it, when it will burn with a smoky flame, and deposit within the jar a large amount of soot. This phenomenon results from the chlorine combining with the hydrogen of the olefiant gas, and rejecting the carbon, the presence of which in the invisible carburetted hydrogen is thus demonstrated.

Light Carburetted Hydrogen.

Equivalent, 8; *symbol,* CH_2; *synonyme, marsh gas, fire-damp; specific gravity,* 555; 

489. This compound is best known as a natural product, being the gas which issues from the ground in various parts of the world, and admits of being kindled. Stagnant water, in which vegetable matter is decaying, gives off this gas, mixed with carbonic acid. Hence its name *marsh gas.* It also issues as a product of decomposition from beds of coal, and when it mingles with air, forms the explosive mixture which leads to so many destructive accidents in our coal-pits. It has been called by the miners *fire-damp.*

490. It can be prepared artificially by strongly heating a mixture of 40 parts crystallised acetate of soda, 40 parts solid caustic potass, and 60 parts of quicklime in powder. The gas is evolved in great abundance, and can be collected over water. The acetic acid is a compound of carbon, hydrogen, and oxygen, and the acetate of soda contains, in addition, water. When heated with alkalis, the hydrogen and oxygen of the water form, with the elements of the acetic acid, carbonic acid and light carburetted hydrogen. The change is illustrated in the following equation:—

$$\left.\begin{array}{ll}\text{Acetic acid, } & C_4H_3O_3 \\ \text{Water, } & H\ O\end{array}\right\} = \left\{\begin{array}{ll}\text{Carbonic acid, 2 equivalents,} & \left\{\begin{array}{lll} C & & O_2 \\ C & & O_2\end{array}\right. \\ \text{Marsh gas, 2 equivalents,} & \left\{\begin{array}{lll} C & H_2 & \\ C & H_2 & \end{array}\right.\end{array}\right.$$

$$\overline{C_4H_4O_4} \qquad\qquad \overline{C_4\ H_4\ O_4}$$

491. *Properties.*—Light carburetted hydrogen is a colourless, invisible, inodorous gas, scarcely soluble in water, which does not support combustion or respiration, but is not poisonous. It burns with a white flame, but has not so great an illuminating power as olefiant gas. The only experiments that admit of being tried with it are the action of flame on it

when taken alone, and when mixed with oxygen or air. It burns in the first case, producing carbonic acid and water; in the second, if mingled with twice its volume of oxygen, or ten times its volume of air, it detonates powerfully.

Coal-gas.

492. Coal-gas is not a definite chemical compound, but a mixture of many unlike substances, obtained by exposing coal to a red heat in iron retorts. The coal preferred for this purpose is cannel coal, the bright shining variety which does not soil the fingers. When heated in a retort, it yields a variety of products, among which three are specially important:—1*st*, Tar, a highly-complex mixture of various compounds of carbon and hydrogen. 2*d*, Ammonia, in combination with carbonic acid and sulphuretted hydrogen. 3*d*, Light and heavy carburetted hydrogen. Besides these, there are small quantities of hydrogen, nitrogen, carbonic oxide, carbonic acid, sulphuretted hydrogen, prussic acid, &c.

493. The gas, as it issues from the retorts, is received into a large horizontal iron chamber, half full of liquid, and from thence passes through a series of large iron siphons, kept cool, in which it deposits the tar and ammoniacal liquor. The gas is then made to traverse another series of tubes, or iron vessels containing slaked lime mixed with water. The lime absorbs the useless carbonic acid and noxious sulphuretted hydrogen, and the gas is then collected in large metallic reservoirs, from which the pipes which distribute it proceed. Ordinary coal-gas, in spite of the purification to which it is subjected, contains a variable amount of different substances, some of which are of no service, and others are positively prejudicial. It consists essentially of about fifty or sixty per cent. by volume of light carburetted hydrogen, and from twelve to fifteen per cent. of olefiant gas, along with carbonic oxide, hydrogen, and nitrogen. The carburetted hydrogens are the only valuable constituents of coal-gas, so far as its application to the production of heat and light is concerned.

DAVY LAMP.

494. The dangerous explosions which occur when a light is applied to a mixture of fire-damp and air, have already been referred to, but the discussion of the methods by which, on the large scale, they may be prevented, has been postponed till the nature of coal-gas should have been made known, because the experiments we are about to mention can be

much more conveniently tried with coal-gas, of which light carburetted hydrogen is the chief constituent, than with fire-damp itself.

495. To prevent accidents in coal-pits, Sir Humphry Davy devised a very ingenious lamp, which goes by the name of the Davy or Safety Lamp, and is intended to furnish the miner with a source of light which shall have no power to kindle fire-damp.

496. Fire-damp alone does not burn or explode. It must be mingled with air before either of these phenomena can show itself. If, however, it be mixed with too much air, explosiveness is again lost. Detonation occurs most powerfully when the fire-damp is mixed with from eight to ten times its volume of air. If the proportion of air be diminished to three or four times that of the fire-damp, or be increased to more than fourteen times its measure, explosion does not happen. Where the volume of air is very small, an amount of oxygen sufficient to burn the fire-damp is not furnished. Where the quantity of air, on the other hand, is too large, it prevents the spread of flame by conducting away heat, and preventing the temperature rising high enough to inflame the combustible gas.

497. The fact last referred to is taken advantage of in the construction of the Davy lamp. Fire-damp cannot be kindled unless it be raised to a white heat, unlike pure hydrogen, which takes fire at the lowest visible red heat. When an explosive mixture, accordingly, collects in a coal-mine, in consequence of the fire-damp issuing from the seams of coal, and mingling with the air, if it meets a naked flame, such as that of a candle which is at a white heat, explosion at once happens. The object of the Davy lamp is to enable the miner to employ artificial light in the midst of such an explosive atmosphere without any risk of kindling it. This is done in the following way :—The safety lamp consists of a small cylindrical oil-lamp, differing in no respect from those in ordinary use, except that a brass wire passes through a canal traversing the lamp from below, and is bent over close to the wick where it issues at its surface, so that by turning this wire, the wick can, to a certain extent, be trimmed without uncovering it (see fig. 46). The peculiarity of the lamp consists in a cover or cage of wire-gauze, which is screwed on to the top of the lamp after the wick is

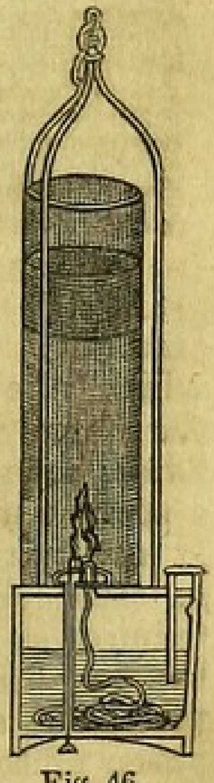


Fig. 46.

lighted. This wire-gauze cover is made double at the top, for the sake of strength, but a single layer of the gauze, so long as it is entire, renders the lamp quite safe in an explosive atmosphere.

498. When the lamp, as we have described it, is carried into an explosive mixture of light carburetted hydrogen and air, no explosion happens. The mixture of gases traverses the apertures in the gauze, and burns around the wick, but the flame does not travel *outwards* through the meshes of the wire-work, so as to kindle the mass of fire-damp without. The lamp makes explosion impossible, not, as is often imagined, by preventing the fire-damp reaching the flame within the cage, but by preventing that flame from reaching the fire-damp without. The light is put out whilst in the very act of traversing the wire-gauze, in consequence of the latter, which is an excellent conductor of heat, carrying that away, and so causing the temperature of the flame to fall below the white heat necessary for kindling fire-damp.

499. A piece of wire-gauze, in truth, consists essentially of a multitude of metallic tubes, or canals, placed side by side (see fig. 47). These tubes are exceedingly short, so that we are apt to forget that they are tubes at all; but canals they certainly are, with walls, comparatively speaking, very thick, and consisting of a metal, one of the best conductors of heat. In the Davy lamp, as we have described it, the flame is at one end of each of these metallic tubes, and the mass of explosive mixture ready to be fired is at its other extremity. The tube, too, is filled with the explosive mixture, which, like a train of gunpowder, must be kindled, otherwise the flame will not be propagated through the tube. The flame, however, never can succeed in traversing the canal, for a portion of the explosive mixture set fire to at one end of it is unable to kindle the portion lying next it in the canal, in consequence of the sides of that canal appropriating to themselves the caloric which otherwise would serve to kindle the gas, but which is unable both to inflame it and to heat the metal, and is compelled, in virtue of the high conducting power of the metal, to raise its temperature rather than that of the gas.

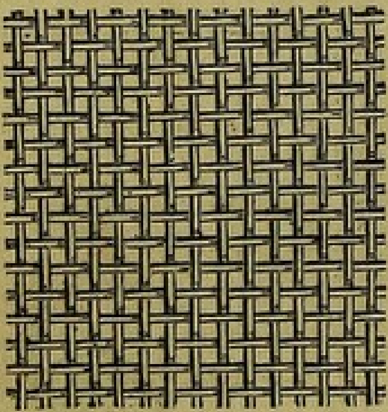


Fig. 47.

500. The following simple experiments will illustrate the facts just explained :—

1. A small metallic spiral may be formed by coiling iron wire round a pencil (fig. 48). If this be gently placed, like an extinguisher, over the wick of a burning candle, which it should be large enough not to touch, the light will go out; the burning vapour of the wax or tallow being unable to maintain itself at a white heat when in contact with a mass of metal.


Fig. 48.

2. A piece of wire-gauze is to be pressed down on the flame of a candle, or, still better, on a jet of burning gas (fig. 49). It will be found to intercept the flame, which will burn only on the lower side of the gauze.

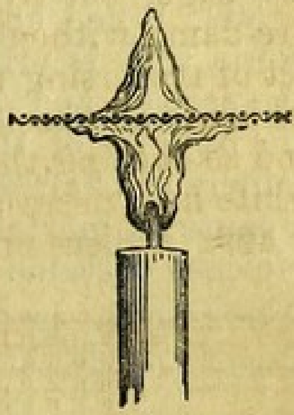


Fig. 49.

3. That the gauze acts by arresting the flame, not by stopping the passage of the gas, may be proved by pressing the wire-gauze over a gas-flame, and then applying a lighted match to the upper surface. It will set fire to a volume of combustible gas, which has all the while been ascending through the meshes of the wirework, but which the flame below was unable to kindle.

4. A still more striking experiment is to lay the wire-gauze on a nozzle from which coal-gas is issuing, and then to light the gas on the upper surface of the wirework. If the gauze be then raised gently, it may be lifted to the extent of two inches or more above the nozzle, carrying a tongue of flame with it, fed by a column of gas ascending from the nozzle, but which is not kindled by the burning gas above.

5. A piece of camphor may be laid on a sheet of wire-gauze and kindled. It will burn with a dark, smoky flame, at the same time melting, and dropping through the gauze. But though the drops are as combustible on the lower as on the upper surface of the wirework, the flame will not descend through the meshes, or kindle the melted camphor below.

6. For the following experiment a Davy lamp, if it can be procured, should be employed. In the absence of it, a cylindrical cage may be constructed of wire-gauze, and laid over a lighted candle, or an oil or spirit lamp. A jet of coal-gas is now to be directed, by means of a flexible tube, against the cage, so as to pass through its meshes, and reach the flame. It will take fire and burn within the cylinder, but the extremity of the flexible tube may be pressed close against the wire-gauze without the flame being communicated to the jet of gas. If the stream be made to envelop the flame of the

lamp in large quantity, the light will go out, in consequence of the exclusion of air; a phenomenon occasionally witnessed in coal-pits, but forming no essential objection to the value of the lamp, as it is only witnessed when the volume of fire-damp is so large that the atmosphere of the pit is irrespirable.

501. The Davy lamp appears to afford a complete protection against explosion, except where a very rapid current of fire-damp, issuing, as it frequently does with great force from cavities in the coal where it has been pent up, impinges against the lamp. In these circumstances, it may hurry the burning gas so swiftly through the wire-gauze, that the latter has not time to lower its temperature below the explosive point.

502. When an explosion happens in a coal-pit, much carbonic acid is produced, along with water, in consequence of the carbon and hydrogen of the fire-damp combining with the oxygen of the air. This carbonic acid is called by the miners the 'after-damp,' or 'choke-damp;' and it is as great a cause of mortality at an explosion as the mere mechanical violence occasioned by the detonation.

STRUCTURE OF FLAME.

503. The artificial lights which we employ—such as lamps, candles, and gas flames, all owe their luminosity to the combustion of compounds of carbon and hydrogen. It is convenient here, accordingly, to discuss the nature of flame, the cause of its luminosity, and the chemical principles involved in the construction and employment of the blowpipe.

504. By the word flame, we denote gas or vapour raised to so high a temperature that it emits light as well as heat. All flames are not equally hot, but their temperature is always high, and when at its maximum, exceeds that of solid bodies at an ordinary white heat.

505. The flame of a lamp, or candle, or simple gas jet, consists of a hollow cone, in the centre of which there is no combustion. If one of these flames, especially that of a candle, which illustrates the phenomena best, be examined closely, it will be seen to have a triple structure. Directly above the wick, a dark or non-luminous space is visible. This is surrounded by a shining envelope, or luminous cone, which deposits soot upon a cold body introduced into it. External to this, a second cone may with difficulty be traced, having far less luminosity than the first, but possessing a very high temperature.

506. The central space appears dark only by contrast with the luminous cone which surrounds it. It consists, in reality,

of transparent, invisible compounds of carbon and hydrogen, which are constantly rising in vapour from the wick. This may be proved in two ways:—1. If a glass tube, open at both ends, be held obliquely in the flame of a candle, with its lower extremity in the dark central space above the wick, it will conduct away much of the combustible vapour, which may be kindled at its upper end in the way shown in the accompanying figure (fig. 50). 2. If a piece of fine wire-gauze be pressed down on the candle-flame, and this be looked at from above, through the gauze, whilst combustion is going on only below, the flame will appear like the mouth of a tube, the walls of which are luminous. The unburnt gas which occupies the centre, and, as it were, fills the luminous tube, rises through the wire-gauze, and, as mentioned under the Davy lamp, may be kindled at its upper surface. If, moreover, a lighted candle be held between the eye of the observer and a sheet of paper or other white object, the latter will be seen through the apparently dark central space (fig. 51). This flameless portion of the flame may be distinguished by the title of *the area of no combustion.*

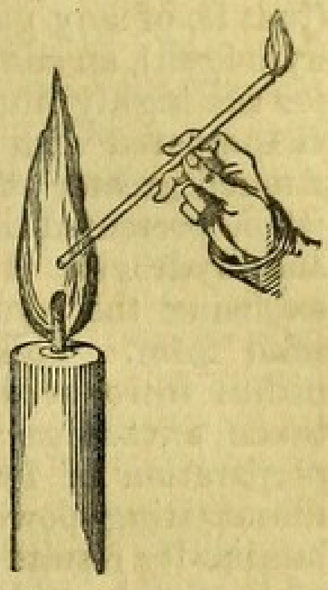


Fig. 50.

507. The luminous cone which envelops the dark space is characterised as *the area of partial combustion.* In it a limited amount of oxidation occurs, in virtue of the oxygen of the air penetrating to that depth, so as to combine with the hydrogen and carbon; but the amount of oxygen which does reach these combustibles is not sufficient to oxidise both, and is almost entirely spent in converting the hydrogen into water.

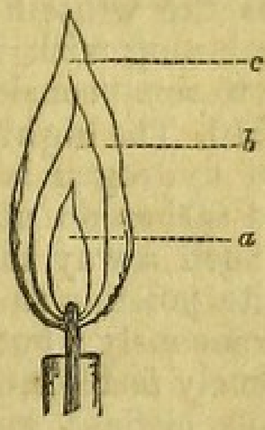


Fig. 51.

a, Area of no combustion.
b, Area of partial combustion.
c, Area of complete combustion.

508. The outer cone is named *the area of complete combustion*, because in it the entire oxidation of the carbon is effected; and as a result of this, a high temperature is produced.

509. These three areas are not sharply marked off by visible lines of demarcation, but, on the other hand, shade away into each other; and in the case of a simple combustible gas, such

as hydrogen, we pass by imperceptible gradations from the central space of no combustion to the outer one of complete oxidation. In the flame, however, of carburetted hydrogens (that is, of any gaseous or vaporous compound of carbon and hydrogen), an additional phenomenon appears, which accounts for the highly illuminating power of compounds of this class, as compared with the simple combustible gases. Oxygen has a much greater affinity for hydrogen than for carbon; so that, when presented in small quantity to a compound of carbon and hydrogen, it is entirely (or almost entirely) spent in oxidising the hydrogen, whilst the carbon separates in the solid form. This is the cause of the deposition of soot on bodies introduced within the inner luminous cone, and is taken advantage of, as we have mentioned already, in the preparation of lampblack. It accounts also for the great illuminating power of the area of partial combustion. Its luminosity results from the fact, that whilst the hydrogen only of the combustible is burned by the oxygen of the air which penetrates to that depth, the high temperature produced by the burning hydrogen raises to a white heat the solid, unburned carbon, which, like the lime in the lime-ball light, is the true source of the brightness of the flame. In the outer area the white-hot carbon meets abundance of oxygen, and combining with it, raises the temperature of the surrounding air to some considerable distance from the visible flame.

510. The highly illuminating power of compounds of carbon and hydrogen is thus traced to the fact, that their hydrogen and carbon do not burn simultaneously, but successively, and in such a way that the one heats the other white-hot. It is quite possible to make them burn synchronously or contemporaneously; but when they do, the light they evolve is extremely feeble, not greater, indeed, than that of pure hydrogen. Thus olefiant gas, and light carburetted hydrogen, which, when kindled at a jet, or the mouth of a jar, burn with highly-luminous flames, exhibit scarcely any luminosity when detonated with air or oxygen. In the latter case, the carbon burns as fast as the hydrogen.

511. The same fact may be illustrated very simply with coal-gas, by placing over a jet from which it is issuing, a chimney or hollow cylinder, covered at the top with wire-gauze. When the gas is turned on, it ascends within the chimney, and mixes with air before passing through the gauze. By a little adjustment of the stopcock, the gas may be supplied in such quantity, that it shall be mixed with enough of air to oxidise, when it is kindled, both its carbon and hydrogen. On lighting it above the wire-gauze, it

burns with a pale-blue flame, somewhat like that of carbonic oxide, and not more illuminating.

512. From these experiments, it appears that it is not the mere presence of carbon in coal-gas, or in oil, or tallow, that makes their flames luminous, but the fact, that the carbon in a solid state is heated white-hot during their combustion. All highly-luminous flames, indeed, contain white-hot *solid* matter. The lime-ball light furnishes evidence of the converse of this—namely, that the most feebly-luminous flame may be rendered highly illuminating by introducing within it a solid which it may heat.

513. In further evidence of this, it may be noticed that where a combustible, as well as the product of its combustion in air or oxygen, is a *solid*, much light is always evolved; but where the inflammable and its oxide are gases, or liquids, the flame is very feeble. Thus iron burned in oxygen, and the metals generally, when undergoing rapid oxidation, are highly luminous; for the metals are solids, and their oxides are also solids. For the same reason, solid phosphorus, which forms solid phosphoric acid when it burns, evolves an intense light; but sulphur, which, though solid, yields, when burned, a gas (sulphurous acid, SO_2), is but feebly luminous; and hydrogen gas, the product of whose combustion is also a gas, or vapour, HO, is still less illuminating.

THE BLOWPIPE.

514. The blowpipe (fig. 52) consists simply of a glass or metallic tube, with a mouth-piece (*a*) at one extremity, and a nozzle (*b*) of small bore at the other, through which a stream of air can be forced across the flame of a lamp or candle (fig. 53). By means of it air is furnished to what in an ordinary upright flame is the central area of no combustion, so that oxidation goes on both in the centre of the flame and along its outer border.

515. When the blowpipe flame is examined, it is seen to consist of two elongated cones, the inner blue, the outer yellow. Between these cones there is a space, corresponding in some measure to the middle area of partial combustion of an upright flame, but at a much higher temperature. This is distinguished as the *reducing* portion of the flame, or, more

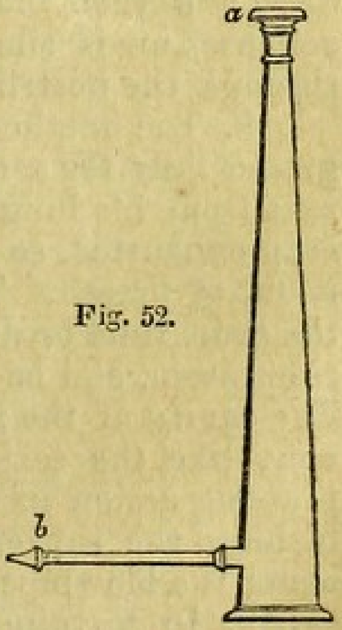


Fig. 52.

briefly, as the *reducing flame* of the blowpipe; because the large amount of white-hot carbon which it contains enables it to reduce—that is, deprive of oxygen—the great majority of metallic oxides, so that their oxygen forms carbonic acid, and the metal separates.

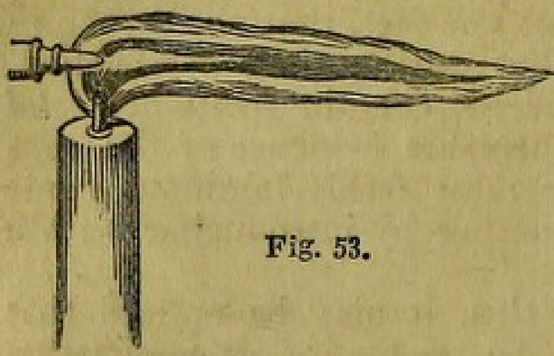


Fig. 53.

516. The tip or point of the outer yellow cone, and to a certain extent its whole external border, is called the *oxidising* flame of the blowpipe; because metals, and other easily-oxidised bodies, are rapidly converted into oxides when held in this portion of the flame, in consequence of the high temperature to which it elevates the air immediately in contact with it. The term oxidising *flame*, in truth, is not strictly correct; for it is the heated air, and not the luminous flame, which produces the oxidation; and bodies must be held a little in front of the visible flame in order to secure their oxidation.

517. When the blowpipe is used, the body to be subjected to its action is held in a loop of platina wire, or placed in a small cup of clay, or in a cavity in a piece of charcoal. A stream of air is then sent through the blowpipe from the mouth, in such a way as to supply the air in an unbroken current. This is effected by closing the lips upon the mouthpiece of the blowpipe, distending the cheeks as a trumpeter does, and then blowing; whilst, without letting the cheeks collapse, air is simultaneously, or at short intervals, drawn through the nostrils.

518. The method of blowing is easily learned. The beginner fails for a time, in consequence of supplying the current from his lungs, the quantity of available air in which is soon exhausted, so that the stream intermits, and the blower is out of breath. To secure an unbroken stream, air must at the same time be drawn in by the nostrils, so as to maintain respiration, and be expelled by the mouth to feed the current. The cavity of the mouth is kept distended, to act as a reservoir, like the sack of a bagpipe, whilst by a slight compressing action of the muscles of the cheeks, partially diminishing the capacity of that reservoir, the air is propelled along the blowpipe.

519. In learning the use of this instrument, the beginner should not blow fiercely. It is continuity, not rapidity, of current that is chiefly desired; and as soon as he can blow,

however gently, and at the same time take a breath by the nostrils, he has mastered the whole difficulty of the blowpipe.

520. From what has been stated as to the structure of the blowpipe-flame, it will be understood that it makes the greatest possible difference as to the effect it produces upon any body introduced into it, whether that substance be exposed to the reducing or the oxidising flames. These flames may be distinguished, as already mentioned, by their colours, the reducing flame being blue, and the oxidising yellow; but the inexperienced manipulator will not be able to produce the flames sharply defined from each other, so as to be able to recognise them by the difference in their tints. When he is directed, however, to expose a body to the oxidising flame, he will find it sufficient to hold it a little in front of the visible point or tip of the flame; and when the reducing flame is prescribed, it will suffice to hold the substance well back within the flame, so that it shall be enveloped by it.

521. In illustration of the opposite powers of the blowpipe flames, the student may place a fragment of metallic lead on a piece of charcoal, and expose it to the oxidising flame. The lead will rapidly become converted into its protoxide, PbO, and melt into a transparent globule. If this be now carried back within the flame, so as to be exposed to its reducing portion, the oxygen will be rapidly removed, and the lead reappear in its metallic state. This oxidation and deoxidation may be obtained alternately with the same piece of metal any number of times.

522. In like manner, if a piece of white flint-glass be exposed to the reducing flame, the oxide of lead which it contains is deprived of its oxygen, and the glass acquires a brilliant, black, metallic coating, which renders it opaque. It may be rendered transparent again by exposing it to the oxidising flame.

523. Experiments similar to those first mentioned may be made with other metals besides lead—such as copper, zinc, bismuth, antimony; but none of them do so well as lead.

BORON.

Equivalent, 10·90; *symbol*, B.

524. Boron is an element having considerable analogy to carbon, but there is little resemblance between their corresponding compounds. It is sparingly diffused in nature, and occurs only in combination with oxygen as boracic acid, BO_3, which is found uncombined in the hot springs of the

volcanic districts of Tuscany, and likewise in union with soda, forming the salt borax, or tincal, which is brought to this country from Thibet and China.

525. Boron may be obtained by heating its only oxide, boracic acid, along with the metal potassium, the process being conducted in a platina crucible. The potassium combines with the oxygen, and the resulting potass unites with undecomposed boracic acid, forming borate of potass, KO,BO_3, whilst the boron remains as an olive-brown powder, insoluble in water, and otherwise resembling carbon in physical properties. When strongly heated in air or oxygen, it burns, forming boracic acid.

Boracic Acid.

BO_3.

526. This acid is generally obtained by adding sulphuric acid to a hot aqueous solution of the commercial salt borax, the biborate of soda, $NaO,2BO_3+10HO$. The sulphuric acid combines with the soda, forming sulphate of soda; and the boracic acid, which is sparingly soluble in cold water, separates in crystals as the liquid cools.

527. Boracic acid melts when heated, losing the water which is generally associated with it, and forming, as it cools, a transparent, colourless, glassy mass. Its taste is only faintly sour, and it does not fully redden vegetable blues, but changes them only to a pale purple, as the analogous body, carbonic acid, does.

528. It dissolves in alcohol, and the solution, when set fire to, burns with a beautiful green flame. This supplies an easy means of detecting the presence of boracic acid in any body. In proof of this, a crystal of borax or tincal may be crushed to powder, and covered with oil of vitriol, which should be left to act upon it for a few seconds, so as to combine with the alkali, and liberate the boracic acid. A little alcohol is then to be poured over the acidulated salt, and kindled, when the characteristic green flame will be seen.

529. The most important compound of boracic acid is borax. It is employed in the arts as a constituent of the finer varieties of glass, and in forming glazes for porcelain. It is likewise used in soldering metals, and to a small extent in medicine.

530. Borax is also of much service to the analytical chemist, in consequence of its power to dissolve metallic oxides, which, in the majority of cases, form coloured glasses by combination with the boracic acid. The tints of these compounds differ according to the metallic oxide present in them, so that their

colours supply an accurate and easily-applied method of identifying compounds before the blowpipe. In illustration of this, the following experiments may be tried:—1. A fragment of borax is to be placed in a cavity in a piece of charcoal, and exposed to the blowpipe flame till the water of crystallisation is expelled. A drop of solution of nitrate of cobalt is then to be let fall on the anhydrous salt, and this is to be treated a second time in the outer or oxidising flame of the blowpipe, till it fuses into a clear globule. On allowing it to cool, it will be found to exhibit a deep blue colour which is characteristic of cobalt. 2. If a similar experiment be made with chloride of manganese, the globule or bead of borax will be of a violet colour; if a salt of the metal chromium be employed, it will be green; and if one of the suboxide of copper or of gold be used, the borax-glass will be a fine red.

SILICON.

Synonyme, Silicium; equivalent, 21·35; *symbol,* Si.

531. *Distribution.*—Silicon, like boron, does not exist in nature uncombined, but its oxide, SiO_3, silica, silicic acid, or silicious earth, is the chief constituent of the crust of the globe. It forms, as it were, the stony skeleton of the earth. Thus sand, sandstone, and quartz, are pure silica; granite and gneiss consist chiefly of silica; and a multitude of minerals, which by their aggregation form other rocks, such as trap, basalt, lava, &c. are silicates—that is, compounds of silicic acid with metallic oxides. Silicon, indeed, is as abundant an element in the mineral world as the analogous carbon is in the vegetable kingdom.

532. Silicon may be obtained by heating pure dry silica in a state of powder with potassium. The metal combines with the oxygen, forming potass, KO, and the silicon is set free, whilst the potass combines with undecomposed silica to form silicate of potass, KO,SiO_3. By washing with water, the silicon is obtained pure, and presents itself as a soft, dark-brown powder, without any metallic lustre. It is insoluble in water, not readily acted on by liquid re-agents, and in general physical characters closely resembles carbon and boron. If strongly heated in air or oxygen, it combines with the latter, forming silicic acid.

Silica or Silicic Acid.

SiO_3.

533. Silicic acid is the only known oxide of silicon. Rock-crystal, white sand, or calcined flints, may be taken to represent pure silica. It may also be obtained from many of its compounds in the following way:—The mineral containing it (such as felspar, granite, or sea-sand) is reduced to fine powder, and mingled with three or four times its weight of a mixture, in equal parts, of carbonate of potass and of soda. The whole is heated in a platina crucible till it fuses into a glassy mass. The contents of the crucible are then boiled with water, to which hydrochloric acid in excess is afterwards added, and the whole evaporated to dryness. During the fusion, the silica enters into combination with the potass and soda (liberating the carbonic acid), and abandoning any oxide with which it was previously in union. The muriatic acid sets the silicic acid free, combining with the alkalies to its exclusion, and at the same time uniting itself to whatever oxides were originally present in the mineral. The separated silica is to some extent dissolved by the diluted acid, but after the evaporation of the liquid to perfect dryness, it loses its solubility, and when acidulated water is poured upon the desiccated mass, it dissolves everything but the silica, which it leaves untouched.

534. Another method of preparing silica will be given under fluorine (see par. 664).

535. *Properties.*—Silica is a snow-white, gritty powder, which, after being strongly heated, is quite insoluble in water, acids, and indeed most liquids. It is infusible by the most powerful windfurnace, but melts when exposed to the intense flame of the oxyhydrogen blowpipe.

536. In spite of its insolubility in water after being heated, it can be obtained in a condition in which it dissolves in that liquid. Natural waters contain soluble silica, some of them in large quantity. The solution is tasteless, and has no action on vegetable colours, so that silicic acid is deficient in two of the characteristic properties of the strong acids. Nevertheless, at high temperatures, it combines with bases with the utmost readiness, displacing every acid more volatile than itself. A very large number of minerals are silicates, consisting of silicic acid, united with a variety of metallic oxides, such as those of iron and of manganese, as well as alumina, lime, magnesia, potass, and soda. The important artificial products, glass, porcelain, and stoneware, are combinations of

silicic acid with different oxides. Clay is the silicate of alumina, and is the constituent of common earthenware. China contains, in addition, lime, potass, soda, &c. besides excess of silica, and frequently also fusible compounds of boracic and phosphoric acids.

537. There are two species of glass, the one consisting of silica united to an excess of potass and soda, and characterised by being soluble in water; the other, and familiar species, which is totally insoluble in water and the immense majority of re-agents, contains excess of silica, and is, besides, a combination of several silicates with each other, as silicate of soda with silicate of lime, or silicate of potash with silicate of lead.

SULPHUR.

Equivalent, 16; *symbol*, S; *synonyme*, ***Brimstone****; specific gravity when solid*, 1·98; *specific gravity as vapour at* 900°, 6634; *combining measure, ⅓d volume; at* 1800°, *density about one-third of above, and combining measure* □

538. *Distribution.*—Sulphur occurs abundantly free, chiefly in volcanic districts, where, as on the flanks of Etna and Hecla, it presents itself in large veins, from which it is quarried. It is also extensively diffused through the globe, in combination with the metals, so that the chief ores of silver, lead, zinc, antimony, &c. are sulphurets. Much also occurs in combination with iron, forming a well-known mineral, iron pyrites. In the state of sulphuric acid, united with bases, it also occurs frequently. Heavy spar, for example, and gypsum, both abundant minerals, are respectively the sulphate of baryta and the sulphate of lime. The sulphates of magnesia, copper, iron, and several other metals, are also found native. It is present in all plants, and is an essential and important ingredient of animals. In the latter, as well as in plants, it exists in a peculiar state of combination, of which a good example is furnished by white of egg, the familiar effect of which in blackening a silver spoon is owing to the sulphur it contains.

539. Sulphur occurs in commerce in two states—*roll* sulphur, which is the substance in a solid state shaped into cylinders by casting it in suitable wooden moulds; and *flowers* (not flour) of sulphur, which present this body in the shape of a fine crystalline powder, procured by condensing its vapour, in imitation of the natural process by which water-vapour changes into snow. Flowers of sulphur are also called sublimed sulphur, and are purer than the substance in rolls.

540. *Properties.* — Sulphur is a greenish-yellow, brittle solid, crystalline in structure, and exhaling a peculiar odour when rubbed. It is a little less than twice as heavy as water, in which it is insoluble, but it dissolves in other liquids, such as oil of turpentine and the fixed oils, but best of all in bisulphuret of carbon, from its solution in which, it may be procured by evaporation, in large transparent beautiful crystals.

541. To avoid repetition, we mention its further properties in connection with experiments which may be tried in illustration of them :—

1. A roll of sulphur held in the warm hand near the ear, will be heard to emit a peculiar crackling sound; and if the difference between the temperature of the sulphur and the hand be considerable, will split into pieces. These phenomena are owing to the bad and unequal power of conducting heat which characterises sulphur, in consequence of which, it expands in one direction more than in another when heated, and, as a result, has the more expanded portions separated, and, as it were, torn from the colder and contracted ones.

2. Pieces of roll sulphur placed in a glass flask, and heated, will melt at 234°, and form a clear, thin, limpid, yellow liquid. If poured in this state into water, it rapidly congeals into a yellow crystalline solid. If, on the other hand, after it has melted, the heat be still continued, the liquid grows darker in colour, and much thicker in consistence, so that between 430° and 480° it resembles in appearance treacle, and is so viscid and sluggish in its movements, that it is some time before it begins to flow from a vessel containing it, after that has been inverted. If liquid sulphur be poured into water whilst in this treacly condition, it consolidates into a soft, elastic, transparent substance, of a dark yellow or pale-brown colour, much resembling caoutchouc in some of its properties, and totally unlike ordinary sulphur. It may be preserved in this state for some time, and can be drawn out into long elastic threads like India-rubber, but in a few days it returns to the hard crystalline state.

542. When the treacly liquid is still further heated, it grows thin and liquid again, though not so fluid as it was at a lower temperature; and when it reaches 788°, it passes into ebullition. It will then be observed to give off a deep yellow vapour, which condenses on cold bodies into solid sulphur, and is highly combustible.

Sulphurous Acid.

Equivalent, 32; *symbol*, SO_2; *specific gravity*, 2210;
combining measure, □□

543. 1. When sulphur is kindled, it burns with a blue flame, and evolves a highly characteristic odour, distinguished as that of burning brimstone, which is not the smell of sulphur itself, but that of its oxide, sulphurous acid.

2. If the experiment of burning sulphur in oxygen described under that gas be repeated, the phenomena described in the preceding paragraph will be witnessed still more fully, and the production of an acid (namely, sulphurous) may be demonstrated by pouring infusion of litmus into the jar in which the sulphur has been burned. When oxygen is thus converted into sulphurous acid, it undergoes no change in volume, although it doubles its weight; sixteen grains of oxygen combining with as many of sulphur to form thirty-two of sulphurous acid.

3. Sulphurous acid is generally prepared from sulphuric acid in the following way:—Quicksilver is heated in a retort with an equal weight of oil of vitriol till effervescence occurs. The mercury deprives the sulphuric acid of one-third of its oxygen, thereby reducing it to the state of sulphurous acid. This comes away as a gas, and may be collected like other gases, but not at the water-pneumatic trough, owing to its solubility in that liquid. The decomposition may be thus represented in symbols:—

$$2(HO,SO_3) \text{ and } Hg = HgO,SO_3 \text{ and } SO_2.$$

$2H, SO_4$

The mercury combines with oxygen, derived from the sulphuric acid, to form oxide of mercury, thereby converting sulphuric acid into sulphurous acid, and the oxide of mercury afterwards unites with undecomposed sulphuric acid to form sulphate of the oxide of mercury. Two stages, therefore, may be recognised in the decomposition.

$$\text{First stage, } (HO)SO_3 + Hg = SO_2 \text{ and } HgO.$$
$$\text{Second stage, } (HO)SO_3 + HgO = HgO,SO_3.$$

544. In the preceding diagrams the water of the oil of vitriol, which only plays a secondary part in the change, is placed within brackets on the left, and is not represented among the products of decomposition on the right.

545. *Properties.*—Sulphurous acid is a colourless, invisible gas, having the odour and taste of burning brimstone. It extinguishes flame, is quite irrespirable, and indeed poisonous.

Water dissolves more than thirty times its volume of the gas. The following experiments may be tried with it:—

1. The weight of the gas, which is more than twice as heavy as air, enables us to dispense with the costly mercurial trough in examining most of its properties. A bottle or jar may be filled with the gas by bringing a glass tube connected with a retort or other arrangement, such as a flask (fig. 54), from which sulphurous acid is issuing, to the bottom of the vessel intended to receive the gas. The gas then fills the bottle or jar from below, chasing out the air before it as it ascends.

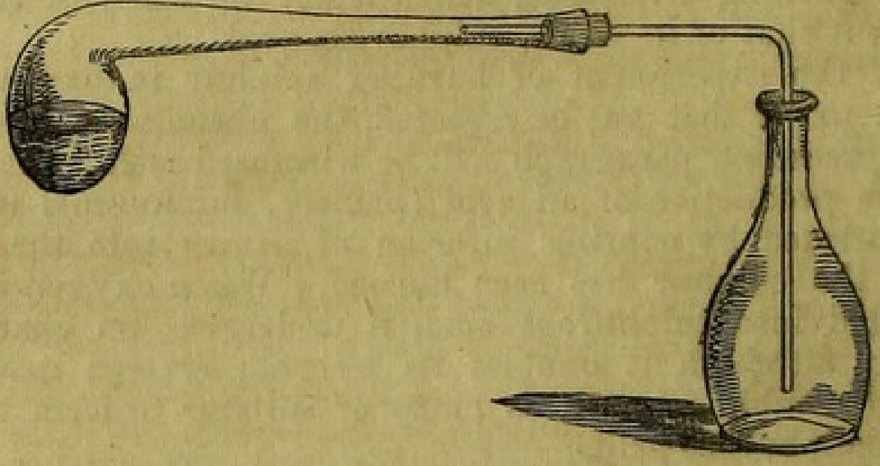


Fig. 54.

2. A candle plunged into a jar of the gas will at once be extinguished. Sulphurous acid, indeed, like carbonic acid, exerts a positively prejudicial influence on combustion.

3. A little infusion of litmus may be poured into a bottle containing it, and the mouth of the bottle closed by the thumb. If the bottle be then briskly shaken for a few minutes, and its mouth afterwards opened whilst under water, the latter will rush up with great violence, and nearly or entirely fill the vessel. In this way both its action on colouring matter and its great solubility in water may be demonstrated by one experiment.

4. It bleaches vegetable colours, however, as well as changes their tints, and is employed in the arts to bleach wool, silk, and straw. To demonstrate this property, a flower (such as a red rose) may be hung in a vessel of the gas, or suspended over burning sulphur, when its colour will slowly disappear; or an infusion of the purple cabbage to which a little potass has been added, so as to change it to green, may have a current of sulphurous acid sent through it, when it will be observed first to grow red, and then to become colourless. The colour, however, is not completely destroyed, as it is by chlorine; for if the bleached cabbage infusion be divided into two por-

3 $Fe_2 SO_2$ = 2 S, HO

tions, and a little sulphuric acid added to the one, and potass to the other, a red tint will be developed in the former, and a green in the latter.

5. Sulphurous acid has a remarkable power of arresting animal decomposition, and preventing putrefaction. In illustration of this, a solution of the gas may be added to a portion of dissolved glue or isinglass, whilst another portion of the latter is kept unacidulated, for the sake of comparison. The simple solution will be found to putrefy long before the other shows any signs of decomposition.

Sulphuric Acid.

SO_3.

546. Sulphuric acid may be considered the most important of the acids, both on account of its own properties, and because, without it, we should not be able to procure other valuable reagents, such, for example, as nitric, muriatic, and acetic acids, carbonate and sulphate of soda, soap, glass, &c.

547. Sulphuric acid does not occur in nature free, unless in small quantity in the neighbourhood of volcanos. In a state of combination, as already mentioned, it is found in various minerals. It is prepared for commercial purposes in two ways: 1*st*, by heating green vitriol, the sulphate of iron; 2*d*, by adding oxygen to sulphurous acid, through the medium of nitrous acid. The variety of sulphuric acid obtained by the first process goes by the name of Nordhausen acid, from the place in Saxony where it is chiefly prepared. It is also called Saxon, or fuming sulphuric acid. Green vitriol consists of sulphuric acid, oxide of iron, and water, its exact composition being $FeO,SO_3 + 7HO$. It is first strongly dried, the effect of which is to expel the greater part of the water it contains. About a seventh part of that, however, is always, and purposely retained. The dried sulphate of iron is then exposed to a red heat in stoneware retorts. Half of the sulphuric acid of the sulphate comes over in combination with water, whilst the other half is decomposed into sulphurous acid, which is evolved as gas, and oxygen, which converts the protoxide of iron into peroxide.

548. Nordhausen acid varies in strength, but when strongest, consists of one equivalent of water and two of sulphuric acid $HO+2SO_3$. It is twice as strong as the strongest English sulphuric acid, or oil of vitriol.

549. It is employed in the arts for dissolving indigo, an acid solution of which is extensively employed in dying blue. It is likewise an object of great interest to the chemist, as it

$3FeO \cdot SO_3 = 2SO_3 HO + Fe_3O_4$

3 F Fe

enables him to procure anhydrous sulphuric acid. For this purpose, the strongest Nordhausen acid is gently heated in a retort connected with a receiver kept very cold. The anhydrous acid, SO_3, rises in vapour at a temperature of about 80°, and condenses in solid fibres, which are soft, and may be moulded by the fingers like wax. It absorbs moisture from the air—giving rise, in so doing, to the production of dense white fumes. This solid body, which is troublesome to prepare, and is rarely seen, is the only substance properly deserving the title of sulphuric acid, what ordinarily goes by that name being a combination of the solid with water.

550. To prevent confusion, the three most important forms of the acid are thus distinguished :—

Anhydrous sulphuric acid,	SO_3
Nordhausen sulphuric acid,	$HO,2SO_3$
Oil of vitriol,	HO,SO_3.

The last is the one sold in the shops under the name of sulphuric acid, and is the most important of the three. The title oil of vitriol is, in strictness of speech, more applicable to the Nordhausen acid, to which it was originally applied, because that substance is a dense *oily* liquid, obtained by distilling green *vitriol.* The term, however, is now restricted to the weaker English acid, which is prepared in the following way :—Sulphur is kindled in a furnace, and freely supplied with air. It becomes sulphurous acid, which is conducted into a large leaden chamber, along with nitrous acid and steam. The sulphurous acid takes oxygen from the nitrous acid, and becomes sulphuric acid, which combines with the steam, and condenses as a liquid on the floor of the chamber: Thus—$NO_4+2SO_2 = NO_2$ and $2SO_3$; or thus—

$$\begin{array}{ll} NO_4 = & \left\{ NO_2 \quad O \quad O \right. \\ 2SO_2 = & \qquad\quad SO_2 \; SO_2 \\ \cline{2-2} & NO_2,SO_3,SO_3 \end{array}$$

The nitrous acid, NO_4, has thus half of its oxygen removed by the sulphurous acid, and becomes, in consequence, nitric oxide, NO_2 : thus—NO_4 *minus* $O_2 = NO_2$. The nitric oxide produced in this way ascends as gas in the leaden chamber, and combining with oxygen derived from the air filling the space, again forms nitrous acid : thus—NO_2 *plus* $O_2 = NO_4$. This nitrous acid, like the first quantity, yields half its oxygen to sulphurous acid, converting it into sulphuric, and itself reverting to the condition of nitric oxide. The nitric oxide then acts afresh upon the air, becoming nitrous acid in the way already described.

551. In this way a small amount of nitric oxide suffices to convert a large quantity of sulphurous into sulphuric acid, provided abundance of atmospheric air be also present. It is the air, in truth, which supplies the oxygen requisite for the conversion of the one acid into the other; but sulphurous acid cannot directly take oxygen from atmospheric air, so as to change into sulphuric acid. The nitric oxide, accordingly, is essential, playing the part, as it were, of a carrier or go-between, alternately as nitrous acid, fetching oxygen from the air to the sulphurous acid, and returning as nitric oxide to procure a fresh supply.

552. At intervals the liquid which condenses is drawn off from the floor of the leaden chamber. In this condition, it is not in a state of sufficient concentration for many purposes. It is deprived, accordingly, of the excess of water it contains, by heating it in shallow leaden troughs, or pans, to a temperature of about 300°, which expels water without dissipating any of the sulphuric acid. The liquid is further concentrated in large vessels of platina, till it acquires a density of 1847 or 1850. When of this specific gravity, it is a definite compound of one equivalent of acid and one of water, and may be distilled without change. The reader will understand that this compound, HO,SO_3, is referred to when we make use of the title oil of vitriol.

553. *Properties.*—Oil of vitriol is a dense, oily, colourless, and odourless liquid. It is highly corrosive, as may be illustrated by letting a drop fall on paper or linen, which is rapidly destroyed by it. This corroding action is accompanied by a blackening or charring of the organic bodies on which it has acted, an effect which is owing to its separating the elements of water from the substance it chars, whilst it rejects the carbon, which appears with its characteristic black colour. This effect may be easily observed by leaving a splinter of wood for a few minutes in oil of vitriol.

554. Sulphuric acid has a strong, sour taste, which can be safely ascertained only with the diluted acid, and it reddens vegetable blues, and changes browns to yellows, like the other strong acids. It is, at ordinary temperatures, the most powerful of these bodies, displacing nearly every one of them from a state of combination. The process for nitric acid was an illustration of the superiority in affinity for the strong bases of sulphuric acid over nitric. It forms an extensive series of salts called the sulphates, many of which are employed in medicine and the other arts.

555. The great affinity of sulphuric acid for water has already been referred to. A bottle partially filled with oil of vitriol, if left unstoppered, will by and by run over, in consequence of the increase of volume occasioned by the water which it absorbs from the atmosphere. Advantage is taken of this property to dry substances which cannot be heated without undergoing decomposition. Organic substances, such, for example, as sugar or starch, may be totally deprived of moisture by reducing them to powder, and placing them in shallow saucers above a basin containing oil of vitriol. The whole arrangement is covered by a bell-jar, to exclude the moisture of the outer air.

556. When sulphuric acid combines with water, much heat is evolved, as may be ascertained by quickly mixing four parts of oil of vitriol with one of water in a glass flask. The vessel will, in a few seconds, become too hot to be held in the hand. A thin flask must be used for this purpose, as thick ones, owing to their slow and unequal conduction of heat, are very liable to be broken.

557. Sulphuric acid dissolves most of the metals, especially if raised in temperature. The acid first changes the metal into an oxide, and then converts that into a sulphate. When the acid is concentrated, the metal becomes oxidised at the expense of the sulphuric acid, SO_3, which it reduces to sulphurous acid. (See par. 540.) This is specially the case with copper and mercury. When the acid is diluted, the metals which dissolve in it derive oxygen from the water associated with it, and hydrogen is evolved, as has already been pointed out when discussing the preparation of that gas. (See par. 366.) Sulphuric acid, whether free or in a state of combination, is readily distinguished from all other bodies by the action of any soluble salt (such as the chloride) of barium, on a solution containing it. Salts of barium produce with sulphuric acid a white precipitate consisting of the sulphate of the oxide of barium, otherwise called baryta. The sulphate of baryta is distinguished from other similar precipitates by its being insoluble in water, and in nitric and muriatic acids.

Sulphuretted Hydrogen.

Equivalent, 17; *symbol*, HS; *density*, 1191; □□

558. Sulphur forms with hydrogen an interesting and important compound, named sulphuretted hydrogen, besides a less important combination called the persulphuret of hydro-

gen. The former is prepared by the action of diluted sulphuric acid on the protosulphuret of iron. This sulphuret is prepared by heating sulphur and iron filings together in a crucible, or by bringing together a stick of roll sulphur and a bar of malleable iron at a white heat. In either case a compound is formed of one equivalent of sulphur and one of iron, FeS, which, when dissolved in diluted sulphuric acid, yields sulphuretted hydrogen.

559. If iron alone be placed in the dilute acid, as we have already seen, pure hydrogen is evolved. If the iron be combined with sulphur, then the hydrogen which is evolved comes off in union with the sulphur.

560. The apparatus employed for the preparation of pure hydrogen is made use of when its compound with sulphur is required. The evolution of the gas depends upon the following change:—The sulphuret of iron decomposes the water of the oil of vitriol, the sulphur uniting with its hydrogen to form sulphuretted hydrogen, the iron with its oxygen to form oxide of iron; which thereafter combines with the sulphuric acid, forming the sulphate of the oxide of iron, green vitriol. Thus in symbols:—

$$\mathrm{FeS} \text{ and } \mathrm{HO,SO_3} = \mathrm{HS} \text{ and } \mathrm{FeO,SO_3}.$$

Or more fully:—

First stage of decomposition, $\mathrm{FeS} + \mathrm{HO} = \mathrm{FeO}$ and HS.
Second stage of decomposition, $\mathrm{FeO} + \mathrm{SO_3} = \mathrm{FeO,SO_3}$.

561. *Properties.*—Sulphuretted hydrogen is a colourless gas, having the odour of rotten eggs. It does not support combustion, but is itself combustible. It is irrespirable, and a powerful poison. Water dissolves about two and a-half times its volume of the gas, and acquires its offensive odour and taste. The class of mineral waters called sulphureous contain this gas in solution; only, however, in small quantity. It is a substance of great value to the chemist, as furnishing him with a most useful test for the distinction of metals, as well as other bodies, from each other. The following experiments may be tried with it:—

1. Jars of the gas should be collected, if possible, in the open air, and not at a pneumatic trough coated with lead pigment, as the paint will be blackened.

2. A jar of the gas may be kindled, when it will burn with a blue flame, at the same time depositing some sulphur within the vessel.

3. If mixed with half its volume of oxygen, and kindled, it burns with explosion, its hydrogen becoming converted into water, and its sulphur into sulphurous acid.

4. Mixed with an equal volume of chlorine, it is at once decomposed, and its sulphur separates, the chlorine combining with its hydrogen to form hydrochloric acid. Chlorine may be used in this way to purify apartments contaminated by the gas.

5. A silver coin, or a piece of paper soaked in a solution of sugar-of-lead, is at once blackened if placed in a jar of sulphuretted hydrogen. This effect depends upon the production of a metallic sulphuret, by the combination of the sulphur of the sulphuretted hydrogen with the silver or lead. This property of the gas causes it to act very injuriously on paintings containing any white-lead, and likewise on silver plate, and metallic utensils in general. Silversmiths, accordingly, are reluctant to burn coal-gas in their shops, because even the trace of sulphuretted hydrogen, which escapes removal during the purification of the former, is sufficient to blacken and tarnish their goods. A white paint having the qualities of white-lead, but which sulphuretted hydrogen would not blacken, has long been a desideratum among artists.

6. A solution of sulphuretted hydrogen may be prepared by allowing a current of the gas to stream through water for a few minutes. If a portion of this be added to a solution of acetate of lead, nitrate of silver, sulphate of copper, and several other metallic salts, it will produce in them black precipitates, which are sulphurets of the metals.

7. A solution of tartar emetic treated in the same way gives an orange precipitate of sulphuret of antimony.

8. A solution of arsenious acid, in like manner, gives a bright yellow precipitate of sulphuret of arsenic.

9. A solution of a salt of zinc, such as the sulphate (to which excess of ammonia has been added), gives a white precipitate of sulphuret of zinc.

10. A solution of the acetate of manganese gives a flesh-coloured or pink precipitate of the sulphuret of the metal.

562. These experiments illustrate the fact that, the majority of metallic sulphurets are black; one white, that of zinc; one orange, that of antimony; one flesh-coloured, that of manganese; one yellow, that of arsenic. The sulphuret of cadmium is also yellow, and so is the bisulphuret of tin. The value of sulphuretted hydrogen as a means of distinguishing the metals from each other will appear from these statements, which only, however, illustrate one of the modes in which it proves serviceable to the chemist.

SELENIUM.

Equivalent, 39·57; *symbol*, Se; *density of vapour unknown.*

563. Selenium is a rare substance, closely resembling sulphur in properties, and occurring in nature associated with it. Its name is derived from the Greek Σεληνή (*Selené*), the moon, in allusion to its similarity in properties to a metallic element, *Tellurium*, which receives its name from the Latin *tellus*, the earth.

564. Selenium is so rare and costly, that the student will not have it in his power to try experiments with it. We mention, therefore, its properties exceedingly briefly. At ordinary temperatures it is a solid, of a brownish-red colour, semi-transparent, and with a lustre somewhat resembling that of the metals. It melts a little above 480°, and boils about 1290°, forming a yellow vapour paler than that of sulphur.

565. It combines with oxygen, forming selenic acid, which corresponds to sulphuric acid; and selenious acid, analogous to sulphurous acid.

566. It unites with hydrogen to form seleniuretted hydrogen, HSe, a colourless gas, obtained by heating selenium in moist air. It has a peculiar disagreeable odour, compared to that of decaying horse-radish, the development of which before the blowpipe-flame enables us to recognise selenium in bodies containing it. This gas, if respired even in very small quantity, produces excessive irritation of the lining membrane of the nostrils and air-tubes of the lungs, so that it has even been conjectured by an eminent chemist that our epidemic influenza may be occasioned by the evolution of this gas from volcanos, and its consequent presence in the atmosphere.

567. Selenious acid, SeO_2, unlike sulphurous acid, is a solid body, easily obtained in crystals by heating selenium in nitric acid.

568. Selenic acid, SeO_3, is procured by fusing selenium with nitre, a process which affords the seleniate of potass, KO,SeO_3. From this the selenic acid is separated by a complicated process. It has never been obtained anhydrous. When most concentrated, it is associated with an atom of water corresponding to oil of vitriol. It is a powerful acid, and has one property possessed by no other simple acid—that, namely, of dissolving gold.

569. None of the compounds of selenium, nor the element itself, are used in the arts.

PHOSPHORUS.

Equivalent, 32; *symbol*, P; *specific gravity of solid*, 1·77; *of vapour*, 4327; *combining measure of latter*, □

570. *Distribution.*—Phosphorus occurs in the state of phosphoric acid, PO_5, in union with bases, chiefly lime and magnesia, in volcanic and other rocks, which, by crumbling down, form our fertile soils. It is a never-failing constituent of the plants used by man and the domesticated animals as food—such as grains, peas, and beans; in which it occurs both in the forms of calcareous phosphates, and in a peculiar state of combination with carbon, oxygen, hydrogen, and nitrogen. It is an equally characteristic and important ingredient of animal structures. Their bony skeletons owe their strength and rigidity to the phosphates of lime and magnesia; whilst phosphorus exists in other states of combination in the flesh, blood, brain, milk, and other tissues and secretions of animals.

571. *Preparation.*—Different processes are followed in the preparation of phosphorus, but the simplest is the following:—Bones are burned to whiteness in an open fire, ground to powder, and mixed with oil of vitriol somewhat diluted. The whole is well stirred, and left at rest for some hours. At the end of this time fresh water is added, and the liquid passed through a filter. What filters through is a solution of phosphoric acid, containing some phosphate of lime and phosphate of magnesia, besides a little sulphate of both these bases. There is left on the filter sulphate of lime, resulting from the combination of the oil of vitriol with the lime of the bones, to the exclusion of the phosphoric acid previously united with it.

572. The impure solution of phosphoric acid is evaporated to the consistence of a syrup, stirred full of charcoal-powder, and heated in an iron vessel till every trace of moisture is expelled. The dried mass is then introduced into a retort made of fire-clay, which is placed in a furnace, and raised to a white heat. From the mouth of the retort a wide copper tube proceeds, which is bent at right angles, and dips below the surface of water contained in a glass vessel.

573. The change that occurs within the white-hot retort is simple. Phosphoric acid consists of one equivalent of phosphorus and five equivalents of oxygen. The latter combine with as many equivalents of carbon, forming carbonic oxide, which escapes by the bent tube, and bubbles up through the

water; whilst the phosphorus, rising in vapour, and descending into the water, condenses there. Thus in symbols :—

$$PO_5 + 5C = P \text{ and } 5CO.$$

574. The phosphorus is melted a second time under the surface of hot water in cylindrical moulds, so that it is met with in commerce in the form of sticks, somewhat like those of barley-sugar.

575. *Properties.*—Phosphorus is, at ordinary temperatures, a soft, transparent, pale-yellow solid, resembling bees'-wax in consistence, and admitting of being cut or moulded like it. It is insoluble in water, under which it is kept, to prevent its spontaneous combustion. It dissolves in the volatile oils, in naphtha, bisulphuret of carbon, &c. and may be obtained from these solutions in crystals, which are not, however, easily preserved. It melts at 108°, and boils at 550°, beginning to rise in vapour a little above the temperature of boiling water.

576. To observe these phenomena, a small piece of carefully-dried phosphorus should be placed at the bottom of a long narrow tube shut at one end. On heating this, the solid will be observed to melt, form an amber-yellow, highly-transparent liquid, evolve a pale-yellow vapour, and finally boil. If a wide tube be taken, the phosphorus takes fire, and the phenomena in question are not observed.

577. The most remarkable property of this substance is its excessive inflammability, and the intense light and heat which it evolves when burning. From this character it has received its name from two Greek words, signifying, in combination, the *light-bringer*, or *light-producer*, being the exact equivalent of the Latin compound *lucifer*.

578. Phosphorus takes fire spontaneously in warm weather, and at all ordinary temperatures is readily kindled by friction, a stroke, or the heat of the hand. It must therefore be handled cautiously. It is luminous in the dark; as may be observed by placing a stick in a jar of air, or using it, like a crayon, to write or draw with on a wall. In employing it thus, the phosphorus should not be kept long dry, or held in the naked fingers. It may be dipped at intervals into a vessel of water, so as to prevent its temperature rising to the combustion-point. The consideration of the compounds of phosphorus with oxygen and hydrogen will lead to the notice of all the striking experiments on the combustibility of phosphorus, so that we do not mention them here.

COMPOUNDS OF PHOSPHORUS WITH OXYGEN.

579. Phosphorus and oxygen form, by their union, four compounds, all possessed of striking properties, and interesting in their method of preparation. Their names and composition are as follows:—

Oxide of phosphorus,	P_2O	Equivalent 72.
Hypophosphorous acid,	PO	Equivalent 40.
Phosphorous acid,	PO_3	Equivalent 56.
Phosphoric acid,	PO_5	Equivalent 72.

580. The oxide of phosphorus is prepared by introducing some fragments of the latter into a champagne or narrow ale-glass containing boiling water. The phosphorus melts, and a current of oxygen is then to be forced upon it from the narrow nozzle of a flexible tube communicating with a bladder or gasholder filled with the gas. The phosphorus takes fire, burning with great beauty under the surface of the water, and becoming converted into a reddish-brown powder, which is its oxide in a state of impurity.

581. When phosphorus is burned in air or oxygen, it is converted in greater part into phosphoric acid, but leaves behind a certain portion of unburned residue of a yellowish-red colour. This also is the impure oxide.

582. Hypophosphorous acid is not itself a substance of special interest; but the process for obtaining a salt of it is interesting, from a striking phenomenon which it exhibits. To observe this, quicklime is heated red-hot in a crucible, which is quickly removed from the furnace; and whilst still at a high temperature, pieces of phosphorus are thrown into it. It is then quickly covered by another crucible inverted over it, and heaped up with sand, to exclude air. The phosphorus combines in part with the oxygen of the lime, CaO, to form phosphoric acid, and this with undecomposed lime, to form phosphate of lime, CaO,PO_5. At the same time another portion of the phosphorus combines with the calcium of the lime, forming phosphuret of calcium, CaP. When the contents of the crucible, which are of a dark-brown colour, and consist of a mixture of phosphate of lime and phosphuret of calcium, are thrown into water, the latter is decomposed by the phosphuret. Its oxygen combines with the calcium to form lime, and with part of the phosphorus to form hypophosphorous acid, PO, which thereafter unites with the lime, forming hypophosphite of lime, CaO,PO. The hydrogen of the decomposed water also unites with the phosphorus, form-

ing phosphuretted hydrogen, PH_3, a gas which, as thus prepared, spontaneously takes fire when it meets air. It is the production of this gas which is the interesting part of the experiment. Every fragment of the phosphuret of calcium dropped into the water gives rise to the evolution of bells of the gas, which rise through the liquid, and burst into flame at its surface, producing beautiful white wreaths of phosphoric acid, and exhaling a strong, offensive, garlic-like odour.

Phosphorous Acid.

PO_3.

583. Phosphorous acid is the least interesting of the compounds of phosphorus. It is prepared in two ways:—

1. If phosphorus be burned with a limited supply of air, this acid, and not phosphoric, is formed. In illustration of this, a tube of glass should be taken about a foot in length and half an inch in diameter. It is to be bent close to one extremity at an obtuse angle, and the shorter limb drawn out at the blowpipe into a conical shape, so as to leave an aperture not larger than would admit a pin's point. Into the tube, held obliquely with the bent end lowest, and the capillary tube pointing upwards, a small fragment of dry phosphorus is to be introduced, and allowed to slide down into the angle. When the tube is heated at this point, the phosphorus takes fire, and burns with a pale greenish flame; but owing to the small quantity of air which reaches it through the narrow aperture, it forms only phosphorous acid, which is carried along with the heated air, and condenses in the upper part of the tube as a soft white powder. This is the anhydrous acid.

2. The second process furnishes it in combination with water. When the terchloride, or teriodide of phosphorus (PCl_3, or PI_3), is moistened with water, the latter is decomposed, and its oxygen forms phosphorous acid with the phosphorus. The iodide of phosphorus is more conveniently prepared than the chloride. To obtain the former, a fragment of phosphorus is placed at the bottom of a tube, and covered with about eleven times its weight of iodine. The two bodies combine energetically together, evolving much heat in so doing. Water is then added. Its hydrogen combines with the iodine, forming a peculiar compound named hydriodic acid, which will be considered under iodine, whilst its oxygen unites with the phosphorus, forming phosphorous acid—

$$PI_3 + 3HO = PO_3 \text{ and } 3HI\text{; or thus:—}$$

R C McKeown Esqre

The liquid is warmed till the whole of the hydriodic acid has escaped as gas, and has left a pure solution of phosphorous acid. This acid is interesting chiefly as a source of pure phosphuretted hydrogen, which it yields when its aqueous solution is concentrated in a retort; one portion of the phosphorus of the phosphorous acid uniting with the oxygen of water, so that phosphoric acid is produced, whilst another unites with its hydrogen, forming the gas in question.

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Phosphoric Acid.

PO_5.

584. Phosphoric acid, as has been already mentioned, may be procured by the action of sulphuric acid on burnt bones. It may also be obtained by the action of nitric acid on phosphorus, which, however, is a troublesome and somewhat dangerous process.

585. It is most conveniently prepared by setting fire to a piece of phosphorus lying on a stoneware plate, or sheet of metal, and covering the combustible after it is lighted with a bell-jar. The phosphorus combines with the oxygen of the air to form phosphoric acid, which ascends in the current of hot air as a thick, white smoke, and as the whole cools, falls upon the plate as a soft white solid, scarcely distinguishable from snow in appearance. Oxygen may be taken instead of air, but is not necessary. Whilst discussing the former gas, we have described the mode in which phosphorus may be burned in it.

586. The snow-like phosphoric acid absorbs moisture with great rapidity from the air, and runs into a liquid. When dropped into water, it hisses like red-hot iron quenched in that fluid, owing to the high temperature produced when it combines with it.

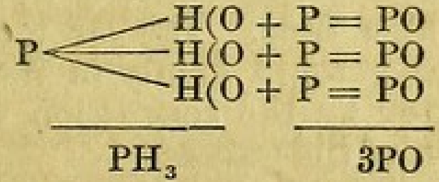
587. Phosphoric acid has a pleasant, sour taste, without any flavour. It is not poisonous, nor, speaking generally, corrosive; but from its power to dissolve phosphate of lime, it acts destructively on the teeth, so that when administered medicinally, it is sucked through a quill or glass tube. It reddens litmus powerfully, and by union with bases, forms a large and remarkable class of salts. Unlike the majority of acids—which combine with bases in the proportion of one equivalent of the base to one of the acid, so that they are said to be monobasic or single-based—phosphoric acid can in certain circumstances unite with three equivalents of base, with two, or with one. We have thus three modifications of it, which are distinguished by the names monobasic, bibasic, and

tribasic—or single-based, double-based, and triple-based phosphoric acid.

Phosphuretted Hydrogen.

PH_3. *Equivalent*, 35; *density*, 1185; ⊞

588. We have already mentioned two processes for phosphuretted hydrogen—namely, the addition of phosphuret of calcium to water, and the concentration of hydrated phosphorous acid. A much more convenient process, however, is to heat phosphorus and sticks of potass along with a little water. The materials are placed in a small stoppered retort, with a long narrow neck. About fifty grains of phosphorus may be taken, as much caustic potass, and no more water than will suffice to cover them. These bodies react on each other nearly in the same way as phosphuret of calcium and water. The phosphorus unites with the elements of the latter, forming, with its oxygen, hypophosphorous acid, which unites with the potass, and phosphuretted hydrogen, which escapes as gas. Four equivalents of phosphorus may be represented as decomposing three of water, producing three equivalents of hypophosphorous acid, and one of phosphuretted hydrogen—$4P+3HO=3PO$ and PH_3; or thus:—



$$\begin{array}{l} P \begin{cases} H(O + P = PO \\ H(O + P = PO \\ H(O + P = PO \end{cases} \\ \underline{\quad PH_3 \quad} \qquad \underline{\quad 3PO \quad} \end{array}$$

589. The beak of the retort must be placed from the first under water, and heat slowly applied. Bells of gas soon begin to ascend through the liquid, and taking fire within the retort, occasion a slight explosion, which is followed by a rushing back of the water along the tube of the retort, to supply the place of the oxygen which combined with the burning gas. It is to prevent accidents during this return of the water that a long tube is prescribed as necessary to the retort. The contraction should not exceed a fifth part of the capacity of the retort; but as the explosion which precedes the contraction is liable to expel some of its gaseous contents, allowance must be made for a greater diminution than that of one-fifth. If the retort be gently heated, the oxygen of the air may be silently consumed, and in any case all danger is over as soon as the oxygen within the generating vessel has been exhausted. The phosphuretted hydrogen then encounters

an atmosphere of nitrogen, and cannot burn till it has escaped from the beak of the retort, and risen into the external air.

590. The preparation of phosphuretted hydrogen is one of the most beautiful experiments in chemistry. Each bubble of gas, when it reaches the surface of the water into which the beak of the retort dips, bursts into flame, and changes into a ring or wreath of white smoke, consisting of phosphoric acid mingled with water-vapour. These rings ascend in the air, widening as they rise, and presenting a very curious combination of movements. The whole ring increases in diameter horizontally, whilst it appears to present a series of internal revolutions in a vertical direction, as if made up of a multitude of smaller rings, placed at right angles to the plane or direction of the large one, and each revolving vertically, whilst the great circle expands horizontally. These circles are produced by the action of the oxygen of the air on the phosphuretted hydrogen, with which it combines, converting its hydrogen into water, and its phosphorus into phosphoric acid.

591. If bells of phosphuretted hydrogen are allowed to ascend into a jar half full of air or oxygen standing on the pneumatic trough, a flash of light is seen within the jar when the gases meet. The experiment is striking, but requires to be cautiously performed when oxygen is employed. Not more than one bell of phosphuretted hydrogen should be allowed to ascend at a time. The jar must be strong and thick, and should be grasped firmly in the hand, to prevent its being thrown over by the concussion which attends the explosive combustion of the gases.

592. At one time there were believed to be two species of phosphuretted hydrogen, differing in composition from each other, and distinguished by the one being spontaneously inflammable in air, and the other not. Hydrated phosphoric acid, when heated, yields the gas in the state in which it is not spontaneously inflammable; as obtained by the other two processes described, it takes fire when it meets the air. No appreciable difference, however, in composition can be detected between the two varieties of phosphuretted hydrogen. Each yields, on analysis, one equivalent of phosphorus to three of hydrogen. The spontaneously-inflammable variety can be deprived of its characteristic property by confining it over porous charcoal, or mixing it with the vapour of certain combustibles, such as sulphuric ether. The less combustible variety may be rendered spontaneously inflammable by adding to it a trace of nitrous acid. A volatile liquid compound of phosphorus and hydrogen has recently been ascer-

tained to be present in very small quantity in the more inflammable variety, and absent from the other, and to be the cause of their difference in properties. The vapour of this liquid is spontaneously inflammable.

593. Phosphuretted hydrogen has a strong offensive odour, and is highly poisonous. It is soluble in water, and produces precipitates in metallic solutions. Unlike sulphuretted hydrogen, it has no acid properties. On the other hand, it has the characters of a base combining with hydriodic acid, and forming a salt.

CHLORINE, BROMINE, IODINE, AND FLUORINE.

594. Chlorine, bromine, iodine, and fluorine, closely resemble each other in properties, and differ in essential characters from the elements already gone over. Unlike them, they have little affinity for oxygen and a great proneness to unite with hydrogen. Their combinations with the metals—such as chloride of sodium, $NaCl$, iodide of potassium, KI, fluoride of calcium, CaF—are salts, and resemble in properties the compounds of the oxygen acids with the oxygen bases. From this peculiarity the four bodies we are now to consider are called *simple salt radicals*, because, by union with metals, they produce true salts, as chlorine, by combining with sodium, produces common salt. They are further characterised by forming acids by combination with an equivalent of hydrogen, such as hydrochloric acid, HCl.

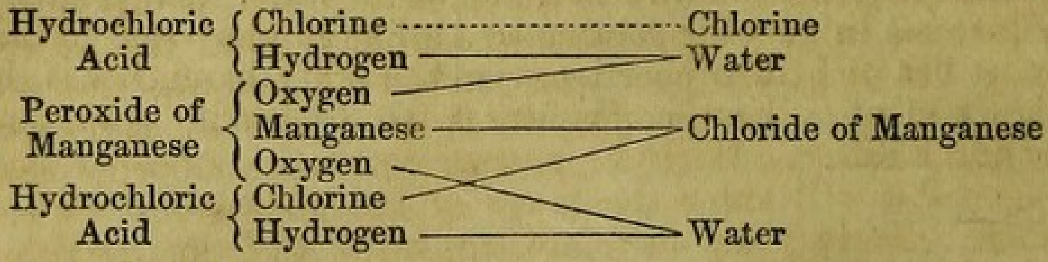
CHLORINE.

Equivalent, 35·5; *symbol*, Cl; *density*, 2440; ☐☐

595. *Distribution.*—Chlorine exists abundantly in nature, chiefly in combination with sodium, in sea-salt, and rock-salt. It occurs in the majority of soils and natural waters; and is found constantly present in plants and in animals. Its name is derived from the Greek χλωρος (chloros), yellowish green, in allusion to the peculiar colour of the gas.

596. *Preparation.*—Chlorine is most conveniently prepared by heating together in a retort or flask the black oxide of manganese, MnO_2, and hydrochloric acid, HCl. A gentle heat is applied, and the gas comes off rapidly. The change which occurs is the following:—Two equivalents of hydrochloric acid react upon one of the oxide of manganese. In this amount of the acid there are two equivalents of hydrogen, and in the oxide two of oxygen. These respectively combine together, forming two equivalents of water. There are thus

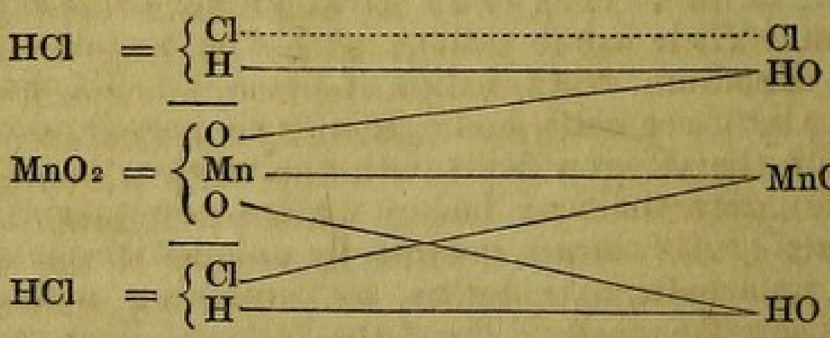
left two atoms of chlorine from the acid, and one of metal from the oxide. The metal combines with one of the equivalents of chlorine, forming chloride of manganese, MnCl, and rejects the other atom of chlorine, which comes off as gas. The diagram below represents this:—



Thus in symbols—

$$2HCl + MnO_2 = 2HO : Cl \text{ and } MnCl,$$

Or more fully—



597. In consequence of the irritating and suffocating action of chlorine on the lungs, as little of it as possible should be allowed to escape into the room where it is prepared. The jars should be filled with water before the collection of the gas is commenced; and the latter should be received in jars from the first, without allowing the air in the retort to pass into the apartment.

598. *Properties.*—No gas has more marked properties than chlorine, or admits of a greater number of interesting experiments being performed with it. We shall mention these properties in connection with the experiments which may be tried in illustration of them.

1. Chlorine, as its name implies, has a yellowish-green colour, a colour markedly visible by daylight, especially if a large jar of the gas be placed side by side with one of air in front of a white object, such as a sheet of paper. The peculiar tint of the gas is less distinguishable by artificial light.

2. The odour of chlorine is peculiar. When in small quantity, it is not unpleasant, and resembles that of fresh seaweeds, or what has been called, characteristically enough, the smell of the sea. In larger quantity, the gas excites

severe coughing, oppression of the chest, and sometimes even spitting of blood. If breathed undiluted, it produces immediate suffocation. The student, accordingly, must be careful, in uncovering jars of the gas, not to hold the mouth or nostrils directly over them; and experiments are best tried in a room with the windows open, or, still better, in one with a fire producing a considerable draught, so that the experimenter can hold the jars between himself and the fire, and thereby secure that the gas which escapes shall pass away by the chimney. With all precautions, more chlorine than is agreeable will enter the lungs of the unpractised experimenter. It is well, therefore, to know that its irritating effects are considerably lessened by inspiring a moderate quantity of the vapour of sulphuric ether or alcohol.

3. The density of chlorine, which is nearly two and a-half times as heavy as air, is such that it may be collected by displacement in the same way as sulphurous acid is. Its weight may likewise be illustrated by pouring it from one vessel to another, when its course may be marked by its colour, or by its characteristic action on chemical compounds, such as the nitrate of silver in solution, with which chlorine, like hydrochloric acid, produces a white precipitate.

4. Water at 60° dissolves twice its volume of the gas, and acquires its odour, taste, colour, and other properties. This solution may be prepared by following the method recommended for procuring that of sulphurous acid and of sulphuretted hydrogen. This solubility of chlorine makes it advisable to add some boiling water to the contents of the pneumatic trough, so as to raise it to the temperature of about 90° before collecting the gas. Chlorine-water, which is a useful reagent, must be kept in the dark. If exposed to direct sunlight, the chlorine combines with the hydrogen of the water, and its oxygen is liberated.

5. The affinity of chlorine for metals may be illustrated by taking antimony reduced to powder, and shaking it into a jar of the gas. The antimony takes fire, and burns brilliantly, combining with the chlorine to form chloride of antimony, $SbCl_3$. In like manner copper and gold-leaf introduced into the gas become red hot, and are converted into their respective chlorides, $CuCl$; Au_2Cl_3.

6. The characteristic affinity of chlorine for hydrogen may be shown by mixing the gases in equal volumes. They will not unite in complete darkness; but they combine, with explosion, if exposed to the direct sunbeam, and more slowly in diffuse daylight. It is more convenient, when experimenting, to determine their union by passing an electric spark through

the mixture, or applying a light to it. The explosion is more feeble than with oxygen and hydrogen, and the light is faint. The product of combustion is hydrochloric acid, which will redden infusion of litmus poured into the jar after the explosion.

7. Chlorine cannot support the combustion of such combustibles as burn most brilliantly in air, owing to its indifference to carbon. If a lighted candle, accordingly, be plunged into the gas, it burns with a smoky flame; the chlorine uniting only with its hydrogen, forming hydrochloric acid, and rejecting its carbon, which shows itself as soot.

599. The intense affinity of chlorine for hydrogen, and its corresponding indifference to carbon, are still more strikingly illustrated by dipping a piece of thin paper soaked in pure spirits of turpentine, C_5H_4, into the gas. The turpentine bursts into flame, hydrochloric acid is produced, and the jar becomes covered internally with a deposit of carbon.

8. Chlorine unites with olefiant gas, as has been mentioned under that substance. It combines also with carbonic oxide, as may be shown by mixing the gases in equal measures, and exposing the mixture to sunshine. They rapidly but silently unite, contracting to half their volume. The compound they produce is called chloro-carbonic-acid gas, $COCl$, and likewise *phosgene* (more properly, *photogene*)—that is, light-produced gas. Its production illustrates very strikingly the curious power of sunlight in accelerating chemical combination.

9. The most important of all the properties of chlorine is that of bleaching, by which term is implied a power to destroy all vegetable and animal colours, but not necessarily those of mineral compounds. The destruction of colour is complete and final.

600. Chlorine bleaches only when associated with water. If deprived of moisture, as it may be by transmitting it through bottles containing oil of vitriol, or tubes filled with fragments of chloride of calcium, it will not destroy the tint of a dry colouring matter, provided, at least, sunlight be excluded. In proof of this, a piece of paper stained with infusion of litmus, and thoroughly dried, may be placed at the bottom of a dry glass bottle, which is then to be filled with dried chlorine by displacement. If the bottle be now closed with a stopper, and set aside, the paper will be found to resist the bleaching power of chlorine for days or weeks, even though moisture be not altogether absent. But if a few drops of water are added, the colour will give way in a few minutes.

10. Other experiments may be made in illustration of the bleaching action of chlorine. The gas or its solution may be poured into vessels containing infusion of litmus, of purple cabbage, of turmeric, of violets, or indeed of any coloured vegetable substance. Ink likewise may be taken, and infusion of cochineal or carmine, to represent an animal colouring matter. The tints of all these bodies will be rapidly and totally destroyed by chlorine.

11. When bleaching is practised on the large scale, a combination of chlorine and quicklime, called chloride of lime, or bleaching powder, is preferred to chlorine. This substance can be readily procured, and is very cheap, so that the student may imitate, by means of it, the process of bleaching cotton. The bleaching powder is to be mixed with water, and the solution filtered. The liquid bleaches very slightly, so that it may be mixed with the solution of any animal or vegetable colouring matter, and the latter will not be destroyed; but if a drop of any of the stronger acids be afterwards added, the colour instantly disappears, owing to the acid combining with the lime, and liberating the chlorine from its state of inactive combination. Cotton is bleached by soaking it first in solution of bleaching powder, and then transferring it to a vessel containing very dilute sulphuric acid. In imitation of this process, a piece of turkey-red cotton cloth—that is, calico, dyed with madder—may be made colourless in a few minutes by soaking it alternately in a saturated solution of bleaching powder and in diluted sulphuric acid. Stains from port wine, fruit juice, ink, &c. may be readily removed in this way from linen or cotton. The solution of chloride of lime employed for this purpose should be very dilute, and a few drops of vinegar, rather than sulphuric acid, should be added to it after the stained tissue is immersed in the liquid. If bleaching does not speedily occur, a little more chloride of lime and acid may be added; but it is safer to err on the side of too little than too much. The former fault only protracts the bleaching, and is quite remediable; but if the opposite error be committed, as is too generally the case in domestic bleaching, the excess of chlorine, lime, and acid, which are all powerfully corrosive, totally destroys the fabric.

12. A pretty experiment may be tried with chloride of lime, in imitation of one of the processes employed in calico-printing. A piece of cloth of any colour, provided it owes its tint to an organic colouring matter, such as turkey-red cotton, is made use of. On this cloth devices are stamped; or where stamps cannot be procured, are painted with a paste

consisting of ordinary flour paste, or gum, to which a little strong sulphuric or tartaric acid has been added. The cloth is then dried, and afterwards immersed in a hot solution of chloride of lime. The result of this immersion is to develop the devices *in white* upon a coloured ground, in consequence of the acid of the paste with which they were executed decomposing the chloride of lime, and liberating its chlorine, which destroys the colour of the cloth at all the points impregnated with acid, but does not sensibly affect its tint elsewhere.

13. A property of chlorine not less important than that of bleaching, is the power it possesses of destroying animal effluvia and offensive odours. It is of great service, accordingly, as a disinfectant in fumigating apartments in which noxious animal matters have collected, or persons have resided whilst suffering from infectious diseases. It admits of valuable application also for the purification of the air of sick-chambers whilst occupied by invalids. The chlorine is evolved in the latter circumstances by adding chloride of lime to hot water mixed with a few drops of acid. Chlorine may in this way be set free in sufficient quantity to destroy unpleasant effluvia, without occasioning annoyance to the patient. Where apartments to be fumigated are not inhabited, the chlorine may be evolved from muriatic acid and oxide of manganese in the way already described.

Hydrochloric Acid.

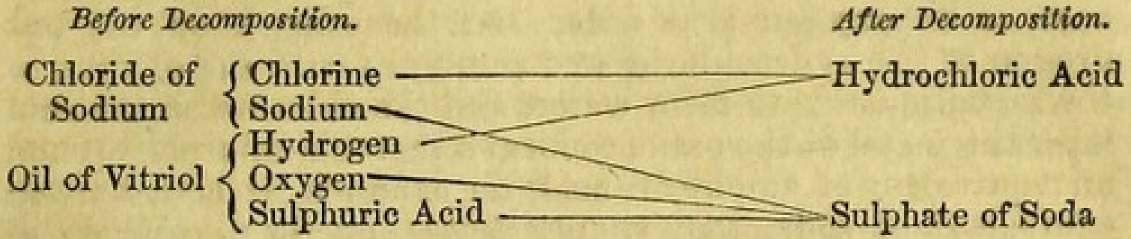
HCl; *synonymes, spirit of salt, marine acid, muriatic acid; equivalent,* 36·5.

601. Hydrochloric acid, the most important of all the hydrogen acids or hydracids, is prepared in two ways:—1. By the direct combination of chlorine and hydrogen, as mentioned under chlorine; 2. By distilling any metallic chloride with oil of vitriol. Common salt, the chloride of sodium, is taken for its preparation, on account of its cheapness and purity.

602. In imitation of the process followed on a large scale, the student may place in a retort connected with a flask, equal weights of common salt and oil of vitriol. The same weight of water is taken, one-third of which is placed in the retort, and the remainder in the receiver. On applying heat, hydrochloric acid is evolved, and condenses in the water of the receiver, whilst sulphate of soda remains behind. The decomposition is as follows:—The sodium of the chloride of sodium, $NaCl$, unites with the oxygen of the water of the oil of vitriol, to form soda, NaO; whilst the chlorine of the salt

unites with the hydrogen of the water, and forms hydrochloric acid, HCl, which distils over. The sulphuric acid and soda unite together, and are left behind as the sulphate of soda, NaO,SO_3.

603. As the preceding is an exceedingly frequent kind of decomposition, with which the student should be well acquainted, we state its rationale still more fully :—



Or in symbols—

$$NaCl \text{ and } HO,SO_3 = HCl \text{ and } NaO,SO_3.$$

604. *Properties.*—Hydrochloric acid, as sold in the shops, is a pale yellow, or colourless liquid. This is not the true hydrochloric acid, which is a gas, but a solution of it in water; and the yellow colour, when present, is owing to impurity. Gaseous hydrochloric acid is obtained by pouring undiluted oil of vitriol on perfectly dry common salt; or more conveniently, by boiling the strong muriatic acid of the shops. It is a colourless, invisible gas, forming dense white fumes when it meets moist air, and possessing a pungent, irritating odour. It has a strong, sour taste, and a powerful action on vegetable colours. Water dissolves nearly 420 times its volume of it, so that it cannot be collected over the water-pneumatic trough. Jars may be filled with it over mercury; but as it is heavier than air in the proportion of 1269 to 1000, it may be made to displace air, and so to fill dry vessels. The following experiments may be tried with it:—

1. An ounce of the strongest commercial muriatic acid is placed in a flask furnished with a tube fitted to it by a cork, and bent twice at right angles. The tube must be long enough to reach to the bottom of the vessels to be filled with the gas. A narrow-necked bottle having been arranged, with the tube descending into it, heat is applied to the flask, and gaseous hydrochloric acid is given off, not absolutely anhydrous, but sufficiently free from moisture to permit its characteristic properties to be examined. The bottle may be known to be filled, by acid fumes issuing freely from its mouth, when the tube is to be withdrawn, and the mouth of the bottle closed with the thumb. If the bottle be now opened below water, coloured blue with litmus, the liquid will rush up with

great force, and at the same time become red, so that by the one experiment the great solubility of the gas in water, and its possession of acid properties, may be illustrated.

2. If a candle be plunged into a jar of the gas, it is extinguished without setting fire to the hydrochloric acid, which is neither combustible nor a supporter of combustion.

605. When hydrochloric acid is added to a metallic oxide, it forms a salt with it, but not by simply uniting with the base, as an oxygen acid does. On the other hand, the hydrogen of the hydrochloric acid combines with the oxygen of the metallic oxide to form water, and the chlorine of the acid with the metal of the oxide to form a metallic chloride. When an equivalent of sulphuric acid, for example, is added to an equivalent of soda, they simply unite, and form sulphate of soda. But when an equivalent of hydrochloric acid meets an equivalent of soda, hydrochlorate of soda is not produced, but the hydrogen of the acid forms water with the oxygen of the alkali, whilst the chlorine and the sodium combine to form chloride of sodium, $HCl + NaO = HO$ and $NaCl$. This mode of action is exhibited by all the hydracids.

606. The test for muriatic acid, whether free or combined, is a soluble salt of silver. The nitrate of silver is generally taken. It identifies muriatic acid by producing in solutions which contain it, or its salts—that is, the chlorides—a white precipitate of the chloride of silver, which is distinguished from other similar substances by being perfectly soluble in ammonia, but quite insoluble in hot nitric acid.

Oxides of Chlorine.

607. There are four important oxides of chlorine, all possessed of acid properties. Their names and composition are as follows:—

Hypochlorous acid,	ClO	43·5
Hypochloric acid,	ClO_4	67·5
Chloric acid,	ClO_5	75·5
Perchloric acid,	ClO_7	91·5*

608. Hypochlorous acid is prepared by adding powdered red oxide of mercury to a bottle containing chlorine gas and a little water. The bottle is then closed with a cork and shaken briskly. The chlorine combines with the mercury to form chloride of mercury, and also with the oxygen to form hypochlorous acid, which dissolves in the water. The solu-

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* A fifth oxide, ClO_3, Eq. 59·5, has also been described. It is called chlorous acid, a name formerly given to hypochloric acid.

tion possesses more powerful bleaching properties than even chlorine. Hypochlorous acid, when free, is a gas of a yellow colour, prepared with difficulty, and very unstable. When slightly heated, it explodes, and is resolved into chlorine and oxygen.

609. Hypochloric acid, ClO_4, is procured by the action of oil of vitriol on chlorate of potass, KO,ClO_5, a salt already referred to, under oxygen. The sulphuric acid combines with the potass, forming sulphate of potass, and sets free chloric acid, ClO_5, but this immediately parts with one-fifth part by weight, or an equivalent of oxygen, and thus becomes changed into hypochloric acid, ClO_4. The application of heat, though not essential, accelerates the change.

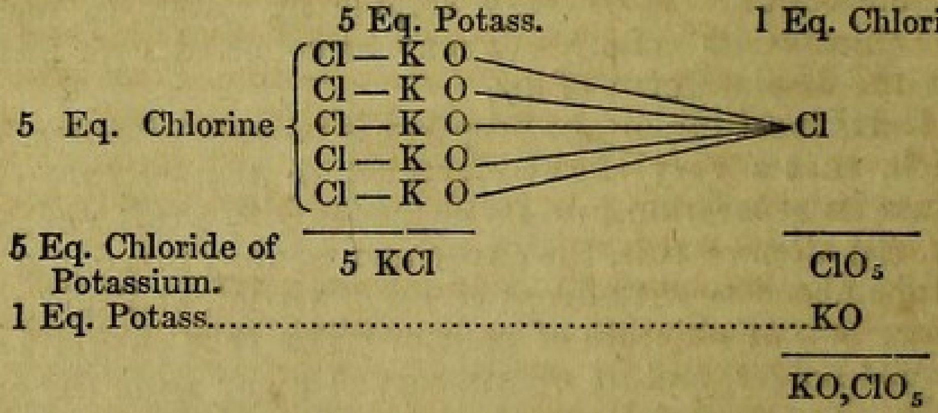
610. Hypochloric acid, or, as it is also called, peroxide of chlorine, is a deep yellow gas possessing a peculiar indescribable odour. It is very soluble in water, to which it communicates its colour. It may be collected over mercury, or by the displacement of air.

611. Its most important property is its explosiveness, which is such, that a very slight elevation in temperature suffices to cause its separation into its elements with great violence.

1*st.* To observe this, the experimenter may place in a small test tube about twenty drops of oil of vitriol, and add to it a grain or two of chlorate of potash. The tube should be held in a tube-holder, and its mouth turned away from the experimenter. The materials may be heated by a long paper match, when a deep yellow gas will fill the tube. If the latter be then warmed along its length, the gas will detonate sharply and become colourless.

2*d.* Hypochloric acid supports combustion readily. A very beautiful experiment, which is quite free from danger, may be tried in illustration of this: Six or seven thin chips of phosphorus are placed at the bottom of a champagne, or narrow ale-glass along with some crystals of chlorate of potash, and the glass is filled nearly to the top with water. Oil of vitriol is then added by means of a small funnel, which may be made of a piece of glass tube, drawn out at one extremity in a lamp flame so as to terminate in a very narrow canal. This funnel is to be filled with oil of vitriol, and then quickly passed to the bottom of the glass, so that the sulphuric acid may not suffer dilution before it comes in contact with the chlorate of potash. The heat evolved by the combination of the sulphuric acid with the water and the potass melts the phosphorus, which takes fire in the presence of the hypochloric acid evolved simultaneously, and burns with great brilliancy. It is advisable to place the glass on a plate, and to cover it with a bell-jar, lest any of the phosphorus should be spirted over the sides of the vessel.

612. Chloric acid, ClO_5, is not itself a substance of particular interest. Its salts, however, are, and especially the chlorate of potass. This substance, which, as well as nitre, is largely consumed in the preparation of lucifer-matches, is prepared by sending a current of chlorine through a solution of caustic potash. The chlorine combines with both elements of the alkali, forming chloride of potassium with the metal, and with the oxygen, chloric acid, which unites with undecomposed potass to form the chlorate, KO,ClO_5. In this decomposition six equivalents of chlorine act on five of potass, forming five equivalents of chloride of potassium and one equivalent of chloric acid, which then unites with a sixth atom of potass. Thus in symbols:—



613. In illustration of this process, the student may send a current of chlorine through a solution of caustic potash till it ceases to turn reddened litmus-paper blue. If the liquid be then gently concentrated by evaporation, it will, on cooling, deposit crystals which are the chlorate of potass, KO,ClO_5. On further concentration it will deposit a second set of crystals. These are the more soluble chloride of potassium, KCl.

614. The process described is very tedious, and requires a large amount of chlorine. The student may content himself with observing, that when a few drops of a strong solution of potass are added to a bottle filled with chlorine, and the vessel shaken, the yellow colour of the gas disappears in a few seconds, owing to its combination with the elements of the alkali.

615. Hyperchloric, or, as it is also and more generally called, perchloric acid, ClO_7, is interesting from the large amount of oxygen it contains. When sulphuric acid acts upon chlorate of potash, as described under hypochloric acid, the oxygen which the evolved chloric acid loses in becoming hypochloric acid does not come off as gas, but combines with

undecomposed chlorate of potass, and converts it into the perchlorate. Thus two-thirds of the chlorate are converted into sulphate of potass, with evolution of chloric acid, and resolution of that into hypochloric acid and oxygen, which converts the remaining third of chlorate into the perchlorate. The latter salt is separated from the sulphate of potass which accompanies it, by crystallisation.

616. Perchloric acid may be obtained from the perchlorate, KO,ClO_7, by the action of fluosilicic acid, a substance which will be described under fluorine. The acid is known only in combination with water. It is the most stable of all the oxides of chlorine, and is characterised by forming with potash a salt very sparingly soluble in water.

617. In addition to the compounds described, chlorine enters into combination with all the other elementary bodies. The chlorides of carbon, boron, and selenium, are unimportant, and very difficult of preparation. The chloride of sulphur, S_2Cl, is prepared by passing a current of chlorine over heated sulphur. The two unite to form a dense yellow liquid, having a powerful peculiar odour, somewhat like that of sea-weeds.

618. Fig. 55 shows an arrangement suitable for the preparation of this substance. *a* is a flask containing the materials for chlorine; *b* a long tube filled with chloride of calcium to dry the chlorine; *c* a bulb containing sulphur, kept hot by a spirit lamp; *d* a bottle kept cold, in which the liquid condenses; *e e* caoutchouc tubes connecting the glass tubes.

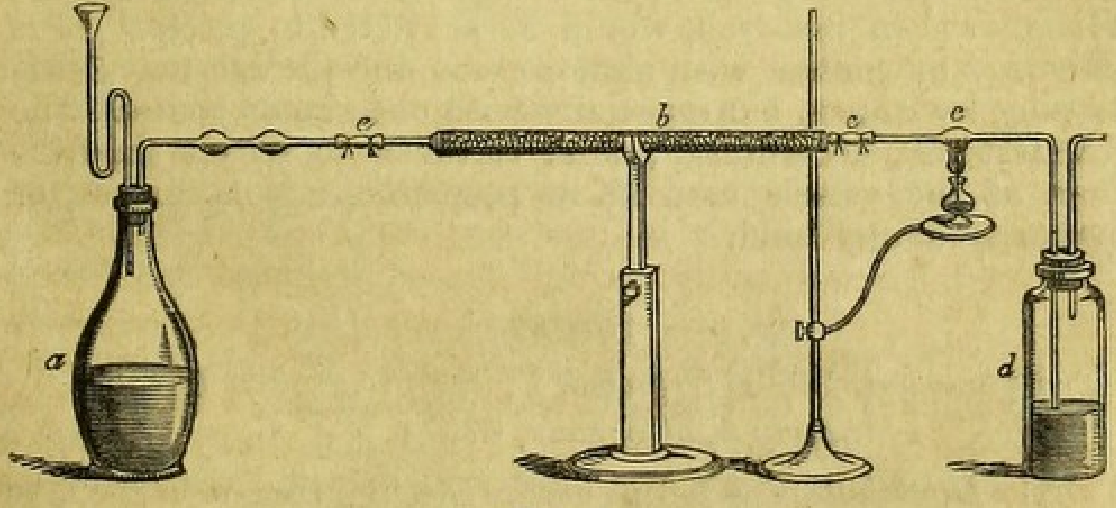


Fig. 55.

619. There are two chlorides of phosphorus, the one a terchloride, PCl_3, a clear, volatile liquid, obtained by heating together phosphorus and corrosive sublimate; the other the

perchloride or pentachloride, PCl_5, is a snow-white, volatile solid, obtained by introducing phosphorus into dry chlorine, when the former spontaneously inflames, and enters into combination with the gas.

620. A more interesting compound than any of these is the terchloride of nitrogen, NCl_3. It is perhaps the most formidable of explosive compounds, and requires to be prepared with the greatest caution. To procure it, four ounces of pure muriate of ammonia are dissolved in three pounds of distilled water. The solution is placed in a large porcelain basin, having a small leaden saucer lying at the bottom, whilst a two-pound bottle, full of chlorine, is suspended with its mouth downwards below the surface of the liquid, and directly over the leaden saucer. The liquid rapidly rises within the bottle as it absorbs the chlorine, and drops of a yellow, oily liquid, which are the chloride of nitrogen, collect first on the surface of the liquid, and afterwards sink through the water into the leaden saucer. The bottle must on no account be touched or disturbed whilst the production of the chloride is going on. At the termination of the process the leaden saucer is cautiously withdrawn, and the chloride may be safely exploded by touching it with a stick dipped in oil. It is immediately resolved into chlorine and nitrogen, with the evolution of heat and light, and the production of a loud noise. It produces a pit, or indentation, on the leaden saucer. Glass, or even cast-iron, would be shattered to pieces. It is exploded by contact with almost every organic substance containing hydrogen, but especially with oleaginous bodies. The greatest care, accordingly, must be taken to secure the freedom of the vessels used in its preparation from grease, or impurity of any kind.

IODINE.

Equivalent, 126·36; *symbol,* I; *specific gravity of solid, nearly* 5, *of vapour,* 8707; ☐☐

621. *Distribution.*—Iodine occurs chiefly in sea-weeds, where it is found in combination with sodium or potassium. It is likewise found in marine animals, such as the zoophytes (sponge), in certain shellfish, and in the cod and skate. It is a constituent also of many mineral waters, but is very rare as a component of the solid crust of the earth.

622. *Preparation.*—Iodine is prepared from kelp, the fused ashes of burnt sea-weeds. Kelp is manufactured on the western shores of Scotland and Ireland by burning dried sea-weeds in shallow pits till the greater part of the vegetable

matter is consumed. The heat thus produced occasions the fusion of the salts contained in the sea-weed; and when the whole cools, it becomes a solid mass, somewhat like gray trap rock.

623. As the first step towards the production of iodine, the kelp is broken into small pieces and digested in water. Not more than half of it dissolves in that liquid, the soluble portion consisting of chloride of sodium and of potassium, carbonate of soda, iodide of sodium, and some other less important salts. Of these, the one last-named is the most soluble, so that when the solution of kelp is concentrated by evaporation, the chloride of potassium, carbonate of soda, &c. crystallise out first, whilst the iodide of sodium is retained in solution after the liquid has been reduced to a very small bulk. This mother-liquor (as it is called) is placed in a leaden retort, along with oil of vitriol and black oxide of manganese, and on the application of heat iodine distils over.

624. In imitation of this process, the student may place in a retort connected with a receiver a solution of the iodide of potassium, KI, a salt easily procured. Some powdered oxide of manganese is then to be added, and afterwards a little sulphuric acid. When the retort is heated, a beautiful violet vapour will appear, and condense in the neck of the retort and in the receiver in the form of black shining scales.

625. The sulphuric acid acts on the iodide of potassium in a manner analogous to that in which it affected chloride of sodium in the process for hydrochloric acid. As a result, hydriodic acid, HI, is produced, and half of the oxygen in the oxide of manganese combines with the hydrogen of that acid, setting free iodine, whilst the protoxide of manganese left unites with sulphuric acid. There are thus three stages in the decomposition:—

1. $KI + HO,SO_3 = HI$ and KO,SO_3
2. $HI + MnO_2 = HO$ and MnO and I
3. $MnO + SO_3 = MnO,SO_3$

626. *Properties.*—Iodine is a bluish-black crystalline solid, with a metallic lustre, greatly resembling plumbago or black lead in appearance. It is a volatile substance, rising in vapour below 32°, fusing at 225°, and boiling at 347°. It then changes into a very beautiful purple or violet-coloured gas, which is more than eight times heavier than air, and is the heaviest gaseous body. The word iodine is derived from Ιώδης (Iodes), violet-coloured, in relation to the appearance of its vapour.

627. Iodine has a peculiar odour, somewhat like that of

chlorine, yet sensibly different. It stains the skin brown, but the mark is not permanent. It dissolves to a small extent in pure water, but largely if the liquid contain a metallic iodide, such as that of potassium. Alcohol dissolves it readily.

628. Iodine is in small doses a valuable medicine, and in large ones a poison. It is readily distinguished from all other bodies by its odour, its violet vapour, and its action on a solution of starch. In illustration of this, the student may try the following experiments:—

629. There is no difficulty in observing the odour of iodine, which cannot fail to be noticed.

1. The colour of its vapour is well seen by throwing twenty or thirty grains at once upon a hot brick; but this must be done in the open air.

2. A more economical and convenient method of exhibiting its tint as a gas, is to place a few grains of it at the bottom of a large dry flask, and then to apply heat. The iodine rapidly volatilises, filling the vessel with its vapour, the great density of which is rendered apparent by its dark purple colour at the bottom of the vessel, as contrasted with its rose tint above, and by the sluggishness with which the purple cloud changes its place when the vessel is inclined. At the same time the upper part and sides of the flask become completely covered with dark, black, shining crystals of the condensed iodine.

3. A solution of starch is to be prepared as if for use by the laundress, and then cooled. A little of this is to be added to water, and then a few drops of an aqueous or alcoholic solution of iodine. A deep-blue precipitate is immediately produced, consisting of the iodide of starch. If either of the liquids be warm, the blue compound is not produced; or if the liquid be heated after its production, the blue is destroyed.

4. The experimenter can certify this by pouring boiling water on a small quantity of the blue iodide of starch, when its colour will disappear.

5. A still prettier experiment is to heat some of the blue liquid in a flask. When it has reached the boiling-point the colour will disappear. If the flask be now suddenly cooled by running cold water on the outside, the blue colour will return. Starch is a test of extreme delicacy for iodine, provided the latter be free, but when its quantity is small a pale purple or rose tint only is produced.

630. The compounds of iodine very closely resemble those of chlorine, but there are fewer of them. The most interesting one is hydriodic acid, HI, which corresponds to hydrochloric acid. It is obtained in the form of a gas, as was men-

tioned incidentally under phosphorous acid (see par. 583), by the action of water on the iodide of phosphorus. The hydrogen of the water combines with the iodine to form hydriodic acid, which is a colourless gas, highly soluble in water.

631. A solution of the acid is more conveniently prepared by passing a current of sulphuretted hydrogen through water in which finely-powdered iodine is suspended. The hydrogen of the sulphuretted hydrogen combines with the iodine to form hydriodic acid, and the sulphur separates. The liquid is warmed and filtered, and furnishes a colourless solution of hydriodic acid, which becomes rapidly brown if exposed to the atmosphere, owing to the combination of the oxygen of the air with the hydrogen of the acid to form water, and the separation of the iodine, which colours the liquid.

632. Hydriodic acid is not a substance of great interest; but its salts, or what correspond to these (namely, the metallic iodides), are important substances. If hydriodic be added to a metallic oxide, such as potass, the hydrogen of the acid combines with the oxygen of the base to form water, and the iodine with the metal, in this case potassium. The resulting salt, the iodide of potassium, is used in the arts, and is a valuable medicine, so that it can always be easily procured. An aqueous solution of it supplies the means of readily observing the deportment of a soluble iodide, or salt of hydriodic acid, with reagents, as the following experiments will illustrate:—

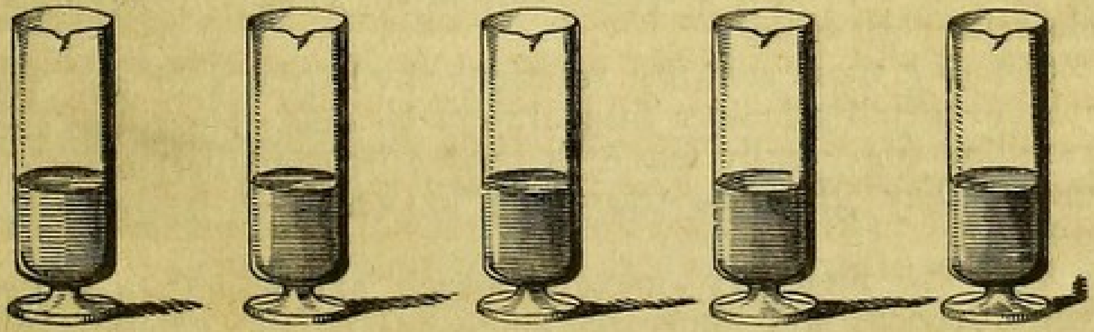


Fig. 56.

633. Five wine or test glasses (fig. 56) are each to be filled one-third full with the solution of the iodide of potassium.

1. To the first solution, starch is added. No blue colour is produced, for the state of combination in which the iodine is, prevents its combining with the starch. If chlorine gas, however, be now poured from a jar on the surface of the liquid, a blue colour will appear at the upper stratum, and if the contents of the glass be now stirred, they will become uniformly blue. The chlorine unites with the potassium of the iodide, and sets free the iodine, which can then act upon the starch.

The experiment will fail if too much chlorine be added, but exhibits, when successful, a very pretty phenomenon.

2. To the second glass a few drops of a solution of nitrate of silver, AgO,NO_5, are added. A pale primrose-yellow precipitate is produced of the iodide of silver, AgI.

3. To the third glass, solution of acetate of lead, $PbO,\bar{A}$, is added. A bright yellow precipitate appears of the iodide of lead, PbI. If this precipitate be boiled with water, it dissolves, forming a colourless solution, from which, as the liquid cools, the iodide separates in brilliant golden crystals of great beauty.

4. To the fourth glass, solution of corrosive sublimate, chloride of mercury, $HgCl$, is added. It produces a fine scarlet precipitate of iodide of mercury, HgI. This precipitate is soluble in excess both of the dissolved corrosive sublimate and of the iodide of potassium. If the iodide of mercury, accordingly, disappears immediately after its production, more of the chloride of mercury is to be added, till a permanent precipitate is produced. If the addition of this salt is not effectual, then there has originally been excess of it, and more of the iodide of potassium must be added. In every case, the addition of the one or the other body will eventually produce the scarlet iodide.

5. To the fifth glass, solution of bichloride of platinum, $Pt\,Cl_2$, is added. It does not produce a precipitate, but occasions in the liquid a deep-red coloration, so that it resembles claret or port wine.

634. By these striking reactions, hydriodic acid and the soluble metallic iodides may always be easily identified, and as iodine is generally found in nature in combination with a metal, they illustrate the mode in which it is generally detected.

635. The first test—namely, starch and chlorine—is the most delicate and generally applicable of the whole. The actions of the other tests may be interfered with, in complex solutions, by the presence of other substances accompanying the iodine.

636. There are two oxides of iodine—iodic acid, IO_5, and hyperiodic or periodic acid, IO_7. The last is unimportant.

637. Iodic acid is prepared by boiling iodine and nitric acid together till the iodine disappears. It is partly volatilised, and is lost—partly acquires oxygen from the nitric acid, which it reduces to the state of nitric oxide. The excess of nitric acid is then distilled off, and the liquid cautiously evaporated to dryness. The iodic acid is left as a white crystalline solid, which is anhydrous, readily soluble in water, and

possessed of all the characteristic properties of a strong acid. It is a substance of interest, as supplying us with a test for opium, or rather for the crystalline principle, morphia, which is present in opium. If morphia be added to a solution of iodic acid, it decomposes it, liberating the iodine, which then becomes manifest by the brown colour it communicates to the liquid, as well as by its odour, and the blue precipitate it gives with starch.

638. The teriodide of nitrogen, NI_3, is an explosive substance like the chloride, but not so formidable, and more easily prepared. It is an insoluble black powder, obtained by digesting together iodine and aqueous ammonia, and then collecting the iodide on a paper filter. The iodide explodes spontaneously as it dries. The filter should be cut when moist into several pieces, each of which may be dried separately.

639. A striking experiment may be performed by transferring a small portion of the moist iodide to a thin china plate, and when it is nearly dry, exploding it by the touch of a hot wire. The iodide blows a hole through the plate at the spot on which it lay, without otherwise injuring it.

640. Iodine and phosphorus combine in several proportions. If a fragment of phosphorus, lying on a metallic plate, be sprinkled with iodine, the substances unite, and heat enough is produced to kindle the phosphorus. The experiment is interesting, as supplying an illustration of what is somewhat rare—namely, the combination of two substances presented to each other in the solid state.

BROMINE.

Equivalent, 78·26 ; *symbol*, Br ; *density as liquid, nearly* 3 ;
as gas, 5393 ; □□

641. Bromine receives its name from the Greek Βρωμος (Bromos), a disagreeable smell, in allusion to its powerful and offensive odour. It very closely resembles chlorine and iodine in character, and is intermediate in properties between them —excelling iodine in strength of affinity, but being inferior to chlorine. It is a comparatively rare and costly substance, so that it cannot be freely used in experiments.

642. *Distribution.*—It occurs in the same circumstances as iodine—namely, in mineral waters, in the sea, and in sea plants and animals. It is found in these, in combination chiefly with the metal magnesium, as the bromide of magnesium, MgBr.

643. *Preparation.*—On the continent it is prepared from

IO 5NO — 3I + 5NO — = 3II

certain mineral waters rich in it. In this country it is procured from concentrated sea-water. When the latter is boiled down with a view to procure from it table salt, the evaporation is never pushed to dryness. Successive quantities of sea-water are concentrated to a small bulk, the crystals of common salt which separate being removed by means of shovels, or colanders pierced with holes. At intervals the residual or mother-liquor is drawn off and set aside. It is a dense oily liquid, containing all the more soluble salts of the sea-water. It is called by the workmen *salt oil*, in allusion to its density, and also *bittern*, in allusion to the unpleasant taste of Epsom salts which it possesses, owing to the large quantity of salts of magnesia which it contains.

644. If the student can procure this bittern, he may prepare bromine from it in the following way:—

645. A current of chlorine is sent through the bittern as long as it causes it to darken in colour. The bittern finally acquires the appearance of table-beer. The change in colour is owing to the liberation of bromine from the bromide of magnesium present in the liquid. The chlorine combines with the magnesium, and the bromine separating, dissolves in the liquid, and colours it.

646. The liquid is now to be transferred to a retort with a receiver, and heat applied. When it reaches the boiling-point, the bromine passes off as a dark-brown vapour, the colour of which enables its course to be traced along the neck of the retort into the receiver, where it condenses along with a little water. If the bittern were rich in bromine, the latter will show itself in dark-brown globules or beads at the bottom of the water.

647. *Properties.*—Bromine is the only element which is liquid at ordinary temperatures, except quicksilver. It has a dark, brown-red colour, and is opaque when seen by reflected light. When examined by transmitted light, it appears transparent, and the red tint predominates over the brown. Its odour is peculiar, but in small quantity recalls the smell of the sea, like chlorine and iodine. If cooled to ten degrees below zero, it freezes into a leaden gray, metal-like solid. At ordinary temperatures it is markedly volatile, so that, to prevent its loss by evaporation, it is preserved in tightly-stoppered bottles under the surface of water. It boils at 116°, yielding a ruddy-brown vapour, not distinguishable in colour from nitrous acid, NO_4, but quite unlike it in odour. It is soluble in water, and more abundantly in alcohol and in ether. When associated with water it bleaches readily. The taste of bromine is harsh and acrid, and it is a powerful

poison. It corrodes the skin, staining it yellow, like nitric acid. With starch, it forms a yellow, or pale-orange compound.

648. Bromine has the same strong affinity for the metals and hydrogen which characterises chlorine. Hydrobromic acid, HBr, is obtained as a gas, in imitation of the processes for hydriodic acid, by decomposing bromide of phosphorus by water, and in solution by the action of bromine on sulphuretted hydrogen. When it meets metallic oxides, it forms with them water and a metallic bromide. The best known bromide is that of potassium, KBr, a white salt closely resembling the corresponding iodide of potassium, and employed to a small extent in medicine and in the arts. Hydrobromic acid and bromides are readily identified by the fact, that when exposed to chlorine, or heated with sulphuric acid and oxide of manganese, they give off a ruddy-brown vapour having the characteristic odour of bromine.

649. There is but one known oxide of bromine, bromic acid, BrO_5. To procure it, bromine is added to the solution of an alkali till it loses alkalinity. On concentrating the liquid, crystals of a bromate first separate and afterwards crystals of a bromide. The change that occurs is closely analogous to that which happens when chlorine acts upon alkalies. If the student, accordingly, will turn back to chloric acid (par. 612), and substitute the word bromine for chlorine, he will find the reaction fully explained.

650. Bromate of baryta, when decomposed by sulphuric acid, yields bromic acid, a substance closely corresponding in properties to chloric acid.

FLUORINE.

Equivalent, 18·70; *symbol*, F.

651. *Distribution.*—Fluorine is found in nature pretty widely distributed, but it does not occur anywhere in large quantity. It is never found uncombined, and its most frequent compound is the fluoride of calcium, CaF, more familiarly known as fluorspar, from its occurrence in which this element receives its name.

652. Small quantities of fluoride of calcium are found in most fertile soils, and in several natural waters, as well as in the sea. Traces of it, also, are met with in different plants; and it appears nearly constantly to accompany phosphate of lime in the bones of the higher animals, and likewise in shells and corals. It is especially abundant in certain fossil bones.

653. Fluorine has never been satisfactorily isolated, owing

$CaF + HOSO_3 = HF + CaOSO_3$

to its great affinity for the metals, and for one of the elements of glass (silicon), so that it cannot be prevented from uniting with these, and eluding our observation. So far as it has been examined, it is said to be a yellowish-brown gas, having an odour resembling chlorine and burned sugar, and capable of bleaching.

654. Although fluorine itself is so little known, it is otherwise with its compounds, several of which can be easily prepared, and possess striking properties. Of these the most important is hydrofluoric acid, HF. To procure this substance, fluorspar, a mineral easily procured, is reduced to powder and heated with oil of vitriol. A change occurs exactly analogous to that which leads to the evolution of hydrochloric acid when sulphuric acid acts on a chloride. The calcium of the fluorspar, CaF, combines with the oxygen of the water of the oil of vitriol to form lime, CaO, with which the sulphuric acid afterwards unites, producing sulphate of lime, CaO,SO_3; whilst the hydrogen of the water, uniting with the fluorine of the fluorspar, forms hydrofluoric acid, HF, which is highly volatile, and passes away in vapour, CaF and $HO,SO_3 = HF$ and CaO,SO_3.

655. In the preparation of this acid, glass vessels cannot be employed. A retort of platina or of lead, with a receiver of one or other metal, must be made use of. Heat is cautiously applied to the retort, and the receiver is kept very cool by surrounding it with ice. The vapour condenses along with a little water into a fuming volatile liquid.

656. Anhydrous hydrofluoric acid is a colourless gas. It is exceedingly irritating to the lungs, and very corrosive, so that it produces severe sores if allowed to condense on the skin.

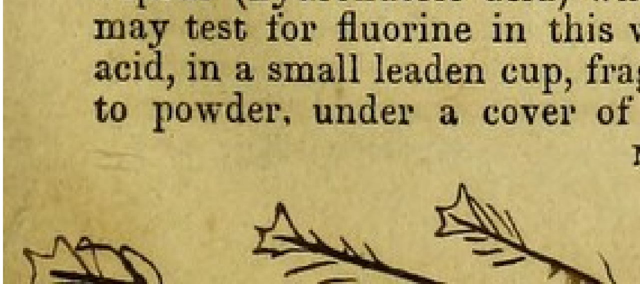
657. Its most interesting property, which leads to its employment in the arts, is that of corroding or etching glass, which it does when strong (but not if anhydrous) with great rapidity. Hydrofluoric acid is employed to act upon glass in two ways. In the one it is intended to etch lines, as of an engraving, or letters, upon a piece of homogeneous glass. In this case the glass is first covered with a layer of bees'-wax, or engravers' etching ground (a preparation of asphaltum and turpentine); and the lines or letters are then drawn, or rather, as it were, cut with an etching needle through the covering down to the glass: when the glass is afterwards exposed to the action of the hydrofluoric acid, directed against it in vapour, or poured upon it in the liquid state, it corrodes the glass wherever it is unprotected by the bees'-wax or asphaltum. In this way tubes, measures, and thermometers,

may be graduated by the student himself, and the expense of costly pieces of apparatus saved.

658. The other use to which hydrofluoric acid is put, is to produce devices in glass-staining, by a process analogous to that by which white figures are produced on coloured grounds in calico-printing, as described under chloride of lime. The glass to be employed for this purpose consists of two sheets, the one colourless, the other coloured, which have been made to adhere to each other throughout, by heating them in a furnace till they agglutinate, and mutual adhesion takes place. Let the object of the artist, for example, be to produce a white star on a blue ground: a sheet of white glass, plated with one of blue, is taken, and on the latter surface all that is to remain blue is painted over with an asphaltum varnish, whilst the portion which is to appear white (in the case supposed, the star) is left uncovered. A wall of wax is then built round the sheet of glass, and liquid hydrofluoric acid, somewhat diluted, is poured on, and left till it has eaten away the whole thickness of the blue glass, and brought the white into view. By a similar process, but reversing the portions of the glass left uncovered, the star could be obtained blue on a white ground.

659. It is scarcely worth the beginner's while to distil hydrofluoric acid, as nothing can be seen, and moreover, the strong acid is a substance requiring to be handled very cautiously. The power of the acid to etch glass may be sufficiently observed in a simpler way. A small cup, saucer, or porcelain basin, but best of all, a vessel resembling these in shape, made extemporaneously from a piece of sheet lead, has some powdered fluorspar placed in it, and oil of vitriol poured upon the spar. A square of glass, large enough to cover the basin, is covered with bees'-wax, and has a device drawn or written on it with any sharp-pointed body, such as a common pencil, not hard enough to scratch the glass. This is laid with its waxed side downwards, as a cover on the basin, and the latter is gently heated, care being taken that the temperature does not rise so high as to melt the wax. In a few minutes the glass may be removed, and the wax cleaned from it by means of a little hot turpentine, when it will be found deeply and permanently etched.

660. The test for fluorine in combination, is the evolution from its compounds, when heated with oil of vitriol, of an acid vapour (hydrofluoric acid) which etches glass. The student may test for fluorine in this way by heating with sulphuric acid, in a small leaden cup, fragments of a burnt bone reduced to powder, under a cover of waxed glass, with a word or



device traced on it. The arrangement must be left in a warm place undisturbed for some hours.

661. Fluorine forms no compound with oxygen, being in this respect peculiar among the elements.

662. With silicon fluorine forms a compound of great interest, the terfluoride SiF_3. To prepare it, a mixture of equal parts of powdered glass and fluorspar is placed in a glass flask with oil of vitriol. A dry tube twice bent at right angles, fitting the flask by a cork, is conducted to the bottom of a glass jar, and made to dip below the surface of a small column of mercury. (See fig. 57.) After the tube has been thus arranged, water is poured over the mercury so as to form a column of some inches in height above it, and heat is then applied to the flask. The sulphuric acid and fluorspar cause the evolution of hydrofluoric acid, which immediately reacts upon the silicic acid of the powdered glass, so that the hydrogen of the one acid combines with the oxygen of the other to form water, and the fluorine of the one with the silicon of the other to form the fluoride of silicon, which is a colourless, invisible gas, as may be observed in the upper part of the flask and bent tube. It is the production of this body that occasions the corrosion of glass when hydrofluoric acid etches it. Thus—

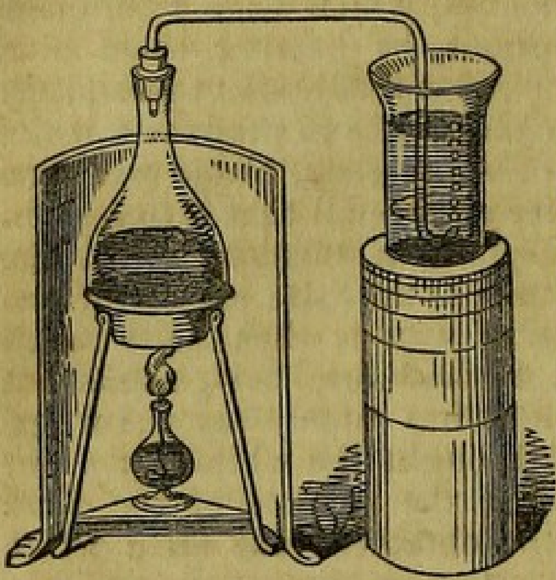
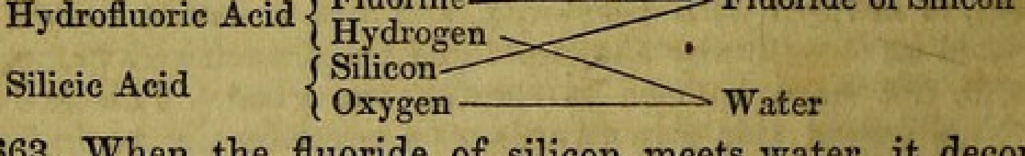
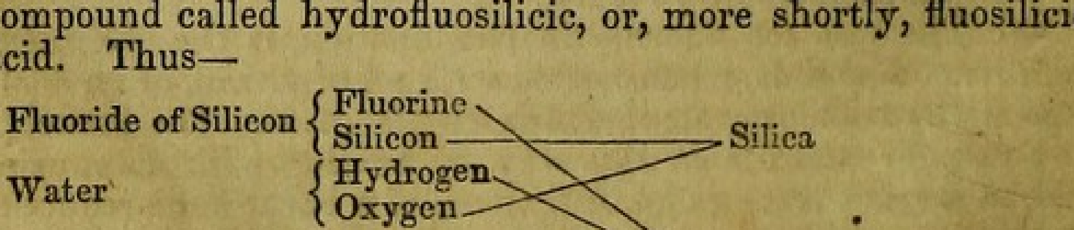


Fig. 57.



663. When the fluoride of silicon meets water, it decomposes it, the silicon in greater part, taking back oxygen and reproducing silica, whilst the fluorine recovers hydrogen and becomes hydrofluoric acid. This unites with a portion of the fluoride of silicon which escapes decomposition, forming a compound called hydrofluosilicic, or, more shortly, fluosilicic, acid. Thus—



This fluosilicic acid is separated by filtration from the silica, and is valuable as a test for potass, and for separating it from acids which cannot otherwise be obtained free. Chloric acid, for example, as well as perchloric, bromic, chromic, &c. are obtained by the action of fluosilicic acid on aqueous solutions of their potass salts.

664. The silica left on the filter is exceedingly pure, and when dried, presents itself in a state of very fine division. The process, indeed, for fluosilicic acid supplies us with one of the most convenient methods known of obtaining pure silica.

665. The production of silica in this process allows a very pretty phenomenon to be witnessed. Each bubble of fluoride of silicon, as soon as it rises out of the mercury into the water, is converted into a little sack or bladder of silica. When these bells are broken the silica exactly resembles in appearance gelatinous starch as it is used in the laundry. If the bubbles of gas succeed each other very slowly, they produce a tube of silica closely resembling one of animal membrane, and extending from the surface of the mercury to the surface of the water. This appearance, however, cannot be produced at will. The object of the mercury is to prevent the fluoride of silicon meeting moisture till it has issued from the tube. If the latter dipped directly into the water, it would soon become plugged up by the silica produced, and the gas, unable to escape, might burst the flask, and occasion dangerous accidents.

THEORY OF ACIDS AND SALTS.

666. We have hitherto referred to two great divisions of acids—namely, oxacids, like sulphuric, and hydracids, like hydrochloric. In connection with these, two dissimilar classes of salts were referred to, the one division all containing an acid and a base, like sulphate of soda, NaO,SO_3; the members of the opposite class each a salt-radical and a metal, like chloride of sodium, $NaCl$.

667. Modern chemistry, however, favours the view that all salts are constructed alike, as well as all acids, common salt being the type of each.

668. The oxacids do not exhibit acid characters in full, unless in association with water. In these circumstances they all contain hydrogen, and may all be represented as hydracids, in which the hydrogen is united to a compound salt-radical.

669. The inorganic hydracids are compounds of hydro-

gen with a simple salt-radical, such as chlorine, bromine, iodine.

Hydrochloric Acid, HCl
Hydrobromic Acid, HBr
Hydriodic Acid, HI

670. The oxacids, as we have hitherto considered them, would be represented thus—

Sulphuric Acid, HO,SO_3
Nitric Acid, HO,NO_5

671. If, however, we suppose all the oxygen united to the sulphur and nitrogen respectively, we may then represent these bodies as hydracids: thus—

Sulphuric Acid, H,SO_4
Nitric Acid, H,NO_6

Here SO_4 and NO_6 are represented as compound salt-radicals, which by combination with hydrogen form acids. The only difference, according to this view, between a hydracid and an oxacid is, that the former contains a simple salt-radical, the latter a compound one.

672. The salt which a hydracid forms with a metallic oxide is, when dry, a compound of the radical of the one and the metal of the other. Thus hydrochloric acid, HCl, and soda, NaO, form chloride of sodium, $NaCl$. The dry salt of an oxacid may in like manner be represented as the compound of a salt-radical and a metal. Sulphate of soda is generally written NaO,SO_3, but may be represented as Na,SO_4. Nitrate of potass, KO,NO_5, may be figured as K,NO_6.

673. Names have been given to these compound radicals. SO_4 is called sulphatoxygen, or sulphion; NO_6 nitratoxygen, or nitration.* The latter names are preferred.

674. According to the view explained, there is no essential difference between a salt and an acid. Each contains a radical, which may be either simple or compound, united in the salt to a metal, in the acid to hydrogen, which has most of the characters of a metal, and probably is one, only very volatile. Hydrochloric acid is the chloride of hydrogen, as common salt is the chloride of sodium. Oil of vitriol is the sulphatoxide or sulphionide of hydrogen, Glauber's salt the

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* The second *t* in this word is pronounced *hard*, and the last four letters form a dissyllable, *ti-on*.

sulphatoxide or sulphionide of sodium. The following table will illustrate these remarks :—

Old View.		New View.	
Hydrochloric Acid,	HCl	Chloride of Hydrogen,	H,Cl
Sulphuric Acid,	HO,SO_3	Sulphionide of Hydrogen,	H,SO_4
Nitric Acid,	HO,NO_5	Nitrationide of Hydrogen,	H,NO_6
Chloride of Sodium,	$NaCl$	Chloride of Sodium,	Na,Cl
Sulphate of Soda,	NaO,SO_3	Sulphionide of Sodium,	Na,So_4
Nitrate of Potass,	KO,NO_5	Nitrationide of Potassium,	K,NO_6

We shall throughout employ the nomenclature of the old view.

⁂ The whole subject of salts will be much better understood after the metals have been discussed. Thus much, however, may be stated here. A salt is always a compound of *two* substances, or it consists of halves; and there are but two great classes of salts. In the one, the halves of the salt are each of them compound, and the one is an *acid*, and the other a *base*. Thus the halves of sulphate of soda are an acid, viz. sulphuric, and a base, viz. soda, and each of these is in turn a compound of oxygen, with sulphur in the one case, and sodium in the other. In the other class of salts, the halves may be, and frequently are, simple. One of them is a metal, or a body acting like a metal; the other is such a body as chlorine. Thus the one half of common salt is the metal sodium; the other is chlorine. Chlorine and other similar bodies, when they form the non-metallic half of a salt, are called *salt-radicals*. Of these there are two divisions; *simple* salt-radicals—such as chlorine, bromine, and iodine; and *compound* salt radicals—such as cyanogen (a combination of carbon and nitrogen), which will be described under Organic Chemistry.

The metallic or metal-like half of a salt is called a *salt-basyle*, or simply a basyle. There are two divisions of basyles: simple basyles—that is, all the metals; compound basyles, which are composite substances, not possessing the physical appearance of metals, but able to act, like them, in combining with salt-radicals. One of the most important basyles—namely, ammonium—will be found described under Ammonia. The remainder, such as ethyle, formyle, &c. are discussed under Organic Chemistry.

A salt is thus either the compound of an acid and a base, or of a salt-radical and a basyle; and in the way represented in the text, salts of the first class may be included among salts of the second, and every salt may be defined to be a compound of a salt-radical and a basyle. A salt-radical is defined to be a body, simple or compound, which, by combination with a metal (or basyle), forms a salt, and with hydrogen an acid. A basyle, again, is a body simple or compound, which, by combination with chlorine, or any other salt-radical, forms a salt. Acid and base have been defined already.

METALLIC ELEMENTS.

GENERAL OBSERVATIONS.

675. The metals are much more numerous than the non-metallic elements, there being at least forty-two of the former, whilst research holds out the expectation that more will be added to the number. Many of them, however, are rare, so that their properties cannot be made matter of general observation; and the more familiar and abundant metals resemble each other very much in properties, so that after the characters of a few of them have been learned, the investigation of the remainder is much less interesting than that of the non-metallic elements. We shall discuss them, accordingly, more briefly than we did the opposite class of simple substances; and with a view to prevent unnecessary repetition, we here give a general preliminary account of their properties.

676. A metal is distinguished from a non-metallic body by three characters, which are presented by it, however, only when it is in mass, and not when it is in the state of a finely-divided powder.

677. These characters are that—1. It reflects light powerfully; 2. Conducts heat excellently; 3. Conducts electricity rapidly. The peculiar brilliancy of polished gold, silver, tin, &c. are illustrations of the first character. It is distinguished as the *metallic splendour*.

678. The high conductive power of metals for heat has been referred to already. Metals, it will be remembered, were the best conductors of heat.

679. They are also the best conductors of electricity. Their employment in lightning-conductors, or thunder-rods, and in the construction of telegraphs, where they convey electricity instantaneously along several hundred miles of wire, sufficiently illustrates this character.

680. Some of the metals, such as gold, occur in nature in small quantity. Others, like iron, are very abundant.

681. A few—such as gold, silver, and platina—occur either uncombined, or associated only with other metals. The great

majority, however, are found solely in combination, partly with other metals, but chiefly with non-metallic elements, such as oxygen and sulphur.

682. These native compounds are called the ores of the metals. This term, which is a metallurgical rather than a chemical one, is applied to any native metallic compound which is smelted or otherwise wrought, so as to procure from it the metal it contains. Ores are occasionally alloys, or combinations of different metals; such, for example, are the ores of platina, in which that metal is associated with palladium, rhodium, iridium, and osmium. More frequently ores are salts, or oxides of the metals. Thus two of the most valuable ores of iron are oxides, and a third is the carbonate of the protoxide. The most abundant ores of lead, zinc, copper, and antimony are sulphurets. Carbonates are pretty frequent; sulphates are less so: but any native metallic compound is an ore which occurs in sufficient quantity to make it worth the metallurgist's while to extract metal from it.

GENERAL PROPERTIES OF THE METALS.

683. The metals are all tasteless when quite pure; even those—such as zinc, copper, and mercury—which, when they enter into combination, produce substances possessing the most strongly-marked taste. The beginner may contrast the tastelessness of silver with the disagreeable taste of one of the compounds of the metal, such as the nitrate in a state of solution.

684. The densities of the metals vary greatly. A few, such as potassium, are lighter than water. One, platina, is twenty-one times heavier. Lead, which is eleven times denser than water, stands intermediate between the two extremes. The majority of the useful metals are between seven and eight times heavier than water.

685. Considerable diversity of colour prevails among the metals. One is yellow, gold; and one red, copper.* The majority are white mixed with black, giving different shades of gray. In others the white has a shade of blue or red. Thus silver, tin, and, it is said, calcium, are white. Iron, aluminum, manganese, nickel, cobalt, &c. are gray. Zinc, antimony, potassium, and lead, exhibit different shades of

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* Till very recently, titanium has been ranked with copper as a red metal; but the copper-coloured crystals which were long supposed to be pure titanium, have been discovered to be a compound of this metal with carbon and nitrogen. The colour of pure titanium is not yet known.

whitish-blue or blue-white. Sodium and bismuth have their prevailing white colour modified by red.

686. The colours of metallic compounds are quite different from those of their metals. Thus the salts of the red copper are blue or green; those of iron are not gray, but green or brown; those of lead are almost all white. Those of chromium, which is gray, are green, yellow, orange, &c. No law has yet been discovered connecting chemical composition with colour.

687. The great majority of the metals are solid at ordinary temperatures. One is a liquid—namely, mercury; and as there is every reason to believe that, if we could condense hydrogen, we should find it presenting all the metallic characters, we may say that one is a gas.

688. The metals which are solid at ordinary temperatures all readily assume regular geometrical forms—that is, occur in crystals; and the majority of them exhibit exactly the same crystalline shapes (see par. 320). The most common of these are the cube (fig. 58) and the regular octohedron (fig. 59). The former is a six-sided solid, with all its faces squares, and all its angles right angles. The octohedron is an eightsided solid, all the faces of which are equilateral triangles. It resembles in form two pyramids, such as the Egyptian ones, placed base to base. Arsenic, tellurium, and antimony, do not crystallise in cubes and octohedrons, but in another shape called the rhombohedron, which has six faces like the cube, but differs from it in its faces not being squares, but rhombic or diamond-shaped, and in its angles not being right angles.

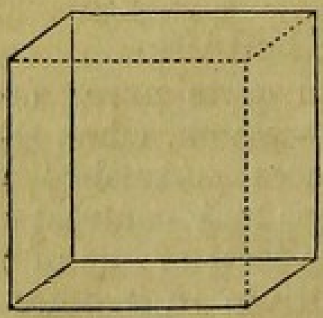


Fig. 58.

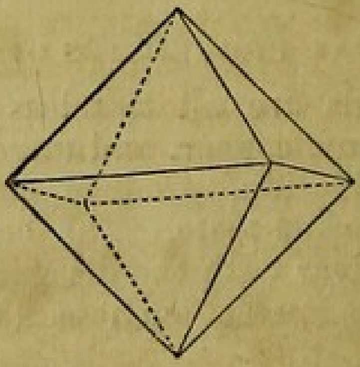


Fig. 59.

689. All the metals are liquid at some temperature, and probably vaporise at very high heats. Their melting-points are very various: thus that of mercury (commonly called its freezing-point), is thirty-nine degrees below zero, whilst that of iron is nearly three thousand times higher; and that of platina, which is not exactly known, is still more elevated.

690. Certain of the metals—such as potassium, sodium, iron, and platina—become pasty and adhesive at temperatures much below their melting-points. In virtue of this property,

the first two metals can be moulded like wax at 60°; pieces of iron are welded—that is, compressed into one—at a red heat, and particles of platina at a white one.

691. A very great difference is observed among the metals in what is called *malleability*—that is, in their susceptibility of being beaten out or rolled into sheets or leaves. The highly-crystalline metals—such as antimony, bismuth, and at ordinary temperatures, zinc—are brittle, and break into fragments when struck with the hammer or passed between rollers. The less crystalline metals, especially those which unite softness with tenacity, exhibit malleability in the highest degree, so that, like gold, they may be beaten into leaves of extreme thinness. These malleable metals admit also in general of being drawn out into wires of great fineness, and are then said to exhibit ductility. Gold is as ductile as it is malleable, but it is otherwise with several of the malleable metals. Iron and platina are both of them highly ductile; the latter has been obtained, in the form of wire, not more than one thirty-thousandth of an inch in diameter. Neither platina nor iron, however, admits of being beaten out into very thin leaves. The most malleable and ductile metals are gold, silver, copper, tin, platinum, palladium, cadmium, lead, zinc, iron, nickel, potassium, sodium, and solid mercury.

CHEMICAL RELATIONS OF THE METALS.

692. The most general chemical character of the metals is combustibility—that is, readiness to combine with oxygen, with the evolution of light and heat, or at least of heat. The majority of the metals burn readily in air, or failing that, in pure oxygen, as may be seen by heating tin, zinc, antimony, &c. before the common, or, still better, the oxyhydrogen blowpipe, or by exposing them in crucibles to the heat of a furnace or smith's forge. Iron, also, as has been mentioned under oxygen, burns brilliantly in that gas.

693. The rarest and most precious of the metals, as silver, gold, and platina, are not combustible, but, on the other hand, have their affinity for oxygen lessened by raising their temperature.

694. All the metals, without exception, combine with sulphur, generally in more than one proportion. The same remark applies to chlorine, bromine, iodine, fluorine, and to the other salt-radicals.

695. To avoid repetition under the head of the individual metals, we state here some general facts concerning the mode in which the chief metallic compounds are obtained:—

696. *Oxides.*—1. Many oxides occur native, and in a state of purity.

2. Others are readily obtained by the combustion in air, or oxygen, of their metals.

3. A third and very frequent method is the addition of an alkali, such as potass or soda, to the aqueous solution of a salt of the metal. Thus to procure oxide of iron, FeO, we add potass to the dissolved sulphate of that oxide, FeO,SO_3. The potass combines with the sulphuric acid, to the exclusion of the oxide of iron, which appears as an insoluble precipitate.

4. A fourth method of procuring metallic oxides is by heating one of their salts containing a volatile acid. Thus red oxide of mercury, HgO, and black oxide of copper, CuO, are obtained by heating their respective nitrates; oxide of barium, baryta, BaO, by heating its iodate, BaO,IO_5. In these processes the acid is volatilised by the heat, and the oxide left free.

697. The protoxides of metals are uniformly strong bases, and form, by union with acids, neutral salts. The highest metallic oxides, on the other hand, are acids, and the intermediate oxides are neutral or indifferent. The oxides of manganese supply the best illustration of this, as the following table will show:—

Protoxide of Manganese,	MnO	Strong base
Sesquioxide of Manganese,	Mn_2O_3	Weak base
Binoxide of Manganese,	MnO_2	Neutral; neither a base nor an acid
Manganic Acid,	MnO_3	Strong Acid
Hypermanganic Acid,	Mn_2O_7	Strong Acid

698. *Sulphurets.*—1. Many metallic sulphurets are found native, as already more than once mentioned.

2. The immense majority of the metals readily unite with sulphur when heated along with it. In this way various sulphurets, such as that of iron, FeS, referred to under sulphuretted hydrogen, are prepared.

3. Sulphuretted hydrogen employed alone, or in combination with an alkali, converts nearly the whole of the metallic oxides into sulphurets; its hydrogen combining with the oxygen of the oxide to form water, and its sulphur with the metal of the oxide to form a metallic sulphuret, as illustrated already under sulphuretted hydrogen.

4. A few sulphurets, scarcely to be prepared in any other way, are procured by heating the sulphate of the oxide of the metal, whose sulphuret is desired, with charcoal, which removes the whole of the oxygen, leaving the sulphur of the sulphuric

acid and the metal of the oxide in a state of combination. Thus sulphate of baryta, BaO,SO_3, when heated with charcoal, parts with its four atoms of oxygen which combine with the carbon, and becomes sulphuret of barium, BaS.

699. *Chlorides.*—1. Metallic chlorides occur native, as, for example, the most important of all, chloride of sodium.

2. Many of them may be prepared by bringing the metals and chlorine together, as mentioned under chlorine.

3. A more convenient and generally applicable method is the addition of hydrochloric acid to the oxide of the metal whose chloride is wanted, when, as stated under that acid, the hydrogen of the hydrochloric acid combines with the oxygen of the metallic oxide to form water, and the chlorine with the metal to produce its chloride.

4. The carbonate of the metallic oxide is often substituted for the uncombined oxide in the process just described. The carbonic acid escapes with effervescence, and the ultimate product (a chloride) is the same as if the pure oxide had been taken. Similar remarks apply to the production of bromides, iodides, and fluorides, so that fuller reference to them need not be made here.

700. The proportions in which a metal combines with oxygen are generally the same as those in which it combines with sulphur and the salt-radicals; so that if the formulæ of the oxides of a metal are known, those of its sulphurets, chlorides, iodides, &c. may to a great extent be predicted.

DIVISIONS OF THE METALS INTO CLASSES.

701. The metals are conveniently divisible into four classes: —1. *Metals of the alkalis*, or alkalifiable metals—that is, metals whose oxides are alkalis. 2. *Metals of the alkaline earths*, or those whose oxides are earthy substances, such as lime, possessed of properties like those of the alkalis, but much less soluble in water than they are. 3. *Metals of the earths proper*, whose oxides are earthy powders, having no alkaline properties, and quite insoluble in water. 4. *Metals proper*—that is, metals with which we are most familiar, in their uncombined or metallic state, which is not the case with the metals of the preceding classes.

702. The metals proper, or familiar metals, are divided into two groups:—1. *Common metals*, such as iron, lead, copper, which are combustible and readily oxidable, and which rust or tarnish in air. 2. *Precious or noble metals*, such as gold and platina, which are not combustible, not readily oxidable, and do not tarnish in air.

METALS OF THE ALKALIS.

703. Three metals belong to this group—potassium, sodium, and lithium. The last is very rare, and will not be further referred to; but, along with potass and soda, ammonia will be considered, as it has all the characters of an alkali, although it is not a metallic oxide.

Potassium.

Synonyme, *Kalium; equivalent*, 39; *symbol*, K.

704. Potassium occurs in nature abundantly, but solely in combination, and chiefly as potass. It is found primarily in granite, trap, and other igneous rocks, associated with different bases in combination with silica. From these rocks, as they crumble down, it finds its way into soils, which are uniformly barren if devoid of potass. Growing plants extract it from the soil; and when they are burned it forms a chief ingredient of their ashes. It occurs in small quantity also in animals, in natural waters, and in the sea.

705. *Preparation.*—Potassium may be obtained by the action of a voltaic current on potass, but is generally prepared from its oxide, or the carbonate of that oxide, by complicated processes, which cannot be tried on the small scale. The principle, however, involved in them is simple enough. Carbonate of potass is heated to a high temperature with charcoal, which removes its oxygen, converting it into carbonic oxide. Thus, $KO,CO_2 + 2C = 3CO$ and K. The metal itself may be had to purchase, and although it is somewhat costly, very small fragments will suffice for the performance of many striking experiments.

706. Potassium has a brilliant white colour with a shade of blue. At the ordinary temperature of the air it is soft like wax, so that it can be readily cut by a knife, or moulded with the fingers. At 32°, it is brittle and crystalline; at 70°, semi-fluid; at 150°, completely liquid, and it may be distilled at a low red heat, forming a vapour of a green colour. It is considerably lighter than water, its density being 0·865, compared with water 1000.

707. The lustre of potassium disappears instantaneously if it be exposed to the air, owing to its combination with oxygen and conversion into the white protoxide of the metal.

708. The following experiments may be tried with the metal:—

1. If a fragment be heated in a small iron spoon till it

begins to rise in vapour, it takes fire, burning with a violet flame.

2. If a fragment be thrown on the surface of water, it kindles spontaneously, burning with a beautiful purple flame, and combining with the oxygen of the water, as mentioned under hydrogen.

3. If this experiment be made with water coloured by cabbage infusion, the latter will change to green as the potassium burns.

4. If a piece of potassium be laid upon ice, it will take fire as if upon water, melting a hole in it with great rapidity.

709. The great affinity for oxygen, which, as these experiments will illustrate, potassium possesses, makes it necessary to preserve it in bottles filled with naphtha, a liquid compound of carbon and hydrogen, and therefore free from oxygen.

710. *Potass.*—Potass, or the protoxide of potassium, KO, can be obtained pure only by exposing slices of potassium to dry air, when oxygen combines with it, and converts it into a white, fusible, and volatile solid, having a great affinity for water. If once permitted to unite with the latter, it cannot be deprived of it by any amount of elevation in temperature.

711. The hydrate of potass, KO,HO, is a much more important substance than the anhydrous oxide. It is prepared by boiling together a dilute solution of carbonate of potass, KO,CO_2, and quicklime, CaO. The lime deprives the carbonate of its carbonic acid, forming with it the insoluble carbonate of lime, CaO,CO_2, whilst the potass, set free, remains in solution in the water. The liquid is filtered from the carbonate of lime and any excess of quicklime, and forms a colourless solution, to which we shall have constant occasion to refer when treating of the subsequent metals. If this liquid be boiled down, it may be deprived of all the water associated with the potass, except one equivalent, which remains in a state of intimate union with an equivalent of the alkali. This compound, the hydrate of potass, KO,HO, is raised in temperature till it melts, and then poured into cylindrical iron moulds, in which it consolidates. It is sold in the shops, accordingly, in the form of sticks, under the name of caustic potash, and must be preserved in stoppered bottles, otherwise it absorbs moisture with great rapidity and runs into a liquid. In the form of sticks it is employed to withdraw carbonic acid and other gases from gaseous mixtures.

712. Solution of potass is intensely acrid to the taste, and highly caustic, so that it should be tasted only when much diluted. It exhibits the characteristic properties of an alkali

in the highest degree. These, it will be remembered, are—1. A peculiar taste; 2. The power of converting vegetable reds into blues or greens, and vegetable yellows into browns; 3. The power of neutralising or destroying the characteristic properties of acids when added in sufficient quantity to them. The student may observe all these properties with solution of potass.

713. The further experiment may be tried of exposing some of the potass solution in a shallow vessel to the air, when it will be found after a time to become milder in taste, and to effervesce when mixed with an acid, owing to its having absorbed carbonic acid from the air. To prevent this absorption occurring, solutions of potass should be preserved in stoppered bottles.

714. If the solution of potass be shaken in a bottle with olive or any of the other fixed oils, it will be found to convert it into a soap, illustrating another character of the alkalis.

715. *Salts of Potass.*—Carbonate of potash, KO,CO_2+2HO, known in its crude form by the name of potashes or pearl ashes, is prepared in large quantities in America and Russia, where wood is abundant. The ashes of the burned wood are lixiviated—that is, placed in large barrels, which are then filled up with water. After some time, the water is drawn off from below saturated with soluble matter, and when boiled down to dryness in large iron cauldrons, forms the crude pot-ashes, and, when further purified, the pearl-ashes of commerce. Both are very impure, from the presence of silicate and sulphate of potass, chloride of potassium, &c. The pure carbonate is obtained by calcining cream of tartar, digesting the calcined mass in water, and evaporating the filtered liquid to dryness.

716. Carbonic acid is too feeble an acid to neutralise so powerful a base as potass. The carbonate of potass, accordingly, has an alkaline taste and action upon colouring matter. It also possesses causticity, but these characters are less strongly marked than in uncombined potass. The carbonate is an important salt, being used in medicine, in the manufacture of soft soap, and of glass, as well as in other arts. It is also consumed in the laboratory in the preparation of potass, as well as of many of its salts.

717. *Nitrate of Potass, Nitre, or Saltpetre,* KO,NO_5.—This valuable salt is brought to this country chiefly from the East Indies, where, as in other warm climates, its formation is constantly going on in the soil. Its employment as a source of nitric acid has been referred to under that substance. It is consumed also to a considerable extent as an antiseptic. Its

other great use is as a constituent of gunpowder, of which it forms the chief part by weight, the other ingredients being charcoal and sulphur. These substances are mixed very nearly in the proportion of one equivalent of nitre, one of sulphur, and three of carbon. When gunpowder is kindled, the oxygen of the nitre combines with the carbon, forming carbonic oxide, or carbonic acid, whilst the sulphur unites with the potassium of the nitre, and the nitrogen is set free. The amount of gas thus produced occupies a space 300 times greater at the ordinary temperature than the gunpowder which evolves it does before being fired. But the heat produced by the combustion triples at least the volume of the gases (carbonic acid or oxide, and nitrogen). It is this rapid expansion of gunpowder to a bulk some 900 times greater than it possessed before being kindled, which confers on it its great propulsive and disruptive powers.

718. Sulphate of potass, KO,SO_3, and bisulphate of potass, $KO,SO_3 + HO,SO_3$, are used in the arts, the former in medicine, the latter in calico-printing.

719. The chlorate of potass, KO,ClO_5, and the hyperchlorate, KO,ClO_7, have been referred to under their respective acids. (See pars. 612 and 615.)

720. *Sulphurets of Potassium.*—The protosulphuret, KS, is obtained by heating the sulphate of potass with charcoal. It forms a crystalline mass, soluble in water, and possessing a caustic, bitter, sulphureous taste. By fusing this compound with sulphur, a bisulphuret, KS_2, and a tersulphuret, KS_3, may be obtained. A pentasulphuret, KS_5, is also known.

721. *Chloride of Potassium* is procured in the process for chlorate of potass, as mentioned under chloric acid. It is also left as the residue when chlorate of potass is heated till it parts with all its oxygen, as stated under that gas. It is likewise one of the constituents of kelp, referred to under iodine.

722. Chloride of potassium closely resembles common salt in appearance, and is employed in the manufacture of the important substance alum, and in the conversion of nitrate of soda into nitrate of potass.

723. *Iodide of Potassium* is of more interest as a preparation of iodine than as a salt of potassium. Its properties as an iodine compound have been discussed under hydriodic acid.

724. *Tests for Potassium.*—A salt of potassium—that is, such a body as chloride of potassium, or nitrate of potass—is distinguished from all bodies, but compounds of the other alkalifiable metals, or of ammonia, by the two following cha-

racters, which the student can observe, with a solution of any pure salt of potassium, such as nitre, KO,NO_5. To one portion of the solution contained in a wine or test glass (see fig. 60) solution of hydrosulphuret of ammonia, NH_3+2HS, is added, which will occasion no precipitate, because the sulphuret of potassium is soluble. To another portion in a second glass, solution of carbonate of potass, or of soda, is added. This also will occasion no precipitate.

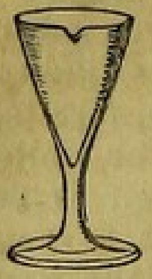


Fig. 60.

725. These negative results prove that either potassium, sodium, or ammonia, is present, but the choice is limited to one of these three (lithium, owing to its rarity, being excluded from consideration), for the salts of all the other metals precipitate one or both of these reagents.

726. That it is potassium which is the metal present, is ascertained by the following tests:—To one portion of the solution, tartaric acid dissolved in water is added. It will produce a white crystalline precipitate, consisting of the acid tartrate of potass (cream of tartar), a combination of tartaric acid, potass, and water, $KO,HO,\bar{T}$.

727. To a second portion of the solution of the salt of potassium, solution of the bichloride of platinum, $PtCl_2$, is added. It will produce a yellow crystalline precipitate of the chloride of platinum and potassium.

728. A third portion of the original solution is evaporated to dryness, or, to save this trouble, a portion of the dry salt with which the solution was made is taken and moistened with alcohol, which is then set fire to. It will burn with a faint violet flame, such as potassium itself exhibits when kindled.

729. The same phenomenon will take place if the potassium salt laid upon charcoal, or held in a loop of platina wire, be heated in the inner or reducing flame of the blowpipe. The violet flame, however, is in both cases indistinct.

730. It may be seen to great advantage by throwing a handful of nitre into an open fire, when a magnificent purple flame is exhibited, owing, as in the alcohol and blowpipe experiments, to the separation of the potassium in the metallic state and its subsequent combustion.

731. We have gone over the tests for potassium in combination more fully than we shall discuss those of most of the subsequent metals, as it is the first under notice. The beginner should be exercised in the application of the tests by having a salt given him of one of the alkalis, with instructions to ascertain whether it be a compound of potassium or not, and so also with the other metals.

Sodium.

Synonyme, Natrium; equivalent, 22·97; *symbol,* Na.

732. *Distribution.*—Sodium occurs in nature abundantly in combination, but nowhere free. Its most important native compound is its chloride, which, as rock salt, occurs in immense beds in the solid crust of the earth, and in solution in probably every natural water, as well as in the sea.

733. Compounds of sodium occur in many minerals and in most soils. They are found in small quantity in the majority of land plants, but largely, as kelp illustrates, in those of the sea. Sodium also occurs abundantly in various states of combination in the structures of the higher animals, which all instinctively swallow large quantities of its chloride.

734. *Preparation.*—Sodium is prepared by complicated processes, similar to those had recourse to for potassium. It is more easily obtained than that metal, and is cheaper.

735. *Properties.*—Sodium has a bright lustre and a white colour, with a shade of red. It is soft, and readily moulded at 60°, melts at 194°, and rises in vapour at a red heat. It is lighter than water, but denser than potassium, its specific gravity being 0·972.

736. The following experiments may be tried with it:—

1. Thin slices exposed to the air will be found to tarnish and grow dim rapidly; and finally, to become converted into a soft, white substance, which is anhydrous soda, NaO.

2. A fragment heated in an iron spoon nearly to redness, takes fire, burning with a yellow flame.

3. An irregular fragment thrown upon the surface of cold water will rapidly assume a globular form, and roll along the surface with great rapidity, decomposing the water as potassium does, but unlike it, not catching fire.

4. If this experiment be repeated with hot water, or if the sodium be laid on a piece of metal, and a drop or two of water allowed to fall on it, it will kindle, and burn with its rich yellow colour.

737. If infusion of purple cabbage be substituted for pure water, it will be coloured green by the soda produced.

738. *Soda.*—Soda, NaO, is obtained anhydrous by the exposure of sodium to the air, as already mentioned. Its hydrate, NaO,HO, is obtained in solution by boiling lime with carbonate of soda dissolved in water. When the liquid thus procured is evaporated to dryness, it leaves a solid residue of the hydrate, which is fusible, highly soluble in water, caustic, powerfully alkaline, and closely analogous to potass in all its properties.

739. *Compounds of Soda.*—NITRATE OF SODA, NaO,NO_5, occurs abundantly in Peru, where it is found covering the soil in many districts. It deliquesces in damp air, and burns much more slowly with combustibles than the nitrate of potass. These properties make it unsuitable for the manufacture of gunpowder; but it is largely consumed as a source of nitric acid, and is employed in agriculture.

740. SULPHATE OF SODA, *Glauber's Salt*, $NaO,SO_3 + 10 HO$.—This salt is manufactured in large quantities by the action of oil of vitriol on common salt, and is the residue of the process for muriatic acid, as mentioned under that substance.

741. Glauber's salt is used to some extent in medicine, but is chiefly manufactured with a view to its conversion into carbonate of soda.

742. CARBONATE OF SODA, $NaO,CO_2 + 10 HO$, is one of the most important chemical substances, from its consumption in bleaching, glass-making, soap-making, washing, baking, medicine, &c. It is obtained from different sources:—

1. One is kelp, which contains from 2 to 5 per cent. of it.

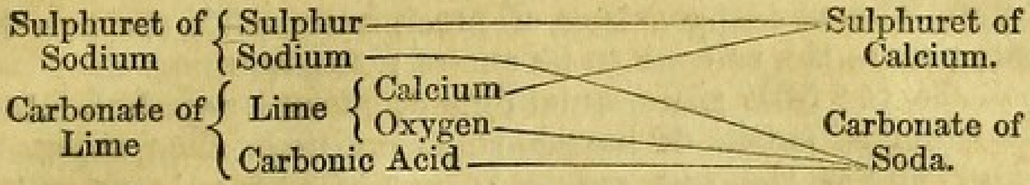
2. A second is barilla—the saline ash left after the combustion of certain maritime, not marine, plants (*Salsola soda* and *Salicornia herbacea*), which are cultivated on the shores of the Levant for the sake of the soda they contain. Barilla contains about 18 per cent. of the carbonate.

3. Another source is the native carbonate (frequently a sesquicarbonate), found on the margins of certain bodies of water in Egypt and other parts of Africa, as well as in Mexico and in Hungary. The Egyptian lakes which are the most familiar are called the 'Natron Lakes,' and have yielded soda from a very remote period. The nitre of the Bible, which is referred to as having detergent properties, is this natron, or carbonate of soda; not our nitre, the nitrate of potass.

4. The greater part, however, of the carbonate of soda used in Great Britain is manufactured from sulphate of soda, which in its turn, as already mentioned, is procured from common salt by heating it with oil of vitriol.

743. The sulphate, in the anhydrous state, is reduced to powder, and heated in a furnace with ground coal, which removes from it all its oxygen, and reduces it to sulphuret of sodium, NaO,SO_3, *minus* $O_4 = NaS$. The sulphuret of sodium is afterwards heated with chalk—carbonate of lime—when the sulphur unites with the calcium of the carbonate, and the sodium with its oxygen and carbonic acid; thus:—

$NaS + CaOCO_2 =$



In symbols—

$$NaS \text{ and } CaO,CO_2 = NaO,CO_2 \text{ and } CaS.$$

744. We have given only the outlines of this important process. The final product is dissolved in hot water, and yields, on evaporation, crystals of the carbonate of soda. These contain generally ten equivalents of water, which may be expelled without otherwise altering the composition of the salt. It is readily soluble in water, has an alkaline taste and action on vegetable colours.

745. The bicarbonate of soda, $NaO,CO_2 + HO,CO_2$, is prepared by passing carbonic acid over the carbonate. It has a milder taste, and feebler alkaline action, than the last salt. It is largely used in the preparation of effervescing powders.

746. *Compounds of Sodium.*—The protosulphuret of sodium, NaS, which has been referred to already, as prepared from the sulphate of soda by withdrawing its oxygen, as a step in the soda process, is also important as one of the ingredients of *lapis lazuli*, from which *ultramarine* is prepared. An artificial ultramarine, rivalling the native pigment in beauty, is obtained by heating sulphuret of sodium with silica, aluminum, and iron. The other sulphurets of sodium, which resemble those of potassium, are not important.

747. The chloride of sodium, $NaCl$, is too well known to require description. The bromide, $NaBr$, is unimportant. The iodide, NaI, resembles the corresponding salt of potassium. It occurs in kelp, and is interesting as the source of iodine, under which it has been noticed.

748. *Tests for sodium in combination.*—A strong solution of common salt, or of carbonate of soda, is to be prepared, and five test-glasses half filled with it.

1. To the first, solution of hydrosulphuret of ammonia is added. It will occasion no precipitate.

2. To the second, solution of carbonate of soda. It will also occasion no precipitate.

749. These negative indications only go the length of proving that the salt tested is a compound of potassium, or sodium, or ammonia.

3. To the third glass, solution of tartaric acid is added. No precipitate.

4. To the fourth, solution of bichloride of platinum. No precipitate.

750. The non-appearance of precipitates with the two last tests proves the salt *not* to be one of potassium.

5. To the fifth glass, quicklime or caustic potash is added. No odour of spirits of hartshorn is emitted. The absence of odour proves the salt *not* to be one of ammonia, as will be explained more fully under that substance. And as it has already been shown not to be a salt of potassium, it must be one of sodium; for the two first tests tried, limited us to sodium, potassium, or ammonia; and the three following tests have rejected the two last bodies, so that we are limited to the first.

751. The solution may now be evaporated to dryness, and its residue examined as to the test it communicates to flame. To avoid this trouble, dry common salt may be taken and heated at the blowpipe, or moistened with alcohol and the latter set fire to. In either case the same bright yellow flame which characterised burning sodium will be observed. It is seen to greatest advantage by throwing a handful of nitrate of soda on a cinder-fire; but in all circumstances it is readily noticed, and is greatly more distinct on the small scale than the violet flame of the potassium salts; so that, if one of the latter be mixed with a compound of sodium, and the effect of the mixture on flame observed, the yellow light will be found completely to overpower the violet. This, accordingly, is a delicate and convenient test for dry salts of sodium. There is no suitable *positive* test for them in solution, but they are easily detected by the negative method explained.

AMMONIA AND OTHER COMPOUNDS OF HYDROGEN AND NITROGEN.

Ammonia.

Equivalent, 17; *symbol* NH_3; *density as gas,* 597.

752. Ammonia is a compound of one equivalent of nitrogen and three of hydrogen. There is no convenient method, however, of causing these to unite, so as to produce it. It receives its name from the substance which yields it most readily—namely, hydrochlorate or muriate of ammonia. This was called by the Romans *Sal Ammoniacum,* or the Ammonian salt, from Ammonia, a district in Libya which supplied it, where Jupiter Ammon, or rather a corresponding Egyptian god, Amun, was worshipped. It was called by the alchemists spirit of hartshorn, because they obtained it by the distillation, in close vessels, of deers' horns. Ammonia is also called the volatile alkali. All those names are still in use.

753. When coals are distilled, as mentioned under coal gas, much ammonia is produced from the combination of the nitrogen and hydrogen of the coal. When bones are similarly treated in the manufacture of bone-charcoal, the same substance results; in both cases, however, in a state of great impurity. The gas or bone-liquor is mixed with hydrochloric acid, which expels carbonic acid and sulphuretted hydrogen, previously in union with the alkali, and combines with the ammonia, forming the hydrochlorate of that base, NH_3,HCl, sal-ammoniac. This salt is purified by repeated solution, crystallisation, and sublimation, and is then ready to yield ammonia.

754. The sal-ammoniac is reduced to powder, mixed with slaked quicklime, and heated in a retort, or flask with a bent tube. Ammonia, in the state of gas, is evolved abundantly; and being very soluble in water, must be collected at the mercurial pneumatic trough, or by displacement of air. As it is only about half as heavy as the latter, jars or bottles to be filled with it must be held above the vessel from which it is issuing, not below, as was the case with sulphurous acid and chlorine. (See fig. 61).

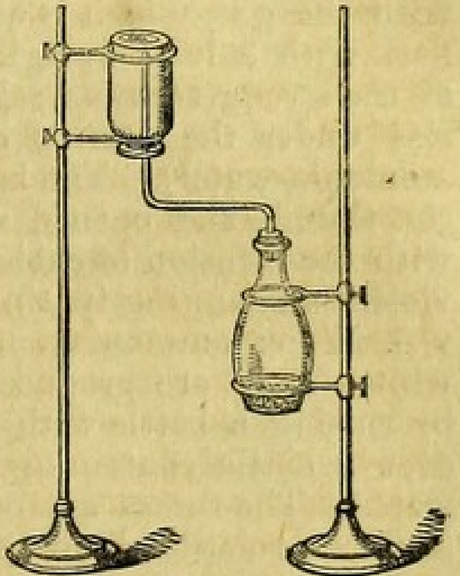
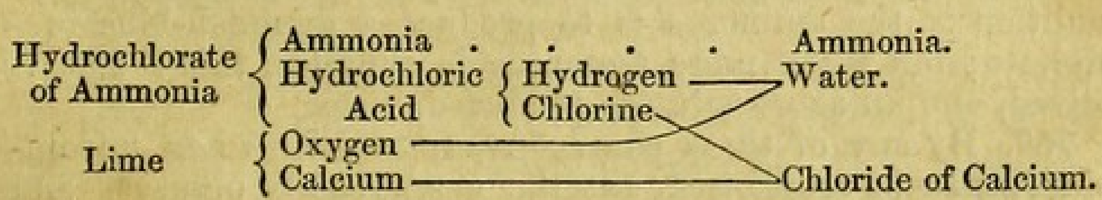


Fig. 61.

755. The following diagram will explain the decomposition that leads to the evolution of ammonia:—



Or in symbols—

$$NH_3,HCl \text{ and } CaO = NH_3 \text{ and } HO \text{ and } CaCl.$$

756. The following experiments may be tried with this important and curious gas, in illustration of its chief properties:—

1. Its odour is familiar to all as that of smelling-salts, or spirits of hartshorn. It is best observed by contrasting the absence of odour which characterises sal-ammoniac, with the

immediate development of the hartshorn-smell which attends the addition to it of moist quicklime or potass.

2. Its harsh alkaline taste must be tried with a dilute solution of the gas.

3. Its alkaline action on colouring matter appears when pieces of paper stained with turmeric, rhubarb, reddened litmus, or the purple cabbage, are exposed to the gas. The first two become brown, the third blue, and the fourth green. The same effects are produced by sending a current of the gas through infusions of these colouring matters.

4. Water can dissolve about 500 times its volume of ammonia. To illustrate this, a bottle is filled by displacement with the gas, which is evolved most quickly by boiling in a flask with a long upright tube (see fig. 61) a small quantity of the strong aqueous solution of ammonia sold by apothecaries under the title of *aqua ammoniæ fortissima* (strongest ammonia-water). The bottle, after being filled, is closed with the thumb, and opened under the surface of water coloured with the infusion of cabbage. The water rushes up with great violence, changing its tint as it ascends from purple to green.

5. When ammonia encounters any of the volatile acids, white fumes are produced. These may be readily observed by rinsing a bottle with hydrochloric acid, and inverting it over a bottle containing a little of the strongest ammonia-water. The fumes are occasioned by the combination of the acid and volatile alkali to form sal-ammoniac.

6. Ammonia forms a splendid azure-blue compound with salts of copper. To produce it, a small quantity of solution of sulphate of copper is added to a glass of water, and a stream of gaseous ammonia sent through it, or ammonia-water is added drop by drop. In either case, the first effect of the addition of the ammonia is to produce a greenish-blue precipitate; but when more ammonia is supplied, this is re-dissolved, and an azure solution produced.

757. By any of those characters, ammonia, when uncombined, may be recognised, but the most readily observed and the most delicate are its odour, and its action as a gas on colouring matter, both of which are eminently distinctive.

758. Ammonia, in association with an equivalent of water, rivals, in all their properties, anhydrous potass and soda. Like them, it unites with acids, and forms salts. When these contain oxacids, or organic acids, there is always one atom, at least, of water present for each atom of ammonia; and this water is essential, for if we attempt to withdraw it, the salt suffers destruction. A striking example of this is furnished by the process for nitrous oxide, where the expulsion of the

equivalent of water from nitrate of ammonia determines the resolution of that salt into water and nitrous oxide, as detailed under that gas. (See par. 429.)

759. The most important compounds of ammonia with the oxygen acids are the nitrate, the carbonate, and the sulphate.

760. The nitrate, HO,NH_3NO_5, has already been sufficiently referred to under nitrous oxide.

761. Ammonia and carbonic acid combine, along with water, in a great number of proportions. The carbonate sold in the shops is in general a sesquicarbonate; or, for each equivalent of hydrated ammonia, there are an equivalent and a-half of carbonic acid. In stating the composition of such a salt in numbers, the proportions are doubled, so as to avoid the notation of half an atom; or, instead of being written $NH_3HO,1\frac{1}{2}CO_2$, it is symbolised $2NH_3HO,3CO_2$.

762. This salt is prepared by heating a mixture of powdered sal-ammoniac and chalk, CaO,CO_2. When the ammonia of the one compound, uniting with the carbonic acid of the other, as well as with water produced during the process, exactly in the same way as in the process for pure ammonia, sublimes as a volatile salt, which condenses in crystals in the upper part of the subliming vessel. On the small scale a flask may be used; on the large an egg-shaped pot of iron is employed.

763. Carbonate of ammonia has an odour scarcely distinguishable from that of the free alkali. It is the smelling-salts of the shops, which are best made by mixing in a bottle coarsely-powdered sal-ammoniac and carbonate of potass. The reaction of these on each other leads to a constant evolution of the volatile carbonate, which may be increased at intervals by stirring the mixture, and putting the bottle in a warm place, with the occasional addition of a drop of water, if the contents appear too dry.

764. The carbonate is one of the most important salts of ammonia. In addition to its direct employment in the arts and in medicine, it is valuable as enabling us to prepare all the salts of ammonia by neutralising it with the acid whose salt is desired. Thus the nitrate is procured by adding the carbonate to nitric acid, and the acetate and citrate, which are used in medicine, by neutralising the carbonate with acetic acid (vinegar) and citric acid (lime juice).

765. The sulphate of ammonia, NH_3HO,SO_3, is now a considerable article of commerce as a fertilizer. It is prepared on the large scale, by neutralising the gas liquor or bone liquor, as well as other liquids containing ammonia, with oil of vitriol, and purifying by crystallisation.

766. When ammonia forms a salt with a hydrogen acid,

the resulting compound, when crystallised, does not contain an essential atom of water, like the salts produced with the oxygen and organic acids, but on the other hand is anhydrous. Thus when ammonia, or its carbonate, is neutralised by hydrochloric acid, the resulting combination, sal-ammoniac, contains dry hydrochloric acid united to dry ammonia, or it is NH_3HCl. The hydriodate, hydrobromate, hydrofluate, and hydrosulphate of ammonia, NH_3,HI; NH_3,HBr; NH_3,HF; NH_3,HS; are all in like manner anhydrous. Of these salts, the first and last only are important. Sal-ammoniac has been already sufficiently referred to as regards its source, its mode of preparation, and its employment to yield pure ammonia and its carbonate. It is sold in the shops in large, hollow, hemispherical cakes, which owe their shape to the leaden domes or cupola-like covers of the iron pots in which the salt is sublimed. It has in cake a peculiar tough and fibrous structure, which makes it one of the most difficult substances to pulverise. When struck with the pestle, it splits into threads without crumbling into powder. It may be obtained in regular crystals, both by sublimation and by evaporation of its aqueous solution. Their shape is the same as that characteristic of the majority of the metals—namely, the cube and octohedron.

767. The other important compound is generally called the hydrosulphuret of ammonia. It consists of one atom of anhydrous ammonia and two atoms of sulphuretted hydrogen, NH_3+2HS. It is prepared by passing a current of sulphuretted hydrogen through diluted ammonia-water, till it ceases to give a white precipitate with a solution of sulphate of magnesia, which proves it to be saturated. It is more important as a compound of sulphuretted hydrogen than of ammonia, and is largely employed as a means of distinguishing the metals from each other, being more useful for this purpose than the simple aqueous solution of that gas.

768. Ammonia has been considered along with potass and soda, because it so closely resembles them in alkaline properties, and because it forms salts exactly analogous to theirs. There are other reasons, however, for discussing it along with the metals. Its compounds may be represented as containing a body, which, although it is not simple, as the metals, according to our present analyses, are, yet has the chemical properties of a metal, so that in combination it can play the part of one. This compound is called ammonium, and consists of ammonia *plus* an atom of hydrogen; or ammonia being NH_3, ammonium is NH_4. It forms one of the best-marked examples of a compound *basyle.*

769. The ammonia salts of the hydracids are represented as compounds of ammonium by transferring the hydrogen of the acid to the ammonia, which then becomes ammonium, and considering the radical of the acid as directly combined with the ammonium. Thus hydrochlorate of ammonia, NH_3HCl, becomes chloride of ammonium, NH_4Cl, by transferring the hydrogen from the hydrochloric acid to the ammonia. This will appear more distinctly if we place in separate tables the same compounds, as salts of ammonia, and as salts of ammonium.

Salts of Ammonia.

Hydrochlorate of Ammonia,	NH_3HCl
Hydriodate of Ammonia,	NH_3HI
Hydrobromate of Ammonia,	NH_3HBr
Hydrofluate of Ammonia,	NH_3HF
Hydrosulphate of Ammonia,	NH_3HS

Salts of Ammonium.

Chloride of Ammonium,	NH_4Cl
Iodide of Ammonium,	NH_4I
Bromide of Ammonium,	NH_4Br
Fluoride of Ammonium,	NH_4F
Sulphuret of Ammonium,	NH_4S

770. These salts, it will be observed, are, according to the second view, exactly comparable to the corresponding compounds of potassium and sodium, which they closely resemble. Thus common salt, sal-ammoniac, and the similar potassium compound, come to be the chlorides of sodium, potassium, and ammonium, each of which has exactly the same crystalline form and common characters as a chloride. They agree in containing an equivalent of chlorine, united in two of them to an equivalent of a separable and apparently simple metal, and in the third to a non-isolable and compound metal, or, as it has been called, a *quasi*-metal, or basyle; that is, to a body which can discharge the functions, although it has not the constitution or physical characters, of an ordinary metal.

771. It is possible, indeed, that ammonium is not behind the isolable metals in the possession of even metallic splendour. There is a striking experiment, well worth repetition, which is thought to prove this. A small quantity of quicksilver is heated in a tube or porcelain basin, and one or two fragments of sodium added to it. The metals unite with evolution of heat and light. The resulting amalgam, which is liquid, like running mercury, is placed in a champagne glass, and covered with a saturated solution of sal-ammoniac. It instantly commences to swell up, and undergoes an enormous

increase in volume, retaining all the while its metallic lustre, but exhibiting a consistence exactly like that of butter, so that if a dimple be made in it with a glass rod, a pit remains after the rod is withdrawn. The amalgam, indeed, provided it be kept under the surface of the liquid, may be moulded into any shape. Its great increase in volume is accompanied by a very trifling one in weight, the augmentation not being more than by about one twelve-thousandth part. This curious compound is not permanent. Soon after its production it decomposes into mercury, hydrogen, and ammonia. It is thought possible that it may be a compound of ammonium and mercury, produced in virtue of the sodium of the amalgam combining with the chlorine of the sal-ammoniac, whilst the ammonium of the latter unites with the mercury, to form what has been called the ammoniacal amalgam; in symbols, NH_4Cl and $HgNa = NH_4Hg$ and $NaCl$. That such is its composition, however, cannot be demonstrated. Its instability makes an accurate analysis impossible.

772. The organic and oxygen acid salts of ammonia are represented as compounds of ammonium, by transferring the hydrogen of the essential atom of water to the ammonia, so as to convert it into ammonium. The oxygen of the water is then considered as combined with the ammonium, as in potass and soda it is with the potassium and sodium. The following table will illustrate this:—

Salts of Hydrated Ammonia.

Nitrate of Ammonia,	NH_3HO,NO_5
Carbonate of Ammonia,	NH_3HO,CO_2
Sulphate of Ammonia,	NH_3HO,SO_3

Salts of Oxide of Ammonium.

Nitrate of Oxide of Ammonium,	NH_4O,NO_5
Carbonate of Oxide of Ammonium,	NH_4O,CO_2
Sulphate of Oxide of Ammonium,	NH_4O,SO_3

773. The nitrate of oxide of ammonium is thus likened to the nitrate of oxide of potassium (nitrate of potass), which it resembles in many properties; and so on with the other salts.

774. There is a third compound of hydrogen and nitrogen, called amidogen, NH_2, which cannot be further considered.

775. *Tests for Ammonia or Ammonium in Combination.*—We have already mentioned fully the characters by which uncombined ammonia is recognised. We have now to state the mode of identifying it, when it is in combination, for example, with an acid.

776. A solution of any salt of ammonia or ammonium, except the carbonate, may be taken for the following experiments. A solution of the hydrochlorate of ammonia, or chloride of ammonium, does best. Six glasses are half filled with this, and treated as follows:—

1. To the first, hydrosulphuret of ammonia is added. No precipitate.

2. Solution of carbonate of soda is added to the second. No precipitate. These negative results prove, as before, the salt originally dissolved to be a compound of potassium, sodium, or ammonium.

3. To the third glass, solution of tartaric acid is added. No precipitate. The salt, therefore, is not one of potassium.

4. To the fourth glass, solution of bichloride of platinum is added. A yellow precipitate. The salt, therefore, is not a compound of sodium. It cannot, accordingly, be anything but a salt of ammonia (or, what is the same thing, of ammonium). But this may be further proved by positive tests.

5. To the fifth glass, quicklime or caustic potash is added. The odour of spirits of hartshorn is immediately evolved.

6. To the sixth glass, lime is also added, and the vessel put in a warm place. Moistened red litmus paper, or yellow turmeric paper, is held above the glass, care being taken that it does not touch the liquid. The former becomes blue, the latter brown.

777. There is, properly speaking, no blowpipe test for salts of ammonia. The great majority of them, when heated, are volatilised with or without decomposition. If the carbonate, sulphate, and nitrate of ammonia be heated in an iron spoon over a spirit lamp, they are in a few seconds completely dissipated, and are thus at once distinguished, without further test, from salts of potassium and sodium, none of which are volatile by a spirit-lamp flame. Compounds of ammonia, however, with the more fixed acids, such as the phosphoric, lose only their alkali when heated, so that a residue of acid is left.

METALS OF THE ALKALINE EARTHS.

CALCIUM, MAGNESIUM, BARIUM, STRONTIUM.

Calcium.

Equivalent, 20; *symbol*, Ca.

778. Calcium, like the other metals of this class, is obtained with difficulty, is put to no use, and has been seen by few persons. It is described by those who have prepared

it as a silver-white metal, which combines with oxygen with great readiness. Its equivalent is 20. It derives its name from the Latin term for lime, *calx*, from which our English word calcareous is derived.

779. *Lime*, CaO.—Lime, or quicklime, is obtained by heating limestone (carbonate of lime) to redness in a limekiln or open fire. The carbonic acid is totally expelled, and the oxide of calcium, lime, is left. Pure lime, such as may be procured by heating statuary marble or Iceland spar, forms a white, brittle, porous mass, which is highly caustic, and about three times heavier than water.

780. If sprinkled with water, it first absorbs it, and then combines with it, forming a definite, dry hydrate. This process is called the slaking or slacking of lime, in allusion to its drinking up, as it were, the water poured on it. The quicklime, or lime-shell, during the process of slaking evolves much heat, and finally crumbles into a fine powder, which is the hydrate, CaO,HO. The temperature produced is sufficiently high to char and even to kindle wood. Carts conveying lime-shell have been set on fire in this way by a casual shower of rain, and similar accidents have occurred to sailing vessels from accidental leakage.

781. If the hydrate be exposed to a red heat, it parts with its water, and returns to the state of unslaked lime. Lime is often slaked in the laboratory, and then unslaked by heating it, as the most convenient way of obtaining it in the state of fine powder.

782. The hydrate of lime is soluble in water to a small extent, and, curiously enough, is more soluble in cold than in hot water. This solution forms the well-known lime-water which is used in medicine, and kept in the laboratory as a test for carbonic acid.

783. All the facts we have mentioned may be easily verified by the student, who may make his own quicklime by burning marble, or procure the former from a lime-kiln. With lime-water he may observe the properties which distinguish an alkaline earth from an alkali, on the one hand, and from an earth proper, on the other.

1. Lime-water is harsh to the taste, acrid, and caustic, as solutions of potass and soda are.

2. Like them, it turns red litmus blue, purple cabbage green, and yellow turmeric brown.

3. It differs from the alkalis in being much less soluble.

4. It forms insoluble salts with carbonic and phosphoric acids, whilst the corresponding salts of the alkalis are markedly soluble.

784. The two chief uses of lime are in the formation of building-mortar, and as an application to increase the fertility of the soil.

785. Ordinary mortar consists of lime made into a paste along with sand, and sometimes chopped hair. The object of the sand is to prevent the irregular contraction and cracking of the lime as it dries. The hair binds together the lime, and prevents its crumbling when very dry.

786. During the process of hardening, a certain amount of carbonic acid is absorbed by the mortar from the air, but in no case does the lime return entirely to the state of carbonate. The truth of this statement may be verified by mixing mortar from any old building with water, and then adding muriatic acid, which will be found to occasion only a slight effervescence.

787. Hydraulic mortar, or that employed for cementing the piers of bridges and other structures which are exposed to the action of water, consists of a natural or artificial mixture of limestone and ferruginous clay—that is, carbonate of lime, and silicate of alumina, containing iron. This is burned in a lime-kiln, and reduced to powder. When mixed with water, it sets as quickly as stucco, and finally becomes as hard as stone, in consequence of chemical combination occurring between the silica, lime, oxide of iron, and alumina. In ordinary mortar no such union occurs between the silica (the sand) and the lime.

788. The action of lime in fertilising soils is still matter of dispute. This much, however, appears to be certain: the efficacy of lime is most striking—first, on lands which are unfertile owing to excess of vegetable matter, such as bog, turf, or peat soils; and secondly, in stiff clay soils. It improves the first by causing the rapid decomposition of the excess of vegetable matter, so that the saline or mineral matter in the soil comes to bear a proportion to its vegetable or organic constituents, compatible with the healthy growth of plants in it.

789. On clayey soils lime appears to act beneficially by liberating the alkalis, especially potass. These are contained in the clay in union with its silica and alumina, so that rain-water cannot dissolve them and carry them into the tissues of plants. The lime, by combining with the silica and alumina, as it does in the hydraulic mortar, sets free the alkalis, which are then available for the nourishment of vegetables. The lime in this case is spread upon the land in autumn or winter, and the ground is not sown till spring.

790. *Salts of Lime.*—Carbonate of lime, CaO,CO_2, is one of

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the most widely distributed of salts, forming whole mountains of limestone and marble, besides being the chief constituent of shells, corals, coral reefs, chalk, &c. It likewise occurs crystallised in various shapes, but most strikingly in the rhombohedral form already referred to as characteristic of the minority of the metals. It goes then by the name of Iceland, calcareous, or calc-spar, and is celebrated for the striking way in which it exhibits double refraction of light, a remarkable phenomenon, which all transparent rhombohedral crystals show, but none so markedly as Iceland spar.

791. The carbonate of lime is insoluble, or nearly so, in pure water, but it dissolves readily in water containing carbonic acid, as was mentioned under that gas. It is important as the source of quicklime, and of carbonic acid. From it all the other salts of lime may be procured by dissolving it in the various acids.

792. *Sulphate of Lime, Gypsum, Alabaster, Stucco, Anhydrite.*—This important salt occurs in nature occasionally anhydrous, CaO,SO_3, and is then called anhydrite. It is much more abundant in combination with two atoms of water, $CaO,SO_3 + 2HO$. In this state it is called *gypsum.* The finer transparent varieties form the alabaster of the artist, and the selenite of the mineralogist. When gypsum is cautiously heated till it parts with the greater portion, but not the whole, of the water it contains, it forms plaster of Paris, or burnt stucco. When this, in the state of powder, is made into a paste with water, it quickly forms a solid mass, or, as it is technically called, *sets.* In setting, the stucco takes back the water it was deprived of when heated, evolving heat in so doing, and returning to the same chemical state as the original gypsum.

793. If sulphate of lime be deprived by heat of the whole of its water, it will not set when moistened, and it is scarcely possible to burn set stucco so as to make it set again.

794. Sulphate of lime appears as a thick pasty precipitate when sulphuric acid is added to a strong solution of any salt of lime. It forms a striking experiment to add oil of vitriol to a saturated solution of chloride of calcium. So much of the sulphate is produced that the whole liquid appears to solidify, and the vessel may be turned upside down without anything escaping.

795. Notwithstanding the fact just mentioned, sulphate of lime is soluble in water to the extent of one part by weight of the salt in 460 of water. Such a solution is kept in the laboratory as a test, and will presently be referred to, as enabling us to distinguish the alkaline earths from each other.

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796. Permanently hard waters, which are not improved by boiling, generally contain sulphate of lime. The lime may be got rid of by the addition of carbonate of soda, which precipitates it as carbonate.

797. *Phosphates of Lime.*—There are many compounds of lime and phosphoric acid, owing to the peculiarity of that acid in relation to the number of equivalents of base it combines with at once. The most interesting phosphate of lime is that which occurs in bones, and is distinguished as the bone-earth phosphate, $3CaO,PO_5$. It has been already referred to under phosphorus.

798. *Chloride of Lime* is more important as a compound of chlorine than as a salt of lime. It has been discussed under chlorine. The other salts of lime are unimportant.

799. *Salts of Calcium.*—The only important compounds of calcium are the phosphuret, fluoride, and chloride. The phosphuret, CaP, has been described under hypophosphorous acid. The fluoride, CaF, is discussed under fluorine.

800. The chloride of calcium, $CaCl$, which must not be confounded with the chloride of lime, $CaO,Cl + HO$, is an important salt. It is the residue of the process for carbonic acid by dissolving marble in hydrochloric acid, and is produced in the course of other chemical processes on the large scale. It is extremely deliquescent, and has, especially when anhydrous, a great affinity for water. It is employed, as has been mentioned already—1*st*, for freezing mercury; 2*d*, for drying gases; it is likewise used, 3*d*, for determining the amount of hydrogen contained in organic bodies.

801. The tests for lime in combination will be given after the other alkaline earths have been discussed.

Magnesium.

Equivalent, 12·67; *symbol*, Mg.

802. Magnesium is obtained from its chloride by heating it with potassium or sodium. It is white, and readily fusible. It burns when heated in the air, and forms its oxide, the familiar substance magnesia. It resembles zinc more than any of the other metals, but it is prepared only as a chemical curiosity, for it is put to no use in the arts.

803. *Magnesia* is its only oxide. It may be obtained pure by heating the magnesia of the shops, which generally contains carbonic acid as well as water. It is a soft, white, light powder, which unites with water to form a hydrate, and dissolves in it, but only to a very small extent. It possesses causticity in a very feeble degree.

804. The solubility and alkalinity of magnesia are best observed by adding a spoonful or two of the powder to solution of reddened litmus, purple cabbage, or yellow turmeric. The colours of all of them will be changed in the way already so frequently mentioned. If the magnesia were not soluble, it could not produce these effects.

805. Magnesia exists in nature abundantly in combination with carbonic acid, forming the carbonate, which is sometimes found singly, but more frequently presents itself in combination with carbonate of lime, forming magnesian limestone, $CaO,CO_2 + MgO,CO_2$. It is found also in many volcanic rocks, and in various minerals associated with other bases, and in union with silica. Plants and animals contain it chiefly in union with phosphoric acid, and it is present in sea-water in considerable quantity, chiefly as the bromide and chloride of magnesium.

806. If a solution of caustic potash be added to concentrated sea-water, or, still better, to the bittern described under bromine, it will occasion an abundant precipitate of magnesia.

Salts of Magnesia.

807. *Carbonate of Magnesia*, MgO,CO_2.—The carbonate has already been referred to. It is not easily obtained artificially. What is sold as such in the shops is prepared by the addition of a hot solution of carbonate of potass or soda to any soluble salt of magnesia, such as the sulphate. A white precipitate falls, containing four equivalents of carbonic acid, to five of magnesia, and six of water. From this compound most of the other salts of magnesia may be obtained by dissolving it in the different acids.

808. *Sulphate of Magnesia*, $MgO,SO_3 + 7HO$.—Sulphate of magnesia, or Epsom salts, is prepared from bittern by evaporating it along with sulphuric acid; or by the action of oil of vitriol on magnesian limestone. In the latter process the resulting sulphates of lime and of magnesia are separated from each other by digesting the mixture in a small volume of water, which takes up the readily soluble sulphate of magnesia, and leaves the greater part of the sulphate of lime undissolved.

809. This salt is distinguished from the sulphates of the other alkaline earths by its great solubility, which is such that sulphuric acid does not occasion a precipitate in the strongest solutions of magnesian salts, whilst in these circumstances salts of lime, baryta, or strontia, yield an abundant precipitate of their sulphates.

810. *Phosphate of Magnesia and Ammonia.*—

$$2MgO,NH_4O,PO_5 + 12HO.$$

If phosphate of soda, or any other soluble salt of phosphoric acid, be added to sulphate of magnesia, a white precipitate slowly separates, consisting of the phosphate of magnesia, $2MgO,HO,PO_5 + 14HO$. If ammonia be added along with the phosphate of soda, a crystalline precipitate appears at once, if the solutions are concentrated, and after some time if they are dilute. The precipitate consists of the phosphate of ammonia and magnesia, the formula of which is given above. The production of this salt, as we shall presently mention, supplies the means of identifying magnesia in combination.

811. *Salts of Magnesium.*—The only important salts of magnesium are its chloride and bromide. The former, $MgCl$, is interesting as the source of the metal; the latter as the source of bromine. Both are very deliquescent, readily soluble in water, and have a very bitter taste.

Barium.

Equivalent, 68·64; *symbol*, Ba.

812. Barium, which is a white metal like silver, forms two oxides, the protoxide, BaO, and the peroxide, BaO_2. The latter is employed in the preparation of peroxide of hydrogen or oxygenated water, and will not be further alluded to.

813. The name barium is derived from the Greek adjective βαϱυς (barys), heavy, in allusion to the conspicuous density of the native salts of this metal, which had long led to the sulphate being distinguished by the title of *heavy spar*.

814. The protoxide, generally called baryta or barytes, is prepared by heating the nitrate or iodate of baryta in a crucible till the acid is expelled. The dry oxide forms a gray, porous solid, which slakes like lime when moistened, with the evolution of heat, forming the hydrate of baryta, BaO,HO. If boiling water be saturated with this, it deposits as it cools crystals containing one atom of baryta and ten of water. The liquid which yields these is a saturated cold solution of baryta, which will be found to act on colouring matters like an alkali, and to have a harsh, acrid taste. The solution, moreover, is caustic and poisonous. It is precipitated by carbonic acid still more readily than lime-water.

815. The salts of barium and baryta are interesting chiefly from their employment as tests for the mineral acids, and especially for sulphuric acid, as mentioned under that sub-

stance. The two most important are the chloride of barium, $BaCl$, and the nitrate of baryta, BaO,NO_5. They are prepared by dissolving the native carbonate of baryta in hydrochloric and nitric acids respectively. When the carbonate cannot be procured, the sulphate of baryta, a much more abundant mineral, is reduced to powder, and heated with ground coal till it is reduced to sulphuret of barium, BaS. The sulphuret is then dissolved in the acid whose salt is desired. The native sulphate, BaO,SO_3, is largely used as a pigment; and the artificial carbonate, BaO,CO_2, is employed in the analysis of minerals.

Strontium.

Equivalent, 43·84; *symbol*, Sr.

816. This metal derives its name from Strontian in Argyleshire, in the lead-mines of which it is found, as carbonate, sulphate, &c. Its protoxide, strontia or strontites, is prepared from the nitrate, as baryta is from its nitrate.

817. Strontia forms a hydrate with water, and then dissolves in it, forming a solution having properties similar to those of baryta-water. Its most important salts are the chloride of strontium, $SrCl$, and the nitrate of strontia, SrO,NO_5. With either of these bodies, the student may observe the only character of the strontia compounds, which can be said to be of much interest. They communicate to flame a splendid crimson colour, which leads to their employment in the arts for the production of red signal-lights and fireworks. This property may be well observed by throwing a large spoonful of the nitrate of strontia into a cinder fire, or, still better, by preparing what the pyrotechnists call red-fire. It consists of nitrate of strontia forty parts by weight, flowers of sulphur thirteen, chlorate of potass five, sulphuret of antimony four; all in fine powder. The chlorate of potass must be pounded separately, and the materials mixed by gentle stirring in a wooden bowl or mortar. If pounded together, dangerous explosions will happen. The mixture, if taken in any quantity, must be fired in the open air, as it produces a large volume of sulphurous acid. The light it produces when well prepared is of the intensest red. For an experiment within doors, a salt of strontia may be moistened with alcohol, and the latter set fire to. The chloride does better than the nitrate for this purpose, and the effect is very fine if a sheet of paper be kindled after being immersed in the solution. The red light may also be witnessed by heating the salts of strontia in the reducing blowpipe flame. Salts of barium in

similar circumstances colour the flame green, but seldom distinctly. The pyrotechnist, however, prepares a fine 'green fire' by substituting nitrate of baryta for the nitrate of strontia of the red fire.

818. Lime, in the reducing flame of the blowpipe, gives a flame somewhat like that of strontia, but duller, and more of a brick red. In the oxidising flame, lime produces an intense white light. Both of these appearances have been referred to already, under the oxyhydrogen blowpipe. Magnesia presents nothing particular in the inner blowpipe flame. In the outer one it evolves, like other infusible bodies, a bright white light.

819. *Tests for the Alkaline Earths in Combination.*—The tests which we are about to describe apply equally to the salts produced when the alkaline earths meet oxyacids and hydracids. The salts of the latter, strictly speaking, do not contain the alkaline earths, but their metals; as we have the chloride of barium, not the hydrochlorate of baryta. As all the salts, however, may be represented as produced by the solution of the alkaline earths in the different acids, we shall, to avoid unnecessary repetition, speak of salts of the hydracids, as well as salts of the oxacids, by the common title of salts of the alkaline earths.

820. The student, then, is first to prepare a saturated solution, or at least a strong one, of one salt of each of the alkaline earths. We shall suppose taken, what upon the whole are the most conveniently prepared, a solution of chloride of barium, one of chloride of strontium, one of chloride of calcium, and one of sulphate of magnesia.

821. These salts may be had to purchase, except perhaps the chloride of calcium, which can readily be prepared by dissolving white marble in pure muriatic acid. We shall distinguish the different salts simply by their metals as salts of barium, strontium, calcium, and magnesium.

822. The first points to be observed, are certain characters which distinguish the alkaline earths, as a group, from the alkalis, on the one hand, and the earths and remaining metals on the other.

1. To each of the four solutions contained in a wine-glass, hydrosulphuret of ammonia is added. It produces no precipitate. The only metallic salts in which this reagent produces no precipitate are salts of the alkalis and of the alkaline earths. Its negative action, therefore, shows us that we need not seek further for any of the earths or ordinary heavy metals, but it leaves undetermined whether each glass contains the salt of an alkaline earth or of an alkali. To determine this, fresh portions of the four solutions are taken, and to each a solu-

tion of carbonate of potass or soda is added. It produces in all of them white precipitates of the carbonates respectively of baryta, strontia, lime, and magnesia. The alkalis, it will be remembered, gave no precipitate with the carbonate of potass or soda. This one test, therefore, distinguishes the whole of the alkaline earths from the whole of the alkalis. In other words, a dissolved salt, which is not precipitated by hydrosulphuret of ammonia, but is precipitated by carbonate of potass, can be nothing but the salt of an alkaline earth. It remains, then, to discover whether it be a salt of barium, strontium, calcium, or magnesium. Fresh solutions of the four are taken, and to each of them a saturated solution of sulphate of lime is added. It will immediately produce in the salt of barium a white precipitate of sulphate of baryta. After some time, it will occasion in the salt of strontium a similar precipitate of sulphate of strontia. But no precipitate will appear in the salt of calcium or of magnesium.

823. The cause of this difference is the relative solubility of the sulphates of the several alkaline earths. The sulphate of baryta is quite insoluble in water, and appears in consequence at once. The sulphate of strontia has a certain solubility, and some time, accordingly, elapses before it shows itself. The sulphate of lime cannot produce a precipitate in a salt of calcium, because there is more than enough of water present to retain dissolved all the sulphate of lime that can possibly be formed. The sulphate of magnesia is greatly more soluble than the sulphate of lime; so that if there be sufficient water present to prevent the latter precipitating, there must be enough to prevent the former.

824. A salt of barium, then, is distinguished from salts of the other alkaline earths by being *immediately* precipitated by sulphate of lime, and no other test is needed.

825. A salt of strontium is distinguished by being precipitated *after a short time* by the same sulphate. The dry salt may be further tested at the blowpipe, or by kindling alcohol upon it, so as to see the crimson flame.

826. If a salt of an alkaline earth gives no precipitate with sulphate of lime, it must be a salt of calcium or of magnesium, To discover which it is, a solution of oxalic acid is taken. It will give a white precipitate immediately, with the salt of calcium, but none with the salt of magnesium. No further test is needed for the lime salt; but in order to obtain a positive assurance that magnesia is present, phosphate of soda is added to the magnesian salt, and then ammonia or its carbonate, when an abundant white precipitate of the phosphate of ammonia and magnesia appears.

METALS OF THE EARTHS PROPER.

Aluminum or Aluminium.

Equivalent, 13·69; *symbol*, Al.

827. There is but one of the earths sufficiently abundant and important to call for special notice. This is alumina, a substance of great interest, and the only oxide of the metal. It is a sesquioxide, so that its symbol is Al_2O_3. It occurs in nature abundantly, in combination with silica, associated with other bases.

828. The most familiar, perhaps, of its native compounds is felspar, a silicate of alumina and potass,

$$Al_2O_3,3SiO_3 + KO,SiO_3.$$

This is one of the constituents of granite and of several other igneous rocks. Certain varieties of these, by exposure to the atmosphere, become completely disintegrated, passing from the state of hard, solid rock, such as we are accustomed to see in building granite, into soft, crumbling, earthy masses. It is the felspar which undergoes the change; and it appears to be owing to the action of rain-water charged with carbonic acid, which dissolves the potass and some of the silica of the felspar, leaving the excess of silica and the alumina still united. It is not known, however, why certain specimens of granite are rapidly corroded and crumbled down, whilst others have resisted for ages the same causes of decay. By such a process of disintegration as we have described, the clays of our arable soils are produced. Clay consists of silica and alumina in a state of chemical combination. It never is pure alumina, but the quantity of silica united to the latter is variable. When it is pure, clay is quite white, as we see in the porcelain clay of Devonshire and Cornwall, which is derived from colourless felspar. More frequently clay is red, owing to the presence of oxide of iron; or black, from the diffusion through it of vegetable matter.

829. When clay is boiled with oil of vitriol, the sulphuric acid combines with the alumina to the exclusion of the silica, forming the sulphate of alumina, a highly-soluble salt. From this pure alumina may be prepared, but the sulphate cannot always be readily obtained; and the student, in general, must have recourse to a compound of the sulphate of alumina with the sulphate of potass, which is largely consumed in the arts, and may always be easily procured. It goes by the name of alum.

830. From alum, alumina is prepared by adding to a solu-

tion of the former, water of ammonia, as long as it occasions a precipitate. The alumina appears as a voluminous, white, gelatinous substance, consisting of the oxide of the metal combined with water. In this state, after being gently dried, it is readily soluble in acids and in alkalis; but if heated to whiteness, it loses the associated water, contracts greatly in bulk, and forms a white, soft powder, not at all gritty or soluble in alkalis, and scarcely acted on by acids.

831. Alumina, whether hydrated or anhydrous, is insoluble in water, possesses no taste, and does not alter colouring matters. It is quite different, therefore, in properties from the alkaline earths, and is a much weaker base.

832. In the anhydrous state it absorbs water with great readiness without combining with it, so that it adheres to the tongue, and is felt to parch it. Clay retains this property, and the ends of tobacco-pipes are glazed, to prevent adhesion to the lips or tongue.

833. Alumina is not fusible by a forge or furnace heat, but it melts before the oxyhydrogen blowpipe into a clear globule, possessing great hardness. It occurs in nature in a similar state. The more coarsely-crystallised specimens form the emery which is used for polishing; the transparent crystals, when of a blue colour, owing to a trace of metallic oxide, constitute the precious gem the sapphire, and when red, the ruby.

834. Alumina, in common with other sesquioxides, is a feeble base. The salts it forms with the acids have almost all a sour taste, and an acid action on colouring matter.

835. Alumina is not directly employed to yield the metal. If mixed, however, with charcoal, and heated red-hot in a porcelain tube passed across a furnace, whilst a current of chlorine is sent through the arrangement, the alumina parts with its oxygen to the carbon, and the chlorine takes the place of the former. In this way a chloride of aluminum is formed, Al_2Cl_3, a crystalline, volatile salt, which, when fused along with potassium or sodium, abandons its chlorine to the alkalifiable metal, and leaves aluminum, as a gray, lustrous metal, resembling iron.

836. SALTS OF ALUMINA.—The chloride of aluminum is the only direct salt of the metal of special interest. The salts of alumina are of much more importance.

837. When alumina unites with an acid, a single equivalent of the earth combines with three of the acid. Thus the silicate of alumina contained in felspar is $Al_2O_3,3SiO_3$. The same thing occurs with other sesquioxides, and it is a particular case of a general law, which teaches that the number of equivalents of an acid which combine with an

oxide to form a salt, is determined by the number of equivalents of oxygen in the oxide. Thus the alkalis and alkaline earths are all protoxides, or contain but one atom of oxygen. They all combine, accordingly, with one atom of acid, to form neutral salts. Alumina, on the other hand, Al_2O_3, sesquioxide of iron, Fe_2O_3, sesquioxide of manganese, Mn_2O_3, oxide of chromium, Cr_2O_3, &c., all of which contain three atoms of oxygen, never unite with less than three atoms of an acid. So also the peroxide of tin, which is a binoxide, SnO_2, unites with two atoms of acid.

838. SULPHATE OF ALUMINA, $Al_2O_3,3SO_3+18HO$, has already been referred to as obtained by the action of sulphuric acid on clay. If raised to a red heat, the acid is expelled, and pure anhydrous alumina is left. The sulphate is largely used in dyeing and calico-printing.

839. SULPHATE OF ALUMINA AND POTASS, COMMON ALUM, $Al_2O_3,3SO_3+KOSO_3+24HO$.—This valuable salt may be prepared by mixing solutions of sulphate of potass and sulphate of alumina, and allowing the liquid to evaporate spontaneously. The alum separates in large regular crystals, which are modifications of the cube and octohedron. It is generally, however, manufactured in another way. At Hurlet, near Glasgow, at Whitby in Yorkshire, and elsewhere, large beds of shale, or indurated clay, occur, associated with abundance of iron pyrites, the bisulphuret of iron, FeS_2. The shale, or alum-schist, as it is called, is dug up, and broken into small pieces, which are piled in heaps, frequently wetted, and left exposed to the air. The pyrites rises in temperature as it absorbs oxygen, which converts its iron into protoxide of the metal, and each of its equivalents of sulphur into sulphuric acid. The one of these combines with the oxide of iron, changing it into sulphate, FeO,SO_3. The other atom of sulphuric acid combines with the alumina of the shale, forming sulphate of alumina. As soon as this change has occurred, water is poured upon the alum-schist. It forms a solution of both the sulphates, which is concentrated by evaporation, and set aside to crystallise. The sulphate of iron, which is much less soluble than that of alumina, separates first, and is in greater part removed in this way, being itself a valuable salt. Chloride of potassium is then added to the solution. It decomposes the remaining sulphate of iron, chloride of iron and sulphate of potass being produced. The latter salt unites with the sulphate of alumina and 24 atoms of water, and the triple compound separates as alum, whilst the chloride of iron, which is now the more soluble salt, remains in solution.

840. Alum has a peculiar sour-sweet and astringent taste.

It acts like a strong acid on colouring matter, and evolves hydrogen when zinc is added to its solution. It is used to a considerable extent in medicine. It is largely employed in the preparation of leather, and still more abundantly in dyeing, and in the preparation of pigments. Its application to the two latter purposes depends upon its attraction for organic colouring matters, and its affinity for textile tissues. The former property may be observed by adding to a solution of colouring matter, such as madder, cochineal, or litmus, first alum, and then an alkali, so as to precipitate the alumina. The latter, as it falls, will carry down the colouring matter combined with it. Such compounds are called lakes.

841. The attraction of alumina for the fibre of cloth may be shown by filtering the acetate of alumina, or a solution of common alum which has been partially neutralised by carbonate of soda, through linen or cotton, when part of the alumina will be abstracted by these tissues, and retained.

842. Colours otherwise fugitive are thus fixed, the cloth to be dyed being first impregnated with alumina, and then immersed in an infusion of the colouring matter, or *vice versâ*. The alumina attaches itself to the fibre on the one hand, and the dye-stuff on the other, so that a coloured compound is produced, insoluble in water, and not destroyed by soap, &c.

843. Alumina, like other sesquioxides, does not readily combine with the weak acids, such as the carbonic. This may be shown by adding carbonate of soda to a hot solution of alum, when carbonic acid will be observed to escape with effervescence. The white precipitate which falls is pure alumina, or contains only a small proportion of carbonic acid.

844. SILICATES OF ALUMINA.—Silicates of alumina, of constant composition, occur in various minerals, such as felspar, as we have already illustrated. The most interesting bodies of this class, however, are the clays, which are very variable in constitution, so that no common formula can be given for them.

845. Clay is an essential constituent of the important fabric pottery. Of this there may be said essentially to be but two kinds—earthenware and porcelain. Earthenware consists of clay alone, which, after being fashioned into vessels, and dried in the air, is exposed to a high temperature, in a peculiar furnace or kiln. In this state the burned clay forms a firm, solid, but brittle mass, which is porous, and pervious to water. It is quite opaque, exhibits no traces of fusion, breaks with an earthy fracture, and gives out, when struck, a dull sound.

846. To render earthenware fit to contain liquids, it is glazed: in other words, a fusible glass, reduced to powder, is made into a cream with water, and spread thinly over its surface. The vessel is then returned to the kiln, and heated till this coating melts, and forms an insoluble glassy varnish, through which ordinary liquids cannot penetrate.

847. Porcelain, on the other hand, may be said to consist of clay and glass, the materials of which are ground to fine powder, and formed into a uniform paste with water. This paste is then dried till it resembles dough in consistence, and can then be formed into vessels. When these are heated in the kiln, the glassy element of the porcelain melts, and binds together its earthy constituent, at the same time rendering the whole mass more or less transparent, as wax does paper when melted into it, and then allowed to consolidate. Porcelain is distinguished from earthenware by being semi-transparent, by breaking with a glassy fracture, and by ringing like a metal when struck.

848. Various substances are employed as the glassy constituent of porcelain. Powdered flints are almost invariably made use of. Felspar is also used, so are phosphate of lime (burnt bones) and borax. Every celebrated pottery has its own recipe, and all the processes are kept very secret. Porcelain, like earthenware, requires to be glazed, to render it impervious to liquids. Unglazed earthenware is largely employed in the construction of water-bottles for hot climates, where it is an object that the water shall slowly percolate through the walls of the vessel, and, by evaporation from its outer surface, cool the liquid within. For a similar reason flowerpots are left unglazed, and so are the porcelain cells of galvanic batteries.

849. TESTS FOR ALUMINA IN COMBINATION.—A saturated solution of alum is prepared, and two glasses are half filled with it.

1. To the first hydrosulphuret of ammonia is added. It produces a white precipitate, as ammonia itself would do, sulphuretted hydrogen escaping as gas. This test alone suffices to distinguish a salt of alumina from the salt of an alkali, or an alkaline earth, as the two latter classes of compounds are not precipitated by hydrosulphuret of ammonia. We shall afterwards find that there is but one other metal—namely, zinc—whose salts give a white precipitate with the hydrosulphuret.

2. To the second is added solution of caustic potass, drop by drop. The first addition of alkali occasions a white precipitate (alumina), but when more of the potass is added,

the precipitate re-dissolves, and the liquid becomes quite clear.

3. This clear liquid is divided into two portions. To the one of them, solution of sulphuretted hydrogen is added; it will produce no precipitate. To the other, solution of muriate of ammonia; it will occasion the reproduction of the alumina as a white precipitate. These tests distinguish salts of alumina from all other compounds, those of zinc included.

4. There is, in addition, however, a striking blowpipe test. If a salt of alumina be heated on charcoal, at the outer blowpipe flame, after being moistened with solution of nitrate of cobalt, it will acquire a splendid blue colour.

Chromium.

Equivalent, 28·15; *symbol*, Cr.

850. Chromium is an interesting metal, from the variety and beauty of the colours of its compounds, which are largely used by the painter and dyer. It receives its name from the Greek χρωμα (Chroma), colour. It differs much in properties from aluminum, but its salts behave with reagents as the compounds of the latter do. We discuss it here accordingly. Chromium forms two important oxides, the one a sesquioxide, Cr_2O_3; the other chromic acid, CrO_3.

851. The different compounds of chromium are procured from a mineral called *chrome iron ore*, which can be readily procured from any dealer in minerals. Its composition is $FeO + Cr_2O_3$. A portion of this is to be ground to powder, and heated in a crucible with a mixture of carbonate and nitrate of potass. The oxygen of the nitre combines with both the metallic oxides, converting the one into the peroxide of iron, Fe_2O_3, and the other into chromic acid, CrO_3, which unites with the alkali, forming chromate of potass, KO,CrO_3, a lemon-yellow salt, which is dissolved when water is digested on the contents of the crucible. A small portion of sulphuric acid is added to the dissolved chromate of potass. It combines with one-half of the alkali, leaving the other in combination with two atoms of chromic acid, forming a rich orange-red salt, easily crystallised, the bichromate of potass, $KO,2CrO_3$.

852. Large quantities of this salt are prepared from chrome iron ore by the process just described, and from this salt, which can be readily obtained, all the other compounds of chromium are prepared.

853. *Oxide*, Cr_2O_3.—The oxide, which contains exactly half as much oxygen as chromic acid, is prepared from the

bichromate of potass by heating it in a crucible alone, or along with sulphur, to a full red heat, and afterwards washing the contents of the crucible with water, and drying them.

854. The bichromate, heated alone, yields the oxide in dark-green crystals of great beauty. The product is not so beautiful, but is twice as abundant, when sulphur is used. The oxide is employed in painting and glass-staining. As procured by the processes described, it is anhydrous, and insoluble in acids. It is obtained hydrated by raising a solution of bichromate of potash mixed with muriatic acid to the boiling-point, and adding alcohol in small quantities at a time, till the liquid changes from orange to green. The alcohol deprives the chromic acid of half its oxygen, reducing it to the oxide which forms with the hydrochloric acid, the sesquichloride of chromium, Cr_2Cl_3. From this liquid caustic potass precipitates the hydrated oxide of a dull blue colour. Hydrosulphuret of ammonia has the same effect, acting on salts of chromium as it does on those of aluminum, precipitating the oxide of the metal, and not a sulphuret. By these characters dissolved salts of chromium are readily recognised. A dry salt of chromium is most easily identified by fusing it with nitre, so as to observe the change from green or purple to yellow, which attends the conversion of the metal into chromic acid, and the consequent formation of chromate of potass, as mentioned under chrome iron ore.

855. *Chromic Acid*, CrO_3.—This acid is obtained almost pure by mixing a cold saturated solution of bichromate of potass with half as much again of oil of vitriol. The sulphuric acid combines with the potass, evolving much heat, and the chromic acid separates in beautiful red crystals as the liquid cools. Chromic acid is exceedingly soluble, and cannot be brought into contact with organic matter, owing to the readiness with which the latter deprives it of half its oxygen. It is employed to bleach palm-oil preparatory to its conversion into soap.

856. The salts of the acid are more important than itself. The chromate and bichromate of potass have already been referred to. The chromate of lead, a bright yellow substance, largely used in the arts, is produced by precipitating a solution of acetate of lead by bichromate of potass. If the chromate of lead be boiled with lime-water, or fused with nitre, half the chromic acid is transferred to the alkaline base, and a subchromate of the metal, of a beautiful orange-red or vermilion colour, is left.

857. Chromate of silver, AgO,CrO_3, is produced by mixing solutions of bichromate of potass and nitrate of silver. It is

a purplish-brown powder, which, when crystallised from its solution in dilute nitric acid, is of a splendid ruby-red colour.

858. The chromate of mercury is brick-red.

859. *Chlorochromic Acid*, $CrO_2 + Cl$.—This interesting compound is made by mixing equal weights of bichromate of potass and common salt, and distilling them, along with oil of vitriol, in a glass retort provided with a receiver. The substance in question rises as a deep-red vapour somewhat resembling nitrous acid, but redder in colour, and condenses into a heavy liquid like bromine in appearance.

860. The vapour of chlorochromic acid is more irritating to the lungs than chlorine, and excites violent coughing even in the most healthy persons. If dropped upon sulphur or alcohol, it sets them on fire. It is at once decomposed by water.

HEAVY METALS, OR METALS PROPER.—I. METALS NOT PRECIPITABLE IN THEIR ACID SOLUTIONS BY SULPHURETTED HYDROGEN—ZINC, IRON, MANGANESE, COBALT, NICKEL.

Zinc.

Symbol, Zn; *equivalent*, 32·52.

861. Zinc occurs in nature chiefly as calamine stone, the native carbonate of the protoxide, ZnO,CO_2, and as zinc-blende, ZnS, the sulphuret of the metal.

862. The carbonate is reduced by mixing it with coke or charcoal, and exposing it in peculiarly-constructed crucibles to a red heat. The carbonic acid of the ore is expelled by the high temperature, and the charcoal removes the oxygen of the metallic oxide, forming carbonic oxide. The zinc rises in vapour, and distilling over, is received in water.

863. Zinc-blende is first roasted—that is, heated in a current of air, which burns away its sulphur, and converts it into oxide, and the latter is then treated like the calamine stone.

864. Zinc is a bluish-white metal, which slowly tarnishes in the air to a slight depth, in consequence of superficial oxidation, and is then protected by this film from further tarnishing.

865. The density of this metal is between 6 and 7. At ordinary temperatures, unless perfectly pure, it is highly crystalline and brittle; but if heated to about 300°, it becomes quite malleable, and may be rolled out into sheets, as it now is extensively, being cheaper than lead and tin, for which it is substituted. It melts at about 800°, and at a red heat rises

in vapour, taking fire in open vessels, and exhibiting a rich green flame, somewhat resembling that of phosphorus when burning in a limited supply of air, but of a finer green. This appearance may be readily observed by heating zinc in a Hessian or fire-clay crucible in a common grate till the zinc begins to burn. It must be occasionally stirred, so as to secure the free admission of the air necessary for its combustion. The zinc, as it burns, is converted into a white flock-like substance, to which the alchemists gave the name of philosophers' wool. It is the protoxide of zinc carried up in the current of warm air.

866. Zinc is largely consumed, as a substitute for lead, in roofing houses, and instead of tin-plate for the construction of milk-pails and similar vessels. It is much employed, also, in the manufacture of galvanic batteries ; and in combination with copper, as the important alloy brass, is of extensive application in the arts. It is interesting to the chemist as the ordinary source of hydrogen, which it furnishes when dissolved in the dilute acids. Its salts, also, are employed in the arts, and largely in medicine.

867. *Oxide of Zinc*, ZnO.—Zinc forms but one oxide, closely resembling magnesia in appearance and properties. It is prepared by burning the metal in air ; by heating the carbonate till the carbonic acid is expelled ; or by adding caustic potass to the solution of a salt of zinc, such as the sulphate, when the oxide is precipitated as a gelatinous, white hydrate, ZnO,HO. If excess of alkali be added, the oxide of zinc, like alumina in similar circumstances, dissolves, forming a clear solution.

868. When the oxide of zinc is exposed to a low red heat, it becomes yellow ; but when it cools to the ordinary temperature, it recovers its original white colour.

869. *Salts of Zinc.*—SULPHATE OF ZINC, $ZnO,SO_3 + 7HO$. —This salt, it will be remembered, was the residue of the process for hydrogen by the solution of zinc in diluted sulphuric acid. The sulphate is used to a considerable extent in medicine.

870. CHLORIDE OF ZINC, $ZnCl$, is prepared most conveniently by dissolving zinc in hydrochloric acid. The metal combines with the chlorine, and hydrogen is evolved. The dry salt is highly deliquescent, and soluble in water and alcohol. An aqueous solution of it is extensively employed as an antiseptic and disinfectant. Wood saturated with it is said not to suffer from the dry rot ; and it arrests the decay of animal matters, and decomposes offensive gases, such as the sulphuretted hydrogen of hydrosulphuret of ammonia, so

as to prove of service on board crowded ships, in hospitals, &c.

871. *Tests of Zinc.*—A solution of sulphate of zinc is to be prepared, which must be free from iron. If it give a black precipitate with hydrosulphuret of ammonia, and a brown one with caustic potass, iron is present. Most commercial specimens of sulphate of zinc contain this impurity; and if a pure specimen cannot be obtained, a solution must be prepared by dissolving the oxide of zinc in diluted sulphuric acid.

872. To the dissolved salt of zinc a few drops of pure muriatic acid are added, and three wine-glasses are half filled with it.

1. To the first, solution of sulphuretted hydrogen is added. It will produce no precipitate. This property is common to zinc, and all the metals of the division to which it belongs. Its importance will appear hereafter.

2. To the second glass, hydrosulphuret of ammonia is added. It produces a white precipitate of sulphuret of zinc, the only white sulphuret known.

3. To the third glass, caustic potass is added, drop by drop. The first additions of the alkali occasion a white precipitate of oxide of zinc. The succeeding additions redissolve this, so that the liquid becomes clear again.

873. The second and third tests, it will be observed, produce the same effect upon a salt of zinc as they do upon one of alumina. The potass solution from 3 is divided into two portions:—To the one (4), solution of muriate of ammonia is added. It produces no precipitate. This proves the salt not to be one of alumina. To the other portion (5), solution of sulphuretted hydrogen is added. It throws down a white precipitate of the sulphuret of zinc. This proves the salt to be one of zinc.

874. There are besides two blowpipe tests:—

1. The sulphate of zinc, or any other dry salt of the metal, is mixed in the state of powder with carbonate of soda, and heated on charcoal in the reducing flame of the blowpipe. The charcoal becomes encrusted with a yellow powder, which changes to white when it cools. This appearance is owing to the production of oxide of zinc, and is characteristic of the metal.

2. A more easily-tried, and more striking blowpipe test, is to moisten a salt of zinc with solution of nitrate of cobalt, and heat it in the outer flame. It acquires a rich green colour.

Iron.

Equivalent, 28; *symbol*, Fe.

875. Iron occurs native to a small extent, uncombined with any other substance. Thin veins of the metal are found traversing certain rocks, only, however, in quantities sufficient to be objects of curiosity. Iron also occurs so pure as to be malleable in many of those remarkable bodies the meteoric stones, in association with nickel and other metals, but with a mere trace of non-metallic matter.

876. The economical sources of this metal, however, are its native oxides and carbonate, which form its most abundant ores.

877. Magnetic iron ore, or the black oxide Fe_3O_4, is abundant in various parts of the world. It can be easily reduced to the metallic state by heating it simply with coke or charcoal, and the iron which it yields affords a much finer steel than that furnished by the metal reduced from the more complex ores which abound in this country.

878. The red oxide of iron also, Fe_2O_3, called by mineralogists Haematite, when it occurs pure, is as easily reduced, and as valuable an ore, as the black oxide.

879. The most abundant and important, however, of the iron ores is the clay iron-stone, which consists of the carbonate of the protoxide of iron associated with clay, the carbonates of lime, magnesia, and manganese, as well as coaly matter. This ore contains, on an average, about 30 per cent. of metallic iron. It requires a much more complex process for its reduction than the native oxides. The clay iron ore is first roasted or calcined, during which process it parts with any water it may contain, and with the carbonic acid and coaly matter. The roasted ore is then introduced into a blast furnace (fig. 62), which resembles in construction a conical or domed chimney, fifty or sixty feet in height, and about sixteen in diameter within at the widest part. The ore, and the materials required for its reduction, are introduced by the top; and a

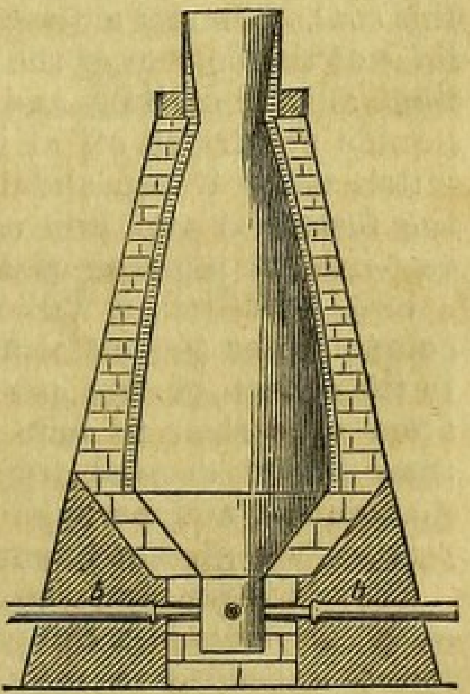

Fig. 62.

high temperature is maintained by forcing in air (*b b*) near the bottom of the furnace through the medium of an air-pump, fanners, or any other convenient form of blower. At one time cold air was employed for this purpose, and the furnace was fed with coke; but within the last few years an immense improvement has been effected by heating the air before it is driven into the furnace. The air is raised in temperature by being made to traverse a series of tubes heated by a fire, and arranged between the blowing apparatus and the furnace. It is thus heated to between 600° and 700°, which is found the most suitable temperature. This is called the *hot blast*. It enables the iron-master to substitute raw coal for coke, and effects a saving of more than three-fourths of the coal which was requisite when the cold blast was employed.

880. Along with the calcined iron-stone and fuel, limestone is introduced into the furnace. The object of this addition is to detach the clay (silicate of alumina) from the oxide of iron, so as to permit the fuel to act upon the latter. This the lime does by combining with the clay, so as to form a fusible glassy compound (the silicate of lime and alumina).

881. The oxide of iron, freed from the clay, readily parts with its oxygen to the fuel, and in one part of the furnace is believed to be present in the state of pure or malleable iron; but as this descends, it unites with the white-hot carbon of the coal, forming a fusible carburet of iron, which accumulates at the bottom of the furnace in the liquid state, with the fluid silicate of lime and alumina floating above it. These liquids are drawn off at intervals by different apertures; the latter, when it consolidates, forms the slag of the furnaces; the former is run into channels of sand, and constitutes the cast-iron, or pig-iron of commerce.

882. Cast-iron, it will be observed, is not pure iron, but a compound of the metal with carbon. The latter occurs in it to the extent of five per cent. or more, which is nearly one atom of carbon to four of iron. Besides carbon, however, some silicon, derived from the silica of the clay, as well as manganese, and perhaps also calcium, magnesium, and aluminum, are present in small quantity in cast-iron.

883. It is possible also that the rare metal titanium is present. Crystals of a compound of titanium are very frequently found imbedded in the slags within the blast-furnaces, when any circumstance leads to these being blown out.

884. Cast-iron differs from malleable iron in being much more fusible, in possessing a highly-crystalline structure, and in being greatly more brittle. Liquid cast-iron expands in

becoming solid, and in consequence takes very sharp impressions from a mould, its increase in bulk causing it to insinuate itself into the finest lines, and so to present a faithful copy of each. This fact is not to be confounded with another, which has led to its being denied—namely, that an iron casting is always smaller than the wooden fac-simile, or original, from which its mould was made. This diminution of size is owing to the contraction of the iron *after* it has consolidated. It has swelled up into every crevice of the mould, however, before contraction commences.

885. Malleable iron is prepared in this country from cast-iron by depriving the latter of carbon. The process by which this is done is called *puddling*. This is effected in a reverberatory furnace—that is, one somewhat resembling a baker's oven, where the current of burning gases proceeding from the hot fuel is reflected or made to reverberate downwards from the arched roof of the furnace to the floor, so as to expose a body lying on the latter to a great sheet of flame and of hot air. (See fig. 63.)

886. The cast-iron is laid in the bed of the furnace, where it speedily melts, and becomes partially oxidised at the surface. The workman then, by means of a long iron rod, or large oar-like spatula, puddles the melted metal—that is, stirs it up, so as to bring each portion of it successively to the surface. The object of the whole process is to convert the carbon of the cast-iron into carbonic oxide, and as the removal of the carbon proceeds, jets of that gas are seen burning on the surface of the metal with its characteristic blue flame. Water is sometimes sprinkled on the melted mass, or oxide of iron or of manganese is added to supply oxygen more speedily to the carbon.

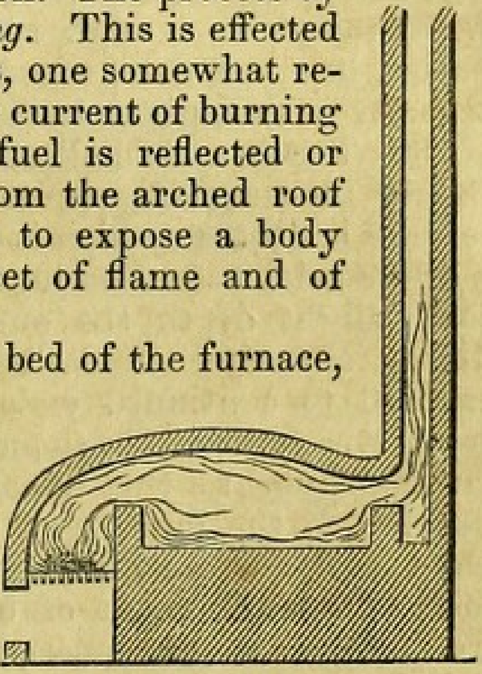

Fig. 63.

887. One marked effect of the withdrawal of the carbon from the cast-iron is the diminution of its fusibility, so that although the temperature of the furnace remains unaltered, the metal ceases to be liquid, and becomes first pasty, and then, as the stirring or puddling is continued, granular—that is, like coarse-grained sand. The temperature of the furnace is now rapidly raised, till the sand-like particles of metal begin to grow pasty, and to agglutinate, a property of iron referred to already under welding. The workman, then, with his puddling-rod gathers together the particles of iron into

large balls, which are removed from the furnace, and exposed on suitable anvils to large tilting or steam-hammers, driven by machinery. These squeeze out of the balls, as from a sponge, any portion of the cast-iron still liquid within them, and at the same time weld the particles of iron together into one solid coherent mass. The block of iron thus procured is heated a second time, and passed between large iron rollers, furnished with grooves, which convert the mass into a long rod or bar. Iron which is to sustain a great strain, such as that for anchor shanks, or the axles of railway carriages, undergoes this process several times, the long bar being cut into several short ones, which are tied side by side with iron wire, raised to a high red heat, forged on the anvil, and passed between the grooved rollers again and again. Great tenacity is thus given to the metal.

888. The bar or malleable iron thus procured is not crystalline in structure, or nearly so brittle as cast-iron. Its texture is fibrous, which is well seen by immersing a wire in a dilute acid, and allowing the latter to act till it dissolves to some slight depth the outer surface. The toughness and fibrous character of malleable iron slowly disappear if it be exposed to continued violent concussion, in consequence, as is believed, of the development of a crystalline structure, so far analogous to that which is always present in cast-iron. Several of the dangerous accidents on our railways which have resulted from the breaking of carriage axles, are referred to such a development of brittle crystalline structure in the iron of the axle, in consequence of the concussions to which it is exposed during the rapid motion of a railway train.

889. The malleable iron of commerce is never quite free from carbon, and contains in addition, to about one-half per cent. of it, small quantities of silicon and the various metals present in cast-iron. (See par. 882.)

890. Malleable iron is converted into steel by adding carbon to it, to a smaller extent, however, than it occurs in cast-iron. Only the purest iron, reduced from its native oxides, is employed for this purpose. Bars of this iron are placed in alternate layers with charcoal powder in iron boxes, and the whole exposed to a high red heat for forty or fifty hours. At the end of that period the iron, without having undergone fusion, is found to have combined with about one and a-half per cent. of carbon. For its finer applications, the bars of steel are welded together under the tilting hammer, which gives the steel greater uniformity of composition and texture; and for the finest cutting instruments, it is melted, cast into ingots, and afterwards forged.

891. Steel is much less fusible than cast-iron, but much more so than malleable iron. It is, on the other hand, inferior to the latter in malleability.

892. The most important character of steel is the property it possesses of acquiring great hardness and elasticity, if raised to a high temperature, and then rapidly cooled, as by plunging it into oil or cold water. The steel at the same time becomes very brittle. If, on the other hand, it be slowly cooled from a red heat, it becomes soft, like malleable iron, loses its brittleness and elasticity, and does not readily take or keep a sharp edge.

893. By varying the temperature to which it is raised, and the rapidity with which it is cooled, it may be obtained of all degrees of hardness, from that given to files, which will scratch glass, down to that of a pallet-knife or spatula. Articles of steel are generally forged and cooled quickly. They are then heated a second time to a temperature which is the higher the softer the steel is intended ultimately to be, and from this temperature they are permitted to cool slowly. This is called the *tempering* of steel.

894. Pure iron, which is very rarely seen, has, when polished, a white colour and brilliant lustre. Its specific gravity is between 7 and 8. It can be rendered magnetic by various processes, but does not retain its magnetism if pure. The addition of oxygen, sulphur, and carbon in certain proportions renders it susceptible of permanent magnetism.

895. Iron does not rust in dry air, but becomes rapidly oxidised if moistened, or under water, at the expense partly of the oxygen of the dissolved air, partly of the water, which it can decompose if carbonic or any other acid be present. The circumstances under which iron decomposes water have been discussed under hydrogen.

Compounds of Iron.

896. *Oxides.*—There are three well-known oxides of iron, and perhaps a fourth—

Protoxide,	FeO
Sesqui or Peroxide,	Fe_2O_3
Black Oxide,	Fe_3O_4
Ferric Acid,	FeO_3

897. The last is still doubtful, and is unimportant. The black oxide has already been referred to as the magnetic iron ore. (See par. 877.) It is the substance produced when iron wire is burned in oxygen, and it may be obtained by other

processes. Though named as a separate oxide, it may be represented as a compound of the two oxides first mentioned, or $FeO + Fe_2O_3$. It is occasionally called, accordingly, the proto-peroxide of iron.

898. *Protoxide.*—The protoxide of iron is an important compound, from the many salts it forms with acids. It is not easily obtained pure, owing to its great affinity for oxygen, and its proneness to pass into the peroxide. To procure it, a solution must be freshly prepared by dissolving clean iron wire in diluted sulphuric acid in the cold. When caustic potass is added to this solution, a precipitate falls of the hydrated protoxide, FeO,HO, which is first white, then green, then gray; and if boiled with water, out of contact with the air, becomes quite black; if exposed to the air, it becomes reddish brown, from absorption of oxygen and conversion into the hydrated sesquioxide. The salts which this oxide forms have all, when pure, a pale-green colour.

899. *Peroxide.*—The peroxide or sesquioxide of iron, Fe_2O_3, has been already referred to as an ore of iron (see par. 878). When anhydrous, it is red; when hydrated, it is brown. It is often called the red oxide of iron. It is procured anhydrous by calcining green vitriol, the sulphate of the protoxide. As mentioned under Nordhausen sulphuric acid (see par. 547), the protoxide of this salt becomes peroxide, at the expense of one-half of the sulphuric acid of the sulphate, which it reduces to the state of sulphurous acid. It is obtained as a hydrate by adding water of ammonia to a solution of green vitriol, which has been boiled with a little nitric acid till its colour changed from green to brown. The alkali throws down the oxide as a reddish-brown precipitate.

900. It forms salts with acids, which are all of a brown colour.

901. *Chlorides.*—There are two chlorides of iron—the protochloride, $FeCl$, prepared by dissolving iron in cold diluted hydrochloric acid; and the perchloride, Fe_2Cl_3, corresponding to the peroxide, and prepared by dissolving it in the acid just named.

902. *Iodides.*—There are two similar iodides of iron; the proto-iodide, FeI, made by digesting iodine and iron-filings with water. It is used in medicine. The periodide, Fe_2I_3, is unimportant.

903. *Sulphurets.*—The protosulphuret, FeS, has been already referred to under sulphuretted hydrogen (see par. 558), in the preparation of which it is largely consumed in the laboratory.

904. The bisulphuret, FeS_2, to which there is no corre-

sponding oxide, has also been described under sulphur and alum. (See pars. 538 and 839.)

Salts of the Oxides of Iron.

905. Both the protoxide and peroxide of iron form, as already mentioned, salts with acids; so that, for example, we have a sulphate of the protoxide and a sulphate of the peroxide; and in like manner two nitrates.

906. To distinguish these two classes of salts from each other, without employing so long a title as, for example, sulphate of the protoxide of iron, sulphate of the peroxide of iron, the salts are simply named protosulphate, and persulphate of iron; the prefix not referring directly to the proportion of the acid in the salts, but to the composition of their component oxide. All the salts of the peroxide, in virtue of the law mentioned under alumina, contain for each equivalent of base three equivalents of acid. (See par. 837.)

907. The protosulphate of iron, FeO,SO_3+7HO, has already been sufficiently referred to under Nordhausen sulphuric acid and alum.

908. The persulphate, $Fe_2O_3,3SO_3$, is prepared by adding to the protosulphate, dissolved in water, half as much sulphuric acid as it contains already. The solution is then raised to the boiling-point, and nitric acid is added, drop by drop, as long as the liquid darkens. It is then evaporated to dryness, and redissolved.

909. The protonitrate of iron, FeO,NO_5, is unimportant.

910. The pernitrate, $Fe_2O_33NO_5$, is used in dyeing.

911. The protocarbonate of iron, FeO,CO_2, has been already referred to as a constituent of clay ironstone. It is prepared artificially by adding a solution of carbonate of potass or soda to the dissolved protosulphate of iron. It then shows itself as a whitish-green precipitate, which, if dried, parts with its carbonic acid, and absorbs oxygen, becoming converted into the hydrated peroxide.

912. The protocarbonate is soluble in water containing much carbonic acid, and exists in this state in many of the chalybeate waters, which are distinguished by their inky taste, and the rust or ochre which they deposit when exposed to the air.

913. The peroxide of iron forms no salt with carbonic acid.

914. *Tests for Iron in Combination.*—The same tests act differently with iron, according to its state of combination; a salt of the peroxide, for example, giving a different-coloured precipitate from that produced with a compound of the pro-

toxide. We accordingly distinguish tests for a protosalt of iron, from those for a persalt. A protosalt is either a salt of the protoxide, or a compound having a composition similar to that of the oxide, such as the protochloride, FeCl. All protosalts of iron are green.

915. A persalt either contains the peroxide, or resembles that oxide in composition, such as the perchloride, Fe_2Cl_3.

916. *Tests for a Protosalt of Iron.*—Protosalts of iron are with difficulty prevented from absorbing oxygen, and passing in part into the state of persalts, in which case they do not act distinctly with the tests. It is best, therefore, to prepare, shortly before use, a solution, by digesting clean iron wire in diluted sulphuric acid. Portions of this are to be put into test glasses, and the following tests, which, to avoid repetition, are understood to be taken in solution, made use of as follows:—

1. To the first glass sulphuretted hydrogen is added. No precipitate.

2. To the second, hydrosulphuret of ammonia. A black precipitate of the protosulphuret of iron, FeS.

3. To the third, caustic potass. A whitish-green precipitate, FeO,HO, changing first to gray, and finally to brown.

4. To the fourth, ferrocyanide of potassium (the yellow prussiate of potass). A bluish-white precipitate, gradually changing into dark blue (Prussian blue).

5. To the fifth glass, ferridcyanide of potassium (red prussiate of potash). A deep-blue precipitate (a variety of Prussian blue).

917. *Tests for a Persalt of Iron.*—The persulphate, $Fe_2O_3,3SO_3$, or the perchloride, Fe_2Cl_3, may be taken indifferently as specimens of a persalt. The one or other is dissolved in water, and treated with the same tests as the protosalt.

1. Sulphuretted hydrogen produces a white precipitate, consisting of sulphur, evolved from the sulphuretted hydrogen, the hydrogen of which has united with the oxygen of the peroxide, or the salt radical (for example, chlorine) of the persalt.

2. Hydrosulphuret of ammonia. A black precipitate of the sulphuret of iron, FeS (not Fe_2S_3).

3. Caustic potass. A brownish-red precipitate of the hydrated peroxide.

4. Ferrocyanide of potassium. A deep-blue precipitate.

5. Ferridcyanide of potassium. A brown colour, but no precipitate.

Manganese.

Symbol, Mn ; *equivalent,* 27·67.

918. Metallic manganese is put to no use, and is known only as a chemical curiosity, obtained with difficulty by heating oxide of manganese with charcoal. Several compounds of the metal are used in the arts, and are objects of chemical interest.

919. *Oxides.* There are no fewer than seven oxides of manganese. Of these, however, two are unimportant. The remainder have the following composition :—

Protoxide,	MnO
Sesquioxide or Deutoxide,	Mn_2O_3
Peroxide, Binoxide, or Black Oxide,	MnO_2
Manganic Acid,	MnO_3
Hypermanganic Acid,	Mn_2O_7

920. *Protoxide.*—The protoxide is obtained anhydrous by heating its carbonate in a stream of hydrogen gas. It appears as a green powder. It is better known in the state of hydrate, as obtained by precipitating one of its soluble salts by an alkali. It appears then as a white substance, rapidly becoming buff-coloured, and then brown, owing to absorption of oxygen from the air.

921. *Sesquioxide,* Mn_2O_3.—This body is the brown substance into which the hydrated protoxide changes by exposure to the air. It is a much weaker base than the corresponding oxide of iron, or than alumina; but it can unite with acids, such as the sulphuric, and form salts.

922. *Peroxide,* MnO_2.—This oxide has already been referred to under oxygen and chlorine. It occurs native abundantly, and is largely consumed in the preparation of bleaching powder, as well as for other purposes.

923. *Manganic Acid,* MnO_3, is obtained in combination with potass by heating in a crucible the black oxide of manganese, along with that alkali and a little nitrate or chlorate of potass. The peroxide, MnO_2, by combining with an equivalent of oxygen, becomes manganic acid, MnO_3. This afterwards unites with the alkali, forming the manganate of potass, KO,MnO_3. This substance goes by the name of *mineral chameleon,* in consequence of the curious changes in colour which it undergoes when dissolved in water. The student should prepare it for the sake of observing these.

924. Mineral chameleon is of a green colour, and if dissolved in a small quantity of cold water forms a beautiful dark-green solution. If this be slowly diluted with a large

quantity of water, the green begins to exhibit shades of red, and various tints, produced by the intermixture of red, green, and blue, successively appear, till ultimately the liquid acquires a deep purple colour. These changes occur much more rapidly if the manganate of potass, dissolved in a little cold water, be afterwards diluted with the same liquid at the boiling temperature.

925. *Hypermanganic Acid*, Mn_2O_7.—The purple liquid obtained by the action of hot water on mineral chameleon is a solution of the hypermanganate of potass, KO,Mn_2O_7. Its production from the manganate is attended by the separation of hydrated peroxide of manganese, which appears as a brown powder, and subsides.

926. Three equivalents of manganic acid contain altogether 3 atoms of manganese and 9 of oxygen. One of the atoms of manganese separates along with two atoms of oxygen as the peroxide, whilst the remaining seven atoms of oxygen, along with the two of manganese, form an equivalent of hypermanganic acid; in symbols, $3MnO_3 = MnO_2$ and Mn_2O_7.

927. *Chloride of Manganese*, $MnCl$.—This salt is left as the residue of the process for chlorine when hydrochloric acid and the black oxide of manganese are used. It is always, however, contaminated by iron, from which it may be purified in various ways. The simplest, perhaps, is to evaporate the impure liquid completely to dryness, and then to heat it to low redness in a gallipot or crucible. By this process the iron is either expelled as the volatile perchloride, or changed into the insoluble peroxide, so that when the heated mass is digested in water, only the chloride of manganese dissolves. Its purity from iron may be ascertained by adding to the liquid the ferrocyanide of potassium, which should produce a pinkish-white, and not a blue precipitate. If the latter appears, iron is present. To get rid of it, a portion of the solution has carbonate of soda added to it, as long as it occasions a precipitate, which is in greater part the carbonate of manganese. This carbonate is boiled with the original liquid, and deprives it of iron by converting the latter into the insoluble peroxide. From the pure chloride the other salts of manganese are prepared.

928. TESTS FOR MANGANESE.—A solution of the pure chloride of manganese is divided amongst three test-glasses, and the following tests are added:—

1. Sulphuretted hydrogen. No precipitate.
2. Hydrosulphuret of ammonia. A flesh-coloured precipitate of sulphuret of manganese, MnS. It changes to a dark-brown when exposed to the air, but as originally produced is

quite peculiar in tint, and distinctive of compounds of manganese.

3. Potass produces a precipitate of the hydrated protoxide, MnO,HO, which is first white, then buff-coloured, and finally dark-brown. These appearances, also, are quite distinctive of manganese salts, and no more tests than the three given are necessary for the recognition of dissolved proto-salts of the metal.

929. There are also two blowpipe tests applicable to any manganese compound.

1. The salt or other compound of manganese is mixed with carbonate of potass or soda, and melted in the loop of a platina wire at the outer flame of the blowpipe, when mineral chameleon is produced, easily recognised by its green colour. This test is very delicate.

2. The experiment is repeated with the substitution of borax for carbonate of soda. A clear, transparent bead is obtained of a violet colour. It becomes colourless if exposed to the inner blowpipe flame. Manganese in the state of oxide is the colouring matter of the amethyst, and is employed to give glass a violet tint.

Cobalt and Nickel.

930. Cobalt and nickel are two metals having the same general characters as the others of the group which has been discussed. Both are used in the arts, but they are not of sufficient chemical interest to call for detailed notice. The equivalent of cobalt is 29·52; symbol, Co. Reference has already been made to the employment of the nitrate of cobalt in blowpipe testing. It gives with salts of alumina, when exposed to the outer blowpipe flame, a deep blue: with salts of zinc a green, and with salts of magnesia a pale rose or pink colour. Its protoxide stains glass of a deep blue. It is largely employed for this purpose and for colouring porcelain. Compounds of cobalt are very easily detected by mixing them with borax, and heating them in the outer blowpipe flame. A transparent bead of an intense blue colour is produced.

931. A solution of cobalt forms sympathetic ink. When concentrated, its solution is rose-coloured, but if sufficiently diluted, characters written with it on paper are invisible when dried in the air. If the paper, however, be heated, or otherwise strongly dried, they appear of a deep blue. The characters again become invisible if removed from the source of heat, or cause of dryness, owing to the absorption of moisture. The changes in colour depend upon the fact, that the anhy-

drous chloride of cobalt is blue, whilst the same salt hydrated is of a pale rose colour.

932. The equivalent of nickel is 29·57; symbol, Ni. Its chief importance is in the manufacture of the substitutes for plate, which are sold under the name of German silver, nickel silver, &c. They consist of copper, zinc, and nickel, combined in different proportions. The salts of nickel have all a rich green colour in solution. They are readily distinguished from other bodies by giving—no precipitate with sulphuretted hydrogen; a black precipitate with hydrosulphuret of ammonia; a green precipitate with caustic potash, which does not alter in the air; and with ammonia a similar precipitate, which dissolves in excess of the alkali, forming an azure solution.

II. METALS PRECIPITABLE BY SULPHURETTED HYDROGEN, WHETHER THEIR SOLUTIONS ARE NEUTRAL, ACID, OR ALKALINE—COPPER, LEAD, SILVER, MERCURY.

Copper.

Equivalent, 31·66; *symbol*, Cu.

933. Copper is an abundant and valuable metal, and occurs native. Its chief ores are copper pyrites, a combination of the sulphurets of iron and copper, and less abundantly, the carbonate of copper, the most valuable, because the most easily reduced, of all the ores of the metal.

934. Copper is the only red metal. It is nearly nine times heavier than water, its specific gravity being 8·95. It is highly malleable and ductile, and an excellent conductor of heat and of electricity. It does not take a sharp impression when cast in a mould. Our copper coins, accordingly, are not cast, but stamped, and the metal is chiefly wrought with the hammer.

935. In moderately dry air, copper slowly acquires a brown tarnish, which is quite superficial, and is probably owing to the formation of a thin film of suboxide, Cu_2O. In damp air it acquires a green crust, from the formation of the carbonate.

936. OXIDES OF COPPER.—Copper has two oxides, each of which forms salts with acids; the one is the protoxide, and is also called the black oxide, CuO; the other is a suboxide, and is distinguished as the red oxide, Cu_2O.

937. *Protoxide*, CuO.—The protoxide is prepared—

1. By heating sheet copper in a furnace to a red heat, with free exposure to air, till it becomes uniformly black.
2. By raising the nitrate to a red heat in a crucible.

3. By precipitating a salt of the oxide, such as the sulphate, by caustic potass. This gives the hydrated oxide, which is blue; but if the liquid be raised to the boiling-point, it loses water, and becomes dark brown and anhydrous. This oxide, as obtained by calcining the nitrate, is largely employed in organic analysis. Its salts are all green or blue.

938. *Suboxide*, Cu_2O.—This is the first suboxide we have had occasion to notice. For each equivalent of copper there is but half an equivalent of oxygen, so that when we indicate it by symbols, we write it Cu_2O, not $CuO\frac{1}{2}$. It occurs native, of great beauty, in transparent octohedral crystals of a ruby-red colour. It may be obtained artificially, by heating together five parts of the black oxide of copper with four of copper filings, or by boiling a solution of sulphate of copper with caustic potass and honey. The sugar of the honey deprives the protoxide of half its oxygen, and the suboxide precipitates as a brown-red powder. The majority of its salts are colourless, and exceedingly prone, like most salts of lower oxides, to absorb oxygen, and pass into compounds of a higher base. When heated with glass, it gives it a beautiful ruby-red colour, which, however, is somewhat difficult to secure, owing to the readiness with which the suboxide passes by absorption of oxygen into the protoxide, which colours glass green.

939. Sulphate of Copper, Blue Vitriol,

$$CuO,SO_3 + 5HO,$$

is prepared on the large scale by oxidising the sulphuret of copper, or by dissolving the old copper sheathing of ships, after calcination in a furnace, in diluted sulphuric acid. It forms large, regular, blue crystals, twice as soluble in hot as in cold water. This salt is employed in medicine, in dyeing, and in the preparation of pigments.

940. Nitrate of Copper, $CuO,NO_5 + 3HO$.—A deep blue, crystalline, very deliquescent, and corrosive salt. Its chief employment is in the production of the black oxide of copper for organic analysis.

941. Carbonates of Copper.—Combinations of oxides of copper with carbonic acid, in various proportions, occur native, and are wrought as ores, or manufactured into ornamental articles. Malachite, which is cut into slabs like marble, and fashioned into vases, is a subcarbonate, consisting of two equivalents of oxide of copper with one of carbonic acid and one of water. A precipitate of the same composition is obtained by mixing solutions of carbonate of soda and sulphate of copper.

942. **Chloride of Copper**, $CuCl,HO$.—The chloride is prepared by dissolving the black oxide in hydrochloric acid, and concentrating till crystals form. It is soluble in alcohol, and the solution burns with a rich green flame, like that which boracic acid exhibits.

943. **Tests for Copper.**—The salts of the suboxide of copper are rarely met with. The following tests apply to salts of the black oxide, or protosalts. A saturated solution of sulphate of copper is taken, and the following tests are applied to it in as many glasses:—

1. Sulphuretted hydrogen produces a black precipitate of sulphuret of copper, CuS. This test would alone distinguish a salt of copper from salts of all the metals already discussed.

2. Hydrosulphuret of ammonia produces the same precipitate.

3. Potass produces a bright-blue precipitate of the hydrated oxide, CuO,HO, which becomes black when boiled with water.

4. Ammonia in small quantity produces a greenish-blue precipitate, which, when the alkali is added in greater abundance, is dissolved, forming an azure-blue solution.

5. Ferrocyanide of potassium produces a reddish-brown precipitate of ferrocyanide of copper. This test shows best with a dilute solution.

6. If a plate of clean iron or steel be immersed in a solution of the sulphate, or any other protosalt of copper, it is almost immediately covered with a thin layer of metallic copper. This of course is the most decisive of all tests, as the metal itself is seen, and the peculiarity of its colour excludes the possibility of its being confounded with any other.

7. If any salt of copper be mixed with carbonate of soda, and heated on charcoal in the inner blowpipe flame, metallic copper is obtained, of its characteristic colour.

944. From the preceding statements, it will be learned that no metal is more easily detected in combination than copper. The tests are easily applied, and are almost all very delicate.

Lead.

Equivalent, 103·56; *symbol*, Pb (plumbum).

945. Almost the only ore of lead is the sulphuret (galena), which generally contains silver as well as lead, in combination with sulphur. By calcination in a current of air it is converted into oxide, which is easily reduced by fuel.

946. The carbonate (white lead), when it occurs in sufficient abundance, is also wrought as an ore.

947. Lead is a soft blue metal, easily scratched, even by

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the nail, and producing a mark upon paper. It is highly malleable, but not very ductile.

948. Its specific gravity is 11·45. It slowly tarnishes in dry air, and the film of oxide produced protects it from further change. Under the surface of water free from salts, such as rain or distilled water, it becomes rapidly converted into oxide and carbonate, which in part dissolve in the water, and render it poisonous, so that very soft waters cannot be conducted through lead pipes, or kept in leaden cisterns. If the water, however, contain (as spring, well, and river water generally does) sulphates and chlorides, then insoluble salts are formed, which incrust the lead, and prevent the water being contaminated. A minute quantity of saline matter is sufficient to prevent water becoming poisonous by contact with lead.

Oxides of Lead.

Protoxide, PbO; Red Oxide, Pb_3O_4; Peroxide, PbO_2.

949. *Protoxide—Litharge, Massicot,* PbO.—Lead is converted into this oxide by exposing it whilst melted to a current of hot air; likewise by heating the carbonate of lead to low redness. When carefully prepared, and not allowed to fuse, it is of a pale-yellow colour, and is named *massicot;* but if raised to a red heat, it fuses, and crystallises on cooling of a brick-red colour. In this state it is called *litharge.* It forms when boiled with oil the sticking-plaster of the surgeon. It enters largely into the composition of flint-glass, on which it confers brilliancy and fusibility, and it forms a large number of important salts by union with the different acids.

950. RED OXIDE, RED LEAD, Pb_3O_4.—This substance is prepared by heating massicot to low redness whilst a current of air flows over its surface. It is employed chiefly as a pigment.

951. *Peroxide of Lead—Brown or Puce Oxide,* PbO_2, is obtained by pouring dilute nitric acid on red lead; the latter resolves itself into protoxide, which unites with the nitric acid, and peroxide which is left as an insoluble purplish-brown powder.

952. SALTS OF LEAD—*Carbonate of Lead, White Lead,* PbO,CO_2.—The carbonate of lead is the most important salt of lead, from its great consumption in painting. It is used not only as a white pigment, but is mixed with the majority of colours used in house-painting, with a view to confer upon them *body* or *opacity.* In virtue of this quality, which it possesses in a high degree, a thin layer of it suffices to conceal

and cover a previous coating of paint. It has the great disadvantage, however, already referred to, of blackening by sulphuretted hydrogen. The carbonate may be prepared on the small scale by mixing solutions of carbonate of soda and acetate of lead. It is prepared on the large scale with excess of oxide, which increases its opacity.

953. *Nitrate of Lead*, PbO,NO_5.—This salt is readily obtained by digesting lead, its protoxide, or its red oxide in nitric acid, and concentrating till crystals separate. It is interesting chiefly as the source of nitrous acid, NO_4, which it yields along with oxygen when heated.

954. *Acetate of Lead, Sugar of Lead*, $PbO,C_4H_3O_3 + 3HO$.—This salt is referred to here although its acid has not yet been described, because it is the salt of lead most easily procured, and, upon the whole, most suitable for exhibiting the tests of lead. It is prepared by dissolving litharge in vinegar, and receives its vulgar name from its intensely sweet taste, and also, perhaps, from its resemblance in appearance, as usually sold, to loaf-sugar.

955. To avoid repetition, the other compounds of lead will be referred to under its tests.

956. A solution of acetate of lead is to be made with rain or distilled water, and afterwards filtered. To this, in separate glasses, the following tests are to be added:—

1. Sulphuretted hydrogen, and hydrosulphuret of ammonia, precipitate the black sulphuret of lead.
2. Caustic potass if added in small quantity produces a white precipitate of the hydrated oxide, PbO,HO, and if added more abundantly, dissolves this, producing a clear liquid.
3. Carbonate of soda throws down white lead, PbO,CO_2.
4. Sulphuric acid produces a white precipitate of the highly-insoluble sulphate of lead, PbO,SO_3.
5. Hydrochloric acid produces a crystalline white precipitate of the chloride of lead, $PbCl$.
6. Iodide of potassium gives a brilliant yellow precipitate of the iodide of lead, PbI.
7. Bichromate of potass produces a bright yellow precipitate of chromate of lead, PbO,CrO_3.

Silver.

Equivalent, 108; *symbol*, Ag.

957. Silver occurs native as the uncombined metal, as sulphuret, and as chloride. From the latter it is procured by tedious and complicated processes. It is obtained pure for

chemical purposes by the following process, which the student may repeat with any fragment of sterling silver, such as a defaced coin.

958. The metal is dissolved in pure nitric acid, in which it will disappear with great rapidity, causing the evolution of much nitric oxide. The solution will have a green colour, from the copper with which silver is purposely alloyed, and provided the nitric acid has been perfectly free from hydrochloric acid, a small amount of black powder will generally remain undissolved. This is gold, which it was not worth while to separate from the silver when it was reduced from its ore.

959. To the clear liquid which contains the nitrates of silver and of copper, a solution of common salt is added as long as a precipitate falls. This is the insoluble chloride of silver, the copper remaining in solution. The chloride is washed, dried, and melted in a crucible, along with anhydrous carbonate of soda. Chloride of sodium is produced, and metallic silver, which consolidates, after fusion, into a pure brilliant knob or button.

960. Silver is the whitest of the metals, and is excelled by none in lustre.

961. It is one of the best conductors of heat and of electricity, and is preferred to all other metals in the construction of delicate electrical instruments where long metallic wires are required.

962. Silver does not oxidise in air or in water, but it becomes rapidly tarnished from the action of sulphuretted hydrogen upon it. It enters into combination with oxygen when melted with glass, communicating to it at the same time a yellow colour, for which purpose it is employed in glass-staining.

963. *Protoxide of Silver*, AgO.—This oxide is obtained in the state of a hydrate by adding caustic potass to a solution of nitrate of silver. It appears as a pale brown precipitate, which, when dry, is very unstable. Light and heat both occasion evolution of oxygen and separation of metallic silver.

964. The only very important salts of silver are the nitrate and the chloride.

965. *Nitrate of Silver, Lunar Caustic*, AgO,NO_5.—This salt is sold in little sticks about the diameter of a quill, for the convenience of the surgeon. They are produced by fusing the nitrate, and pouring it into moulds.

966. The salt, however, can be readily obtained in crystals by dissolving pure silver in nitric acid, and concentrating the solution.

967. *Chloride of Silver*, AgCl, has already been referred to under hydrochloric acid, and the purification of silver. It is obtained by mixing solutions of any soluble chloride, and almost any salt of silver. When heated, it fuses, and crystallises, on cooling, into a substance resembling horn in appearance and softness.

968. All the salts of silver, when in contact with vegetable or animal matter, blacken when exposed to light. Marking-ink consists essentially of a solution of nitrate of silver thickened with gum, and occasionally, to prevent its corroding action, mixed with ammonia.

969. The beautiful designs produced on paper in different shades of brown, and distinguished as the Talbotype, or calotype, are obtained by saturating the paper with various salts of silver, such as the chloride, bromide, iodide, nitrate, gallate, &c. and then exposing it to the regulated action of light. Wherever the light falls, the paper darkens, owing to the production, as some suppose, of a suboxide of silver; according to others, in consequence of the separation of the metal itself.

970. TESTS FOR SILVER.—

1. A solution of nitrate of silver is taken, and to one portion of it sulphuretted hydrogen is added. It produces a black precipitate of sulphuret of silver, AgS.

2. To a second portion hydrochloric acid is added. It produces a white precipitate of the chloride, AgCl.

971. The liquid containing the curdy chloride is divided into two portions. To the one nitric acid is added. It produces no effect. To the other ammonia. It dissolves the chloride, producing a clear solution.

972. No other tests are requisite for the identification of silver.

Mercury or Quicksilver.

Equivalent, 100·07; *symbol*, Hg (Hydrargyrum).

973. Mercury occurs native uncombined, but more abundantly as sulphuret, forming the ore called cinnabar, which is identical in composition with vermilion, HgS.

974. The metal is procured by heating the cinnabar along with iron turnings or lime.

975. The student may imitate the process on the small scale by mixing vermilion with quicklime in a test-tube, and applying heat. The red colour will rapidly disappear, as the sulphur combines with the calcium of the lime, which gives

off its oxygen, whilst the mercury condenses in globules in the cool part of the tube.

976. Mercury is the only element, except bromine, liquid at ordinary temperatures. From this character, and its silvery colour, it receives its ordinary name of quicksilver. It has, however, a shade of blue.

977. It becomes solid at the temperature of —39° F. It is then soft, ductile, and malleable. It rises in vapour at or rather below 80°, and dangerous accidents have occurred on board ships conveying it from South America, in consequence of leakage of the vessels containing it, and the poisonous action of the mercurial vapour on the crew and living creatures in the vessel.

978. Liquid mercury has the specific gravity (at 60°) 13·56. It contracts greatly when it solidifies, so that the density of frozen mercury is 14.

979. Mercury does not alter in the air in ordinary circumstances, nor does it tarnish, if pure.

980. It forms two oxides, which are generally distinguished by their colour, the lower, which is a suboxide, Hg_2O, being named the gray or black oxide; the higher or protoxide, HgO, the red oxide.

981. The suboxide is prepared by adding caustic potass to its nitrate, Hg_2O,NO_5, or, more conveniently, by shaking together calomel (Hg_2Cl) and lime-water. It is a dark-gray, nearly black, heavy powder, readily decomposed both by heat and by the sun's rays. It forms salts with acids.

982. The red oxide, HgO, also called red precipitate, is procured by heating its nitrate, HgO,NO_5, till the acid is expelled. The oxide is left as an orange-red crystalline body. It is also procured by adding caustic potass or lime-water to a solution of corrosive sublimate ($HgCl$).

983. It appears as a yellow precipitate, paler in colour than the crystallised oxide. It yields pure oxygen when heated, and is employed for that purpose, as mentioned under that gas.

984. *Chlorides of Mercury.*—There are two chlorides corresponding to the oxides—the subchloride, calomel, Hg_2Cl, and the chloride, corrosive sublimate, $HgCl$.

985. Corrosive sublimate is prepared by mixing the sulphate of the red oxide of mercury, HgO,SO_3, with an equal weight of common salt, and applying heat to the mixture contained in a small retort. The chlorine of the chloride of sodium combines with the mercury, forming the chloride of mercury, which rises in vapour, and condenses as a crystalline sublimate. The sodium of the salt remains behind in combination with the oxygen and sulphuric acid previously

united to the mercury. The fixed residue, accordingly, is sulphate of soda. The change may be thus stated in symbols—

$$HgO,SO_3 + NaCl = NaO,SO_3 \text{ and } HgCl.$$

986. Corrosive sublimate is soluble in water, alcohol, and ether. It is a deadly poison, and serious accidents have occurred from its substitution for calomel. It forms an insoluble compound with white of egg, which is administered as an antidote to its poisonous effects.

987. To prepare the subchloride of mercury, calomel, the sulphate of the red oxide has as much metallic mercury as it contains already ground with it in a mortar. Common salt is then added, and the mixture is heated, as the materials for corrosive sublimate were. Calomel, which, as well as the higher chloride, is volatile, rises in vapour, and condenses in crystals.

988. If a sulphate of the black oxide, Hg_2O,SO_3, could be prepared as readily as a sulphate of the red oxide, HgO,SO_3 can, it would be employed in the preparation of calomel. The mechanical mixture of mercury and the higher sulphate is equivalent to a salt of the black oxide, and acts as such when heated with common salt. The most convenient mode of procedure is to take any quantity of mercury, and divide into halves by weight. The one half is boiled with oil of vitriol, till it forms the sulphate of the red oxide. It is then dried and triturated in a mortar with the other half of the quicksilver, and the resulting mixture is sublimed along with an equal weight of salt.

989. Calomel, unlike corrosive sublimate, is quite insoluble in water, and much less poisonous than the higher chloride. The student should be careful when preparing it, or corrosive sublimate, to avoid inhaling the vapours of the volatilising salts, as salivation is readily induced by a small amount of either chloride of mercury when it enters the body by the lungs.

990. It is necessary also to point out that the names of calomel and corrosive sublimate have been frequently changed in consequence of alterations of opinion as to the atomic weight of mercury, some representing it, as is done in this book, as 100 (100·07), others as twice that number. If the atomic weight be made 100, calomel is the subchloride, and corrosive sublimate the protochloride. If 200, calomel becomes the protochloride, and corrosive sublimate the bichloride or perchloride. The protochloride of one person approving of the one atomic weight, thus comes to be the perchloride of another, employing a different equivalent—a circumstance which may lead to the most dangerous results when the chlorides of mer-

cury are purchased for medicinal use, since the fraction of a grain of the higher chloride is a sufficient dose, and a party who had corrosive sublimate given to him instead of calomel would, in the majority of cases, receive a fatal dose. It is best, therefore, to distinguish them by their trivial names of calomel and corrosive sublimate; but if it is deemed necessary to use chemical titles, it will be found safest to call calomel the *sub*chloride, and corrosive sublimate the *per*-chloride, although these are not according to strict theory. For all are agreed that calomel is the lower or *sub* compound of chlorine, and corrosive sublimate the higher or *per* compound; the proportion of chlorine in the former being only half as great as that in the latter.

991. There are two iodides of mercury, corresponding to the chlorides. The higher, HgI, which is the only important one, has been referred to under the tests for hydriodic acid.

992. There are two sulphurets. The lower is unimportant. The higher is the valuable pigment vermilion, which is black as prepared by the full action of sulphuretted hydrogen on a solution of corrosive sublimate, but becomes red when sublimed.

993. There is a nitrate of each of the oxides of mercury. That of the black oxide, Hg_2O,NO_5, is obtained by dissolving mercury in cold diluted nitric acid.

994. The nitrate of the red oxide, HgO,NO_5, is procured by dissolving the metal in strong hot acid.

995. The sulphate of the red oxide, HgO,SO_3, is obtained by boiling mercury and oil of vitriol together till the metal is entirely changed into a crystalline precipitate, which is the salt in question.

996. Tests for Mercury.—Salts of mercury are most conveniently identified by mixing them dry with anhydrous carbonate of soda, and exposing the mixture, contained in a test-tube, to the flame of the blowpipe. In these circumstances, all mercurial compounds, without exception, suffer decomposition, and the metal, rising in vapour, condenses in globules in the cool part of the tube.

997. When the salts of mercury are in solution, a distinction must be made between salts of the black oxide and those of the red. The most easily-prepared salt of the lower oxide is the nitrate, Hg_2O,NO_5.

1. A solution of it will give a black precipitate with sulphuretted hydrogen, or hydrosulphuret of ammonia, Hg_2S.
2. With hydrochloric acid, a white precipitate of calomel, Hg_2Cl.
3. With potass, a black precipitate of oxide, Hg_2O.

998. A solution of corrosive sublimate, $HgCl$, does better than one of a salt of the red oxide to illustrate the method of recognising the higher salts of mercury. It is treated as follows:—

1. To one portion solution of sulphuretted hydrogen is added drop by drop. The first effect is the production of a white precipitate, which, as the addition of the sulphuretted hydrogen is continued, changes first to yellow, then to brown, and finally becomes quite black. The ultimate product is the sulphuret, vermilion, HgS.

2. To another portion caustic potass is added freely. It produces a yellow precipitate of the hydrated red oxide, HgO,HO.

3. To a third portion solution of protochloride of tin is added drop by drop. The first additions produce a white precipitate of calomel; but if the salt of tin is added in excess, the colour of the precipitate changes from white to gray, owing to the separation of mercury in the metallic form. It has no lustre as thus precipitated; but if boiled for some time with muriatic acid, the gray particles aggregate into brilliant globules.

III. METALS WHICH GIVE NO PRECIPITATE WITH SULPHURETTED HYDROGEN IN ALKALINE SOLUTIONS.

Gold.

Equivalent, 98·33; *symbol*, Au (aurum).

999. Gold is probably the most widely-diffused of the metals. It is found in every country, and always in the metallic state, often beautifully crystallised, in the shapes characteristic of the majority of the metals.

1000. The gold-dust of commerce consists of small particles of the metal, which have been washed by streams from their original position in the veins of rocks, and which are diffused through the sands at the bottom of the rivers fed by such streams. By taking advantage of the difference in specific gravity between the gold and the sand, the latter is washed away, and the gold-dust left.

1001. Gold is the only yellow metal. Its specific gravity is 19·5. It does not tarnish in air or water, either by oxidation, or from the action of sulphuretted hydrogen, and it resists the solvent action of all the ordinary acids. A mixture of nitric and hydrochloric acids (*aqua regia*) is generally employed to dissolve it. The solution occurs in consequence of the combination of the metal with the chlorine (set free from the hydrochloric acid) to form a sesqui-chloride.

Chemical

1002. The only important salt of gold is this perchloride, Au_2Cl_3. It may be prepared by solution in the way just mentioned, but more conveniently on the small scale, by suspending gold-leaf in water, and sending a current of chlorine through the liquid. The gold rapidly dissolves, and yields at once a solution without excess of acid.

1003. If the solution be evaporated, it will yield crystals of the chloride, which are very deliquescent, soluble in water, alcohol, and ether, and readily decomposed by heat and light. It stains the skin, or other organic tissues, purple, if they are wetted with its solution, and exposed to light.

1004. When this chloride is cautiously heated, it loses two-thirds of its chlorine, and leaves a subchloride, Au_2Cl.

1005. There are oxides corresponding to both the chlorides, as well as bromides, iodides, sulphurets, &c.

1006. TESTS FOR GOLD.—A solution of the perchloride of gold is prepared as directed :—

1. To one portion a fresh solution of the protosulphate of iron is added. It immediately produces a precipitate, which remains long suspended in the liquid, and appears brown when looked at by reflected light, but bluish-green when the glass containing it is looked through so as to see it by transmitted light. This precipitate is metallic gold. If it be collected on a filter, dried, and rubbed with any smooth body, it will exhibit the characteristic yellow colour and lustre.

2. To a second portion of the perchloride, largely diluted with water, a few drops of solution of protochloride of tin are added. It produces a purple-red precipitate, which has long gone by the name of *purple of Cassius.*

Platinum.

Equivalent, 98·68 ; *symbol*, Pt.

1007. Platinum, or, as it was originally named by the Spanish Americans, platina, in allusion to its silvery lustre,—from the Spanish *plata*, silver—is comparatively a rare metal, found in South America, Russia, and Ceylon, associated with palladium, rhodium, iridium, osmium, and a little iron. It is extracted from this alloy by a complicated process.

1008. The specific gravity of this metal is as high as 21·5. It is infusible, except by the oxyhydrogen blowpipe. It is, however, very malleable and ductile, so that it can be wrought comparatively easily into vessels. It is not tarnished or corroded by air, whether moist or dry. The ordinary acids, and the immense majority of chemical reagents, have likewise no action upon it. Aqua regia alone dissolves it, and caustic potass oxidises it, if fused upon it. It is a metal, accordingly, of the greatest value to the chemist, from its twofold power of resisting high temperatures and chemical action. Crucibles made of it are constantly in use in the performance of analysis (see fig. 64); and although it is some five times more costly than silver, large vessels of platina are employed in the concentration of oil of vitriol.


Fig. 64.

1009. The only important salt of platinum is the bichloride, $PtCl_2$. It is prepared by dissolving the metal in nitrohydrochloric acid (aqua regia), evaporating to dryness, and dissolving the residue in water.

1010. This salt, it will be remembered, enabled us to distinguish the alkalis from each other, and was also a test for salts of hydriodic acid. (See pars. 633 and 727.)

1011. A salt of platinum, such as the chloride in question, is readily recognised by its giving, with muriate of ammonia, a yellow precipitate, which, when heated to redness, leaves the metal in the state of a black powder. In this state it is called spongy platinum. It can be obtained in a state of still finer division, when it is called *platinum-black*. This is procured by adding sugar and an excess of carbonate of soda to solution of the bichloride of platinum. The liquid is then slowly raised to 212°, with occasional shaking. The metal separates as a black powder, which is washed, and dried on a filter. It will be referred to under Acetic Acid, in the department of Organic Chemistry. (See par. 1039.)

Tin.

Equivalent, 58·82; *symbol*, Sn (stannum).

1012. Tin occurs in nature chiefly in combination with oxygen, as tinstone, which, when pure, is the peroxide of the metal, SnO_2; but it is generally associated with other metals, and with sulphur.

1013. Tin is, next to silver, the whitest of the metals. Its density is a little above 7. It is soft and malleable. A bar of it, when bent, produces a peculiar creaking or crackling sound. It tarnishes very slowly and slightly by exposure to the air, and is little acted on by dilute acids or reagents. It is peculiarly suitable, accordingly, for cooking vessels, in the construction of which it is much employed. Ordinary tin-plate is sheet-iron coated at the surface with tin. Copper also is frequently covered on one side with it.

1014. Salts of Tin.—The most interesting salts of tin are the chlorides. The protochloride, SnCl, is prepared by dissolving tin in hot hydrochloric acid. It may be obtained in crystals, but is generally kept in solution. It is interesting as a test for mercury and for gold.

1015. The perchloride or bichloride, $SnCl_2$, is prepared by dissolving tin in aqua regia. It is largely used in dyeing. Compounds of tin resemble those of alumina in their power to fix organic colours on textile tissues. Each of these chlorides, when precipitated by carbonate of potass, yields a corresponding oxide, the carbonic acid escaping.

1016. The protoxide, SnO, is unimportant.

1017. The peroxide, SnO_2, is white when hydrated, and pale yellow when anhydrous. In the latter state it is employed by jewellers in polishing, under the name of putty powder. It is also used to render glass white and opaque, as in the preparation of the enamel for the dials of watches.

1018. TESTS FOR TIN.—A solution of protochloride of tin may be taken to represent a protosalt of the metal.

1. Sulphuretted hydrogen, or hydrosulphuret of ammonia, produces in it a dark-brown or black precipitate of the protosulphuret, SnS.

2. Potass, a white precipitate of hydrated protoxide, SnO,HO, which is soluble in excess of the alkali.

3. Perchloride of gold produces the purple of Cassius. (See Gold.)

4. Corrosive sublimate, a white precipitate, turning to gray. (See Mercury.)

1019. The perchloride, and other persalts of tin, give—

1. With sulphuretted hydrogen, or hydrosulphuret of ammonia, a yellow precipitate of bisulphuret of tin, SnS_2.

2. Potass, a white precipitate of the hydrated peroxide, soluble in excess of alkali.

1020. Both proto and per salts of tin, when mixed with carbonate of soda, and heated in the inner blowpipe flame, yield metallic tin, which is distinguished from other white metals by being converted into a white powder (peroxide of tin) when strong nitric acid is dropped upon it.

Antimony.

Equivalent, 129·03; *symbol*, Sb (stibium).

1021. Antimony occurs in nature in combination with sulphur, SbS_3. This sulphuret, which is its only ore, yields the metal readily when heated with iron, which combines with the sulphur.

1022. Antimony is a brilliant metal, of a bluish-white colour, highly crystalline, and very brittle, so that it is easily powdered.

1023. Its specific gravity is 6·8. It does not oxidise at ordinary temperatures, but it is readily combustible when heated, burning into the oxide, SbO_3.

1024. It forms with oxygen three oxides—oxide of antimony, SbO_3; antimonious acid, SbO_4; and antimonic acid, SbO_5. The first of these is the only important compound of the series. It is prepared by the combustion of antimony, also by roasting the sulphuret in a current of air. The oxide in this case is impure.

1025. By combination with acids it forms salts, of which the most important is the tartrate of potass and antimony (tartar emetic), which is prepared by boiling the oxide with a solution of cream of tartar (the bitartrate or acid tartrate of potass). The liquid, on concentration, yields crystals, consisting of one atom of potass, one atom of oxide of antimony, and one of tartaric acid, besides water; in symbols—

$$KO,SbO_3,C_8H_4O_{10}+2HO.$$

1026. *Chloride.*—The chloride of antimony, $SbCl_3$, is prepared by dissolving the metal in hot hydrochloric acid. The anhydrous salt is volatile, highly corrosive, and very deliquescent. Hydrochloric acid dissolves it, and when the solution is dropped into water, a white precipitate appears, consisting of chloride and oxide (oxichloride) of antimony. This is one of the characters by which salts of antimony are known.

1027. *Sulphuret.*—The sulphuret of antimony, as it occurs native, is a dark-gray crystalline solid, but as obtained by the precipitation of tartar emetic by sulphuretted hydrogen, it is of an orange colour, and it may be deprived of water without losing this tint; but if strongly heated, it becomes black, without any change in composition.

1028. TESTS FOR ANTIMONY.—To observe these, a solution of tartar emetic should be taken.

1. To one portion sulphuretted hydrogen is added. It produces an orange-red precipitate of sulphuret, SbS_3, the only sulphuret of this colour. The precipitate is collected on a filter, washed, and gently dried. It is then transferred to a test-tube, and a few drops of hydrochloric acid added. Sulphuretted hydrogen is given off, and terchloride of antimony ($SbCl_3$) formed. If the liquid be poured into water, a white precipitate appears. These tests are sufficient to characterise a soluble salt of antimony.

1029. Another method of identifying the salts of this metal is to add zinc and sulphuric acid to their solution. The hydrogen gas which is given off separates the antimony, and combines with it, forming a gaseous compound, Sb,H_3. If this be set fire to whilst issuing from a glass jet, such as that used in the case of pure hydrogen, or if the gas be made to pass along a narrow glass tube placed horizontally, and heated red-hot by a spirit-lamp, the antimony will be deposited as a thin metallic coating. (See fig. 69, par. 1038.)

1030. A second process is to heat the salt of antimony (such as dry tartar emetic), mixed with carbonate of soda, on charcoal in the inner flame of the blowpipe. Globules of the metal will easily be obtained. That the metal obtained by both methods is antimony, may be proved by dissolving it in hot hydrochloric acid, and observing the white precipitate which the chloride gives with water, and the orange precipitate with sulphuretted hydrogen.

Arsenic.

Equivalent, 75; *symbol*, As.

1031. Arsenic is a steel-gray metal, having a brilliant lustre when first obtained, but soon losing its splendour if exposed to the air. It is nearly six times (5·9) heavier than water.

1032. It is not known in the liquid form, for when its crystals are heated, they change directly into a colourless gas, and condense again into crystals, provided air be excluded. If exposed to the air when raised in temperature, it combines with its oxygen, forming arsenious acid, AsO_3; and when this is heated with nitric acid, a second oxide is formed, called arsenic acid, AsO_5. There are corresponding sulphurets, chlorides, &c. all highly poisonous. To avoid repetition, we shall include the description of the more interesting of these in the statement of the process by which the most important arsenical compounds—namely, arsenious acid—is detected.

1033. In trying the following experiments, great care must be taken to avoid tasting or inhaling the vapours of any of the arsenical compounds. All papers containing arsenic in any form, or bottles containing its solutions, should be carefully labelled, and kept out of the way of children and servants.

1034. Arsenious acid, with which we begin, is known also by the names *white oxide of arsenic*, *white arsenic*, and simply *arsenic*, which last term the chemist applies only to the metal. Arsenious acid consists of one atom of the metal and three of oxygen, AsO_3. It is sold in the shops as a powder, which is white, heavy, and gritty. With it the following experiments may be tried:—

1. As much of it as will lie on the tip of a penknife blade is placed at the bottom of a dry, wide, test-tube (fig. 65), and slowly heated by a small spirit-lamp held at the shut end. The arsenious acid changes into a colourless, inodorous vapour, and ascending in the tube, condenses in small, regular crystals, which are quite unlike those of any other white sublimate. They are distinguished by their great brilliancy and play of colours, which rival those of the diamond, and likewise by their shape, which, when perfect, is that of the regular octohedron. Entire crystals can seldom be seen, but if the sublimate be examined with a magnifying glass, equilateral triangular faces may readily be observed; and this is enough, for no crystals except regular octohedrons possess faces bounded by equilateral triangles.

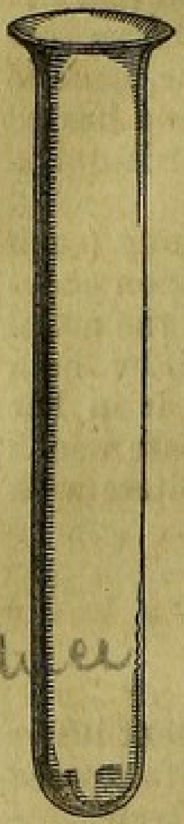

Fig. 65.

to reduce it

2. A second portion of the arsenious acid is mixed with dry charcoal powder, and anhydrous carbonate of soda, or, still better, simply with cyanide of potassium (see par. 1212), and placed at the bottom of a tube such as is shown in fig. 66. The mixture is introduced on a small slip of paper, so as not to soil the sides. The tube is then very gently moved backwards and forwards over a spirit-lamp, so as to expel moisture, and the drops of water which collect are wiped away by a roll of blotting-paper. The bulb is now heated to redness, when the metallic arsenic, deprived of its oxygen by the charcoal, or cyanide of potassium, rises in vapour, and condenses in the narrow neck above the bulb. Here it forms a brilliant ring of a dark-gray colour as seen through the glass, but on its inner surface of a lighter tint, and rough from the projection of crystalline points.

3. The narrow neck containing the ring of arsenic is cut off by a file, and introduced into a wide test-tube, which is then heated over a spirit-lamp. The small tube rapidly becomes empty and transparent, as the arsenic rises out of it in vapour, and meeting with abundance of air, combines with its oxygen to form arsenious acid, which condenses in its characteristic brilliant octohedral crystals in the cool part of the tube.

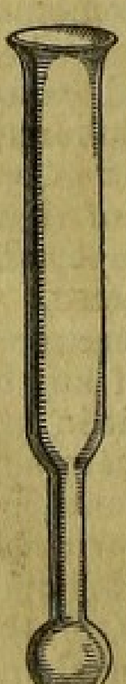

Fig. 66.

4. A third portion of arsenious acid is boiled for some time with water and a little hydrochloric acid, and the liquid is then filtered. It is a saturated solution of arsenious acid. Three test-glasses are half filled

with this solution. 1. To the first, sulphuretted hydrogen is added. It produces a bright-yellow precipitate of sulphuret of arsenic, AsS_3. This body is also called orpiment, and is the basis of the pigment king's yellow, which is frequently used to poison flies, but is too deadly a substance to make its employment advisable for this purpose in places where children can have access to it. 2. To the second glass a solution of nitrate of silver, which has been mixed with a little ammonia, is added. It produces a primrose-yellow precipitate of the arsenite of the oxide of silver, AgO,AsO_3. 3. To the third glass a solution of sulphate of copper, with which a little ammonia has been mixed, is added. It produces a bright green precipitate of the arsenite of copper, CuO,AsO_3, known also as Scheele's green.

1035. These tests are amply sufficient for the identification of arsenious acid, when it is obtained in the state of a powder, or dissolved in a colourless liquid; but in coloured solutions, such as tea, coffee, or porter, the liquid tests would be of no value. The following process is adopted for such liquids, and is also applicable to colourless solutions. To illustrate its application, solution of arsenious acid may be added to coffee or porter. The liquid is then transferred to a flask, and a little hydrochloric acid, and some small pieces of copper wire, or copper leaf, or thin sheet copper, added to it. The contents of the flask are then raised to the boiling-point, and kept at this temperature for some time. The copper separates the arsenic in the metallic form, and combines with it, becoming at the same time of a dark-gray or black colour. This effect may be best observed with a colourless solution of arsenious acid. The pieces of blackened copper are removed from the flask, washed with a little water, and gently dried. They are then introduced into a narrow test-tube, and heated (fig. 67), when the metallic arsenic abandons the copper, and rising in vapour, forms such a ring as has already been described. The part of the tube containing the arsenic may then be cut off, and transferred to a wider tube, where its conversion by heat into arsenious acid may as before be observed.

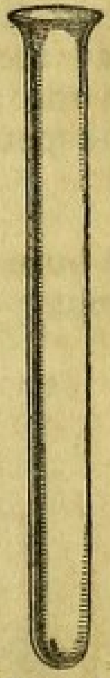
Fig. 67.

1036. A little water may then be boiled in the tube with a drop or two of hydrochloric acid, and the solution (of arsenious acid so procured) divided into three portions, tested with sulphuretted hydrogen, the ammoniated nitrate of silver, and the ammoniated sulphate of copper.

1037. Arsenic forms a compound with hydrogen, called arseniuretted hydrogen, AsH_3. It is the most poisonous of all the compounds of arsenic, and has already occasioned the death of three chemists who were experimenting with it. It must therefore be prepared and examined cautiously. To obtain it, zinc and sulphuric acid are added to an aqueous solution of arsenious acid contained in a bottle, with a glass jet passed through a cork which fits its neck. Fig. 68 represents an apparatus sold for the preparation of arseniuretted hydrogen. A piece of zinc is placed at the bend, and the acidulated solution of arsenious acid poured in. The stopcock is kept open till the air is chased out, and then closed. The gas accumulates in the shorter limb of the syphon, and forces the liquid past the zinc into the longer tube. In this way evolution of gas ceases, when the liquid and zinc are separated from each other. When the stopcock is opened, the liquid returns from the long limb, and reproduces gas, forcing out what had accumulated. The hydrogen combines with the oxygen of the arsenious acid, producing water, and thereafter with the metal, to form the gas in question.

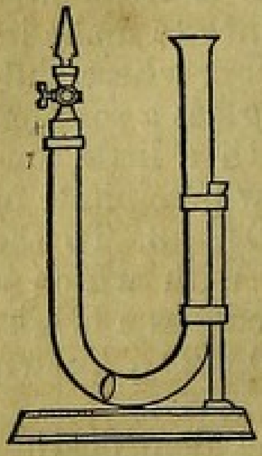

Fig. 68.

$$6H + AsO_3 = 3HO, \text{ and } AsH_3.$$

It burns with a grayish-white flame, producing a thick white smoke, which is arsenious acid; but if a cold body, such as a piece of porcelain, be pressed down upon a burning jet of the gas, the metal itself is deposited in a thin film. This experiment should be tried either in the open air or with the bottle from which the gas is issuing standing on the hob of a grate.

1038. In this way complex liquids are frequently examined as to the presence of arsenious acid in them. Pure zinc and sulphuric acid are added, and the gas which is evolved is passed through a horizontal tube heated by a spirit-lamp. (See fig. 69.) This occasions the separation of metallic arsenic (if it be present), which condenses in the tube a little in front of the flame. It is proved to be arsenic by the tests already given.

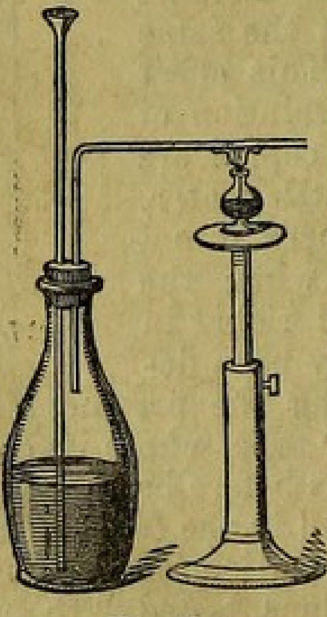

Fig. 69.

1039. Arsenic acid, AsO_5, is soluble in water, and gives a reddish-brown precipitate with nitrate of silver, which is highly characteristic. Films of metallic arsenic are sometimes identified by heating them with nitric acid, which converts them into arsenic acid, easily recognised by the reddish-brown precipitate of arseniate of silver, AgO,AsO_5, which it gives when added to a solution of nitrate of silver.

⁂ The process for detecting arsenic by means of copper and hydrochloric acid (par. 1035) is called Reinsch's test or process. That by means of zinc and sulphuric acid (par. 1038) is named Marsh's process. A third process, applicable to complex liquids, consists in passing sulphuretted hydrogen through them as long as it occasions a precipitate of sulphuret of arsenic (par. 1034, 4), and then heating this with cyanide of potassium or carbonate of soda in the way arsenious acid is directed to be treated (par. 1034, 2, 3, and 4). This process is applicable to coloured liquids, such as coffee or porter, where the colour of the sulphuret cannot be seen, but it is not superior to Reinsch or Marsh's processes.

ORGANIC CHEMISTRY.

1040. Organic Chemistry is that department of the science which considers the substances which occur in the structures of plants and animals, as well as the compounds derived from those primary structural components. It is called *organic* because plants and animals consist of certain organs—that is, instruments or apparatus, in connection with which alone life is manifested. Thus a plant is made up of such organs as roots, leaves, flowers, fruit; an animal of such as limbs, eyes, heart, brain.

1041. Organic chemical compounds, then, are, in the first place, such compounds as enter into the construction of the different organs of plants and animals, as well as such substances as are produced during the living action of these organs.

1042. The flesh of an animal, for example, and the wood of a tree, are examples of organic chemical compounds, and so are the sugar, gum, starch, oil, &c. which are produced and deposited in various tissues of the plant. The blood and milk of animals are in like manner organic chemical compounds, or rather mixtures of many of these. The new compounds, moreover, which are produced by the changes which occur in substances primarily derived from organized structures are also called organic. Thus no plant or animal produces alcohol, but it is the product of a peculiar change which sugar, an organic product, undergoes. Alcohol, accordingly, is classed among organic compounds.

1043. Again, by the action of powerful reagents, such as the acids and alkalis, on organic products, new substances are produced, which are also ranked among the objects of organic chemistry. Thus a large class of fragrant liquids, known as the ethers, are produced by the action of the different acids upon alcohol. Organic chemistry, then, may thus far be defined to be the chemistry of those compounds which are directly or indirectly derivable from plants and animals, and only from them.

1044. A sharp line of demarcation cannot be drawn between organic and inorganic compounds, considered in relation to their source. The same substance, indeed, may be classed among both. Carbonic acid, for example, when evolved from heated limestone, is an inorganic product; and when produced during the respiration of animals, is an organic one. It is never, however, named an organic compound, because the action of living organs is not essential to its production. This important peculiarity, indeed, belongs to the immense majority of organic compounds, that they cannot be formed artificially from their ultimate elements. They must either be derived *ready-made* from plants and animals, or deduced from such ready-made substances, which are, as it were, the essential raw material of the more complex organic compounds. Thus, although sugar contains nothing but carbon and the elements of water, we are quite unable to combine those bodies into sugar; and in like manner, when we wish to produce alcohol, we are compelled to have recourse to sugar as the raw material out of which to develop it by fermentation. This is one great reason why the department of organic is kept distinct from that of inorganic chemistry.

1045. The prevailing element in organic compounds is carbon, then oxygen, then hydrogen, lastly nitrogen. Two or three, or all of these elements, make up the greater part of the majority of organic compounds; but although this is the case, it must not be forgotten that small quantities of other elements, especially sulphur, phosphorus, chlorine, fluorine, potassium, sodium, magnesium, calcium, and iron, are also found very frequently in association with the first four.

1046. The predominance of carbon in their composition confers upon organic compounds a common character of combustibility in the open air, which may be said to characterise them. When they are heated, on the other hand, without free access of air, as in retorts or test-tubes, their excess of carbon remains unburnt, and is left as a black mass, so that they exhibit the phenomenon of charring. This appearance is not presented by every organic substance, at least by merely heating it in a narrow-mouthed vessel, but it occurs with a very large number of the compounds in question, and every substance which chars when heated is entitled to a place among organic compounds. It may be considered, therefore, a convenient though not a universally-applicable proof of a body being an organic compound.

1047. Organic chemistry presents us with many examples of a remarkable phenomenon which has not hitherto been referred to, because it is of comparatively rare occurrence among inorganic compounds.

1048. In general, each of the latter contains its constituent elements in a proportion in which they occur in no other substance. This, however, is not invariably the case; and among organic bodies we find many examples of a body containing not only the same elements, but the same proportion of elements, as another, and yet differing from it totally in properties.

1049. Bodies which present this character are said to exhibit *isomerism*, from the Greek ισος (isos), equal; and μερος (meros), part—the whole term signifying equiproportionality (or equality of ratio) of elements. In other words, bodies which are isomeric contain the same proportion of the same elements. Thus cane-sugar and gum-arabic each contain $C_{12}H_{11}O_{11}$.

1050. One large class of the essential oils, among which are oil of lemons, and of turpentine, contain C_5H_4.

1051. At first sight, it seems impossible that two bodies should differ so much in character as gum and sugar do, and yet contain exactly the same proportion of the same elements. The fact admits so far at least of an explanation, if we suppose the two bodies to contain their elements differently arranged, so that the function of the same constituent is different in each compound. The one body is thus like an anagram on the other; and as the letters in a word acquire a different significance according to their places in it, so the atoms in a compound will give it different characters according to their mode of arrangement. Thus *ape* and *pea*, on the one hand, *ate*, *eat*, *tea*, on the other, have the same alphabetical elements, but the difference in the disposal of the letters totally alters their verbal value. There is reason to believe that similarly, whilst the formula for gum may be written $C_{12}H_{11}O_{11}$, that of sugar is $C_{12}H_9O_9 + 2HO$.

1052. In the volatile oils, on the other hand, although we have in each 5 atoms of carbon for 4 of hydrogen, we have good grounds for inferring that each of the oils has a different equivalent; so that though all have the same proportion of the same elements, the combining quantity of each—that is, its atomic weight—is different. Thus one may contain C_5H_4, another $C_{10}H_8$, another $C_{20}H_{16}$, and so on. The following table of a series of isomeric bodies, all containing carbon and hydrogen in the proportion of one atom of the one element to one of the other, but all exhibiting multiples of the lowest conceivable numbers, C H, will illustrate this:—

	Equivalents.
Olefiant gas, ...	$C_4\ H_4$
Gas from oil, . . .	$C_8\ H_8$
Naphthene, . . .	$C_{16}\ H_{16}$
Cetene, ...	$C_{32}\ H_{32}$

1053. Isomeric bodies of the last class may be likened to words which, as compared with each other, contain the same letters arranged in the same way, but a different number of these letters. Thus in the words *ma*, *mama*; *tar*, *tartar*; *do*, *dodo*, we have in each couple the same syllable, but the second contains it twice as often as the first.

1054. The discussion of organic compounds, which follows, is commenced with the consideration of the constituents of food. These admit of a simple and convenient division into those which contain nitrogen, and those which do not. The former are termed the azotised or nitrogenous, and the latter the non-azotised or non-nitrogenous, ingredients of food. The azotised are also called the albuminous, and the non-azotised the amylaceous, principles of diet. The latter are considered first, in virtue of their greater simplicity of composition: the name of the group is taken from one of its members, *starch*, in Latin *amylum*.

NON-AZOTISED OR AMYLACEOUS PRINCIPLES OF FOOD.

1055. Four remarkable substances, of each of which there are several varieties, occur largely in vegetables, and are important constituents of the food of animals. These are gum, lignine, starch, and sugar. They may all be represented as consisting of charcoal and water. In other words, they consist of carbon, hydrogen, and oxygen, and of each of the two last elements there is the same number of equivalents, or eight times as much oxygen by weight as hydrogen:—

Gum.

1056. There are probably several varieties of gum, but two have been specially noticed: the one, of which the gum-arabic of the shops is a good example, quite soluble in cold water, and named *Arabine*; the other, of which an example is found in gum tragacanth, softening only and becoming gelatinous when digested with water. It is called *Tragacanthine*.

1057. Gum-arabic occurs in irregular semi-transparent, yellowish-white masses, which have concreted from the liquid state in which they exuded from the tree. Its solution in water is generally called mucilage. It is precipitated by solution of sub-acetate of lead, and also by the addition of alcohol, in which gum is totally insoluble. By this character the gummy exudations of trees are distinguished from those which are resinous, the latter being quite soluble in alcohol.

1058. Gum-arabic has the composition $C_{12}H_{11}O_{11}$.

Lignine.

1059. Lignine, from the Latin *lignum*, wood, is the name given to the woody fibre of plants when perfectly purified. Fine linen or cotton may be taken as a nearly pure example.

1060. Vegetable fibre consists of an arrangement of cells filled with what, when dry, forms the chief part of the ligneous tissue. The substance forming the walls of the cells has been named *cellulose*. It has the composition $C_{12}H_{10}O_{10}$, whilst that of the matter encrusting the walls, which some alone call lignine, is $C_{35}H_{24}O_{20}$; the hydrogen not being in the proportion to form water. Hay and straw, which form so large a part of the winter food of the larger domesticated animals, are variable mixtures of cellulose and lignine.

1061. Lignine—by which we signify, according to its wider meaning, vegetable fibre, including, under the term, cellulose and the so-called lignine—if mixed with strong oil of vitriol, and left for some hours exposed to its action, is converted into a substance closely resembling gum, or starch in its more soluble modification (dextrine). The experiment may be tried by triturating in a mortar shreds of linen with half their weight of oil of vitriol. The mixture is to be left for some hours, then diluted with water, and afterwards gently warmed and filtered. Chalk is added to the clear liquid to remove the sulphuric acid, and the liquid filtered a second time. If it be raised to the boiling-point before the chalk is added, and kept at that temperature for some hours, whilst water is from time to time added to supply the loss by evaporation, the linen is entirely converted into grape-sugar.

1062. There is reason to believe that lignine undergoes changes similar to those just mentioned, in the digestive organs of the horse, cow, sheep, &c.

1063. A substance of great interest in connection with lignine is gun-cotton. To prepare it, a mixture is made in equal volumes of nitric acid of density 1·5, and of oil of vitriol. In this, after it is cooled, cotton wool is immersed, and moved about with a glass stirrer till it is thoroughly soaked with the acid. It is then removed and washed in a stream of water till every trace of acid is gone, and afterwards dried cautiously at a steam heat, or in small quantities before a fire. It is now ready for use.

1064. Gun-cotton has a harsh, rough feeling, unlike the original fibre. Its composition is $C_{12}H_7O_7 + 3NO_5$. It is soluble in sulphuric ether, and the solution has been recommended as an application to wounds. If spread over a cut, the lips of which are held together, the ether rapidly evaporates, leaving the gun-cotton like a thin piece of plaster holding the sides of the wound together. The gun-cotton adheres with great tenacity, and has the advantage of being quite insoluble in water.

1065. The most interesting property, however, of this substance is its explosibility. In illustration of this the following experiments may be tried:—

1. A small ball or pellet of gun-cotton is laid upon an anvil, or other smooth hard surface, and struck with a hammer. It will detonate sharply, like fulminating mercury.

2. A lock of the gun-cotton is touched with a hot wire. It will burn away with great rapidity, showing a yellow flame, and leaving scarcely a trace of ashes.

3. This experiment may be repeated with the gun-cotton lying on the hand. The experiment is quite safe; the looseness of the texture of the explosive cotton, and its rapid combustion, prevent its burning the skin.

4. A lock of gun-cotton may be laid on a little gunpowder, and fired by a hot wire. It will not kindle the powder.

5. A lock may be dipped in water, slightly dried between the folds of a towel, and touched with a hot wire. Its combustibility will be found scarcely impaired.

6. Gun-cotton may be employed, like gunpowder, to charge firearms of any description. The weight of the cotton taken should be about a third of that of gunpowder necessary to charge the weapon, and it should be rammed down with a wooden (at least not with a metal) ramrod. It may be fired by a match or percussion-cap, exactly like gunpowder.

7. If gun-cotton be soaked in a solution of chlorate of potass, and then dried, its combustibility is increased, and it burns with a faint violet flame.

8. Tow, sawdust, muslin, and other tissues of which lignine is the basis, may all be rendered explosive by preparing them like the gun-cotton.

1066. Great caution must be used in drying explosive cotton and the similar preparations, and it must be experimented with only in small quantities, for fatal accidents have occurred both in making and employing it.

Starch.

1067. Starch or fecula probably occurs in every plant. It is obtained from many seeds, such as those of the cereal plants or grasses (wheat, oats, barley). It is abundant in the pea, and is found also in many roots, such as those of the potato, the arrow-root, cassava, &c. It is extracted also from the stems of certain palms, and exists in the woody tissue of the birch, the willow, and other trees which are occasionally had recourse to as sources of food in seasons of scarcity by the inhabitants of the countries where they grow.

1068. The most important varieties of fecula are wheat and potato starch. The former is obtained by permitting coarse wheaten flour to stand under water till it grows sour. The acid developed along with the water dissolves all the constituents of the flour except the starch and bran, which subside, and are separated from each other by means of a sieve.

1069. A considerable quantity of starch is now prepared from rice-flour by exposing it to the action of a very dilute solution of caustic soda, which acts on the flour as the acid does in the other process.

1070. Starch may be prepared on the small scale from wheaten flour by a mechanical process. A spoonful of flour is tied up in a piece of linen, and compressed by the fingers under water as long as the latter becomes milky. The milkiness is owing to the separation of the starch, which passes along with the water through the apertures in the linen, and very slowly subsides.

1071. Potato starch may be prepared on the small scale, in imitation of the manufacturing process, by rubbing a sliced potato on a grater, whilst a small stream of water falls upon it. The starch is washed through, and may be collected by subsidence, and dried.

1072. Arrow-root is procured by a similar process from a plant named the *Maranta arundinacea*. Sago is the starch of the sago palm. Tapioca is obtained from the root of the cassava plant, which is abundant in South America. Both these varieties of starch owe their peculiar appearance in rounded semi-transparent grains, and their solubility in cold water, to the treatment which they undergo after their separation from the plant. They are stirred, whilst moist, over a fire till they assume the condition of spherical granules, and at the same time, in consequence of the high temperature inducing a modification of the starch, to be presently noticed, it acquires solubility in cold water.

1073. The most prominent characters of starch are its total insolubility in cold water, whilst boiling water converts it into a mucilaginous liquid, which forms a jelly on cooling. In its gelatinous condition starch gives a blue precipitate with iodine, as noticed under that substance. Gelatinous starch is occasionally called *amidine*. If boiled for a long time with water, and still more quickly if acids or alkalis be present, amidine is converted into a substance closely resembling gum, to which the name of *dextrine* has been given. The change is marked by the solution ceasing to be gelatinous, and becoming limpid and transparent. Sago and tapioca consist in whole or in part of amidine and dextrine. *British gum*, largely used in calico-printing, is dry starch heated in an oven till it acquires a brown colour, and becomes soluble in water. It consists in greater part of dextrine.

1074. Dextrine, when boiled for some time with water and a small quantity of acid, is converted into sugar. The experiment succeeds best with sulphuric acid, and may be made with wheat or potato starch, of which 3 parts may be taken to 12 of water, and 1 of acid. The starch will be converted first into amidine, then into dextrine, and after some hours' boiling, into that variety of sugar which is found in the grape. The liquid is then neutralised by chalk, filtered, mixed with animal charcoal (which decolorises it), and boiled down to a small bulk. It is then filtered a second time, and placed aside in a shallow vessel, where it slowly consolidates into a crystalline mass of grape sugar.

1075. This curious conversion of starch into dextrine and sugar occurs in all germinating seeds and buds, and in roots such as the hyacinth, or tuber of the potato, when sprouting; and by rendering the starch soluble in the water absorbed by the growing germ, makes it available in the sap for the development of the plant. The change is induced by a peculiar substance, to which the name *diastase* is given. It is not found in the seed or bud till it begins to germinate, and appears to be developed from the nitrogenous or azotised constituent of the germ (gluten or albumen), which will be referred to in the next section.

1076. Diastase is procured from malt, but not in a state of purity. Barley is *malted* by exposing it whilst moist in a warm place till it begins to sprout, and then drying the sprouted seed to prevent further growth. Malt, unlike the original barley, has a sweet taste, in consequence of much of the original starch having been converted into sugar, the production of which is the chief object of malting. At the same time a large amount of diastase is developed. No method is known by which it can be obtained in a state of purity, but its curious power of altering starch may be observed by making an infusion of ground malt in warm (not boiling) water, and adding this to several times its volume of the thickest gelatinous starch. The mixture is then to be raised to the temperature of about 170°, but not higher, and kept there for some hours. In a very short time the liquid will become quite limpid from the conversion of the starch into dextrine, and at the end of some hours very sweet, from the change of the latter into sugar.

1077. The first stage of brewing, or what is called the mashing of the malt, is exactly such a process as we have described, and has for its object the development of a maximum of sugar from the malt. The second stage of brewing will be referred to under alcohol.

1078. In the preparation of whisky from barley, the cost of malt can to a great extent be avoided, in consequence of this saccharifying power of diastase. A certain portion only of the grain is malted, and this suffices to convert the starch of ten or twelve times its weight of raw grain into sugar.

1079. The part which starch plays in nourishing animals will be referred to in another section.

Sugar.

1080. The term sugar is applied vaguely to any sweet substance of animal or vegetable origin; but a convenient distinction is made by dividing saccharine substances into those which are fermentable (or which yield alcohol and carbonic acid, when treated with yeast) and those which are unfermentable. The chief fermentable sugars are cane sugar, grape sugar, and milk sugar. The more important unfermentable sugars are manna, sugar of liquorice, of gelatine (glycocoll), and of oils (glycerine).

1081. **CANE OR ORDINARY SUGAR**, when crystallised, has the composition $C_{12}H_{11}O_{11}$. It occurs in the juice of many plants, but less abundantly than grape sugar does. It is prepared as an article of food from the beet-root, which is cultivated for that purpose in France. In North America it is obtained from the sugar-maple by boring a hole to a short depth in the wood in the spring, when the sap is ascending in large quantity to supply the young leaves, and in Ceylon from the juice of the cocoa-nut palm; but the sugar-cane is by far the most abundant source. The general principle of preparation is the same, whatever plant is employed to yield it. The sugar-cane, for example, which is extensively cultivated in both the Indies and in South America, is crushed between rollers. The expressed juice, mixed with a little slaked lime, to neutralise some free acid, is rapidly evaporated in open pans till it is sufficiently concentrated. The liquid is then transferred to shallow vessels, where it is occasionally stirred. It separates into a mass of crystals more or less brown, which form the raw, brown, or Muscovado sugar of commerce, and into a dark thick syrup, which cannot be crystallised, and is known by the name of treacle or molasses. The raw sugar is purified in this country by dissolving it in water, adding to it white of egg, or the clear liquid (serum) of bullock's blood, and then raising it to the boiling-point. The albumen of the egg or blood coagulates, forming a skin or membrane which envelops the mechanical impurities, and carries them to the top or bottom with it. The syrup is then filtered hot through animal charcoal, which deprives it of colour, as mentioned under that substance. The colourless liquid is afterwards concentrated to the crystallising point in shut pans, from which the vapour is constantly drawn off by means of an air-pump, whilst they are heated by steam. In this way the temperature of the syrup never rises above 150°, so that all risk of its boiling over or becoming browned by burning is completely avoided. Various new processes for the preparation of sugar have been proposed recently, and are at present undergoing trial.

1082. The crystallisable liquid drawn off from the pans, if left at rest, allows large crystals to form. Threads are hung in the liquid as points of attachment for the crystals, which, as thus procured, form sugar-candy.

1083. The greater part, however, of the crystallisable syrup is purposely stirred, so as to prevent large crystals from forming. It concretes, accordingly, into grains, like those of salt or brown sugar. These are transferred to hollow cones of clay, which have a small aperture in the point or apex, and after each mould has been filled with sugar, it is put in a warm place with the apex downwards, and left there for some days, till a portion of treacle, which the purifying processes have not removed, has drained away. The complete removal of the treacle is secured by percolating a strong solution of pure syrup through the mould or shape, so that it shall sink through the sugar and drive the treacle before it. The mould is then allowed to dry, when its contents consolidate into a crystalline mass, such as we see in a sugar-loaf.

1084. Sugar is very soluble in water, sparingly so in alcohol. It is quite permanent in the air. Two pieces struck together in the dark evolve a pale beautiful light.

1085. Dry sugar, when heated, melts into a clear transparent liquid, which solidifies into a pale yellow glassy mass. This is barley-sugar. More strongly heated, sugar becomes of a dark-brown colour. It is known by the names of burnt sugar or *caramel*, and is used for colouring spirits.

1086. GRAPE SUGAR.—This variety of sugar is much more widely distributed in the vegetable kingdom than the last. It is occasionally called *sugar of fruits*, *sugar of starch*, and *glucose*, from the Greek adjective γλυκυς (glucus), sweet. It contains the elements of one atom more of water than cane sugar, its composition being $C_{12}H_{12}O_{12}$, after it has been heated to 212°. In its ordinary condition, it contains two atoms more of water, and is $C_{12}H_{14}O_{14}$. It is most conveniently prepared from the grape or raisin, or in this country from honey, of which it forms the more solid portion. Concreted honey, well washed with alcohol, may be taken to represent this variety of sugar. We have mentioned already the interesting processes by which starch and lignine can be converted into grape sugar.

1087. It is less soluble in water than cane sugar, and not nearly so sweet. It crystallises slowly, and never in large crystals. Considerable quantities of it are now prepared from potato starch, chiefly, however, with a view to its conversion into spirit.

1088. Grape sugar may be distinguished from cane sugar in the following way :—A solution of cane sugar is made, and one of grape sugar; or, in defect of the latter, a solution of honey will suffice. Each liquid is placed in a test-tube, and a little solution of sulphate of copper is added to it. Solution of caustic potass is afterwards poured in till the precipitate which it first produces is redissolved. Both test-tubes are then heated by a spirit-lamp. The blue liquid in the one containing the grape sugar rapidly becomes nearly colourless, at the same time yielding a precipitate which is first of a dirty green, then scarlet, and finally dark-red. This is the red or suboxide of copper. The liquid containing the cane sugar remains blue, yielding only a trifling red precipitate.

1089. Sugar of Milk, or Lactine.—This interesting variety of sugar is contained in milk in a state of solution, and is obtained in white crystals by evaporating whey, and purifying the sugar by digestion with animal charcoal, and repeated crystallisation. It is not manufactured in this country, but considerable quantities of it are prepared in the Swiss dairies, and it reaches us from the continent. It is employed in Great Britain to a small extent as an article of medicine.

1090. Milk sugar readily forms crystals, which are hard and gritty between the teeth, and not so sweet as cane sugar. Its composition is $C_{24}H_{24}O_{24}$. It can be fermented by certain processes into alcohol and carbonic acid.

1091. The Tartars prepare an intoxicating drink called *koumiss* from mares' milk. It owes its inebriating power to alcohol derived from the lactine of the milk.

1092. More commonly, however, milk undergoes another kind of fermentation, in which its sugar is converted into an acid called the *lactic*, which is the cause of the sourness of butter-milk.

1093. MANNA.—The only interesting unfermentable sugar of vegetable origin is manna. It is not, like the fermentable sugars, a hydrate of carbon, its composition being $C_6H_7O_6$. It is an exudation from a species of ash and from some other trees, such as the cherry and plum. It occurs also in some grasses, mushrooms, and sea-weeds, and is produced during the fermentation of certain vegetable juices containing sugar. As it is sold in the druggists' shops, it occurs in soft oblong masses of a yellowish-white colour, possessing a faint, somewhat heavy odour, and a sweet but nauseous taste. From this the pure manna sugar is obtained by dissolving the former in boiling alcohol, and filtering it whilst hot. As the liquid cools, the manna sugar, or *mannite*, as it has been called, separates in small crystals. It is used to a small extent in medicine.

AZOTISED OR ALBUMINOUS PRINCIPLES OF FOOD.

1094. Six interesting substances belong to this division—three derived from the vegetable kingdom, and three from the animal. These are vegetable albumen, fibrine, and caseine; and animal albumen, fibrine, and caseine:—

1095. VEGETABLE ALBUMEN.—Vegetable albumen derives its name from its resemblance to the analogous animal principle—white of egg. It occurs largely in the oily seeds, such as the almond. It is soluble in water, and, like white of egg, is coagulable by heat, by alcohol, by acids, and by solution of corrosive sublimate. In short, it agrees closely in characters with animal albumen.

1096. VEGETABLE FIBRINE.—When wheaten flour is washed in a linen bag, as described under starch, till water ceases to come through milky, there is left behind an adhesive mass, which has been called, from its glutinousness, *gluten*. It consists in greater part of vegetable fibrine, and differs from albumen in being quite insoluble in water. It forms an elastic, tenacious, soft mass, which dries into a body resembling horn. It is soluble in alkalis, and in acetic and phosphoric acid.

1097. VEGETABLE CASEINE OR LEGUMINE.—Vegetable caseine occurs in most plants, but it is most conveniently prepared from leguminous or podded vegetables, such as the pea and bean. It is obtained by diffusing pease-meal through cold water, when the starch sinks to the bottom, and the caseine remains dissolved. Its solution does not coagulate when heated, like one of albumen, but forms a skin or pellicle on the surface, as milk, which contains animal caseine, does in the same circumstances. It is coagulated by the addition of many acids.

1098. Animal Albumen.—Animal albumen is one of the chief soft constituents of animal bodies, in which it occurs in two conditions—namely, soluble in the blood, in the egg, in the humours of the eye, &c.; and insoluble in almost all the solid tissues. It receives its name from the Latin word for white, in reference to its constituting the white of egg, which furnishes it in the condition most convenient for studying its properties. In its pure form it is soluble in water. It contains a little free soda, the existence of which may be demonstrated by dropping white of egg into cabbage infusion, which it turns green. It dries at ordinary temperatures into a brittle, yellow, gumlike mass, which dissolves in water without change of properties; but if raised, whilst liquid, to the temperature of 150°, it coagulates, or becomes solid, and insoluble in water. It is likewise coagulated by alcohol, creosote, most acids except the acetic, and the majority of metallic salts, such as those of lead, copper, and mercury, for poisoning with the two last of which it is given as an antidote.

1099. Animal Fibrine.—Animal fibrine is found in the blood of living animals in a soluble state, which it loses after death or separation from the body, giving rise to the phenomenon in drawn blood of coagulation or clotting.

1100. It occurs also in the muscles or red flesh as a soft elastic solid, arranged in fibres, and has received its name from this mode of aggregation.

1101. It is procured by stirring fresh-drawn blood with a stick or bundle of twigs. The fibrine separates from the permanently-liquid or serous portion of the blood, and from the colouring matter, and adheres to the stirrer in the form of a stringy mass. It may be obtained also by washing the clot of blood tied up in a piece of linen, till the serum and colouring matter are carried away.

1102. Caseine.—Caseine is the curd or coagulable portion of milk, and receives its name from the Latin word for cheese, of which it is the chief constituent. It exists in milk in a state of solution, along with sugar of milk, and accompanied by globules of oil in a state of suspension, which appear at the surface as cream, or may be separated as butter.

1103. Caseine, like the other bodies of its class, readily admits of transformation from the liquid into the solid state.

When milk becomes sour from the conversion of its sugar into lactic acid, which neutralises the alkali, the caseine coagulates. Its solution differs from that of fibrine, as the latter occurs in the blood, in not coagulating spontaneously; and from dissolved albumen, in not coagulating by heat; whilst, unlike it, it is coagulable by acetic acid.

1104. Milk also is coagulated in an interesting way by *rennet*, the inner membrane of the fourth or true digesting stomach of the calf. This is kept dried and salted in the dairies, to be used in the curdling of milk and preparation of cheese. An exceedingly small portion of rennet suffices to thicken milk. One part, for example, has been known to coagulate nearly two thousand times its own weight of that liquid.

1105. The six substances described contain exactly the same proportion of carbon, hydrogen, oxygen, and nitrogen. They all contain likewise sulphur; and albumen and fibrine possess in addition phosphorus. If we include under oxygen the sulphur and phosphorus, which occur in small quantities, their common composition will be as follows:—

Carbon,	54·84
Hydrogen,	7·16
Nitrogen,	15·97
Oxygen and Sulphur, &c.	22·03
	100·00

1106. The sulphur is best observed in albumen. If white of egg be boiled with caustic potash and acetate of lead, it gives a black precipitate of sulphuret of the metal.

1107. These six bodies, which are chemically identical, and differ only in their form, possess a remarkable power of inducing changes in the members of the amylaceous group. Thus *diastase* is a mere modification of the vegetable albuminous principles; so is yeast. Any one of them can induce the *vinous* fermentation. They can also determine the *acetous*, or the conversion of alcohol into vinegar. They possess likewise the power of changing sugar into lactic acid—a process which is best seen in milk, where caseine is the ferment, and the lactine becomes lactic acid. They can also determine in saccharine juices a peculiar fermentation, called the *viscous*, in which much gum is developed, and also manna.

1108. The albuminous principles, however, do not act as ferments till they have been exposed to the air, and begin in consequence to decompose. They are active as ferments only whilst decomposing, and the kind of fermentation they induce in the amylaceous principles depends upon the kind of decomposition which the ferments are undergoing.

RELATION OF THE AMYLACEOUS AND ALBUMINOUS CONSTITUENTS OF FOOD TO THE SUSTENANCE OF ANIMALS.

1109. In sustaining the life and growth of animals, the albuminous and amylaceous principles play very different parts. Thus a graminivorous animal, such as a cow, finds both in its food. The albuminous principles go to enrich the blood, which contains in its coagulable portion fibrine, and in its liquid or serous portion albumen; and from the blood the red flesh—which is chiefly fibrine, but contains also albumen—is formed.

1110. The amylaceous principles, on the other hand, serve an important purpose in relation to the maintenance of animal heat.

1111. The oxygen of the air which enters the lungs dissolves in the blood there, and passing in a state of solution from them to the heart, travels along with the blood in the arteries over the whole body. Whilst thus circulating, the oxygen combines with carbon to form carbonic acid, and with hydrogen to form water, separating these elements from the substance of each structure. During this combination heat is evolved in the same way, and to the same extent, as if carbon and hydrogen were burned or combined with oxygen out of the body. In this way the high temperature essential to the maintenance of life is kept up. The carbonic acid and water which are thus constantly produced in the body are taken up by the blood, and returning by the veins to the heart, pass with the venous blood to the lungs, and are there in greater part exchanged for oxygen and nitrogen, and given out in the expired air. The water can be made manifest by breathing against a glass, and the carbonic acid by blowing through lime-water. (See par. 473.)

1112. The oxygen which enters the lungs is thus like the air which feeds a furnace, and the carbonic acid and water-vapour are like the products of combustion which pass away by the chimney, only there is no smoke, because the carbon is entirely converted into the invisible carbonic acid.

1113. As the heat of a furnace, moreover, is kept up only by a constant consumption of fuel containing carbon and hydrogen, so the heat of the animal body is maintained by a similar consumption of its carbon and hydrogen. The office of the amylaceous principles is to supply this constant waste or withdrawal of the combustible elements of the living tissues.

1114. When a larger amount of the amylaceous substances is eaten than is required for the support of the animal heat, it is converted into fat, which consists chiefly of carbon and hydrogen. In the opposite state of circumstances the body becomes emaciated, because the fat is then burned by the oxygen, which enters the body in as great quantity as before. Animals which hybernate or sleep during the winter, such as the marmot, dormouse, and bear, are fat when they begin their slumbers, and lean when they awake from them.

1115. The amylaceous principles may thus be defined as the *heat-producing*, and the albuminous as the *flesh-producing*, constituents of food. All articles of diet which can alone sustain life for any length of time, such as bread or milk, contain both; and the albuminous principles, as they occur naturally, are associated with phosphate of lime, as well as other salts, which are essential to the production of the teeth, bones, and certain other tissues of the body.

PRODUCTS OF THE ACTION OF THE ALBUMINOUS ON THE AMYLACEOUS PRINCIPLES—ALCOHOL AND ITS DERIVATIVES.

1116. When the saccharine juice of any plant, such as grape juice, is exposed to the air at a temperature of between 70° and 80°, bells of carbonic acid speedily begin to rise from it. It loses more or less completely its sweet taste, and instead of sugar, it is found to contain alcohol.

1117. A pure solution of sugar in water does not undergo this change; and this difference is traced to the presence in the natural juice of a peculiar substance, which, after exposure to the air, possesses the power of compelling sugar to break up into alcohol and carbonic acid. Such a body is called a ferment. It is a compound of carbon, hydrogen, oxygen, and nitrogen, with sulphur and phosphorus, and closely resembles white of egg in composition and properties.

1118. In this country we are best acquainted with fermentation as occurring, not in a natural fruit juice, but in an infusion of malt. The change, however, is essentially the same. The malt contains sugar, and in addition, one of the azotised or albuminous bodies already described, which, after exposure to air, acquires the power of fermenting the accompanying sugar. This substance, when in the condition in which it acts most powerfully as a ferment, is called *yeast*. An infusion of malt will ferment spontaneously; but in brewing, the yeast of a previous fermentation is always added, to determine the commencement of the new fermentation. During that process the sugar of the malt becomes alcohol and carbonic acid; and its albuminous constituent or constituents, one or all, change into yeast, which is deposited by the beer as a viscid, yellow, insoluble substance.

1119. Yeast will occasion fermentation in a solution of pure sugar. In proof of this, let a solution of cane sugar, or, still better, grape sugar, be made, and a teaspoonful or two of yeast be added to it, whilst it is placed in a warm room, so that it shall be at a temperature of 70° or 80°. The liquid will soon become effervescent and frothy, from the disengagement of gas; and if the process be carried on in a gas bottle, with an exit or delivery tube, the gas may be collected at the pneumatic trough, and will be found to be carbonic acid, as mentioned under that gas.

1120. When the escape of gas has ceased, the liquid may be transferred to a retort connected with a receiver, and heated, when it will yield alcohol. The change which occurs is the following:—

1121. The fermentable sugars all change into grape sugar before yielding alcohol. One atom of grape sugar, $C_{12}H_{12}O_{12}$, yields 4 of carbonic acid and 2 of alcohol. Thus:—

$$
\begin{array}{rl}
 & \begin{array}{lll} C_{12} & H_{12} & O_{12} \end{array} \\ \cline{2-2}
\begin{array}{r}\text{2 Equivalents}\\ \text{Alcohol.}\end{array} & \left\{\begin{array}{lll} C_4 & H_6 & O_2 \\ C_4 & H_6 & O_2 \end{array}\right. \\
\begin{array}{r}\text{4 Equivalents}\\ \text{Carbonic acid.}\end{array} & \left\{\begin{array}{lll} C & & O_2 \\ C & & O_2 \\ C & & O_2 \\ C & & O_2 \end{array}\right. \\ \cline{2-2}
 & \begin{array}{lll} C_{12} & H_{12} & O_{12} \end{array}
\end{array}
$$

Or, $C_{12}H_{12}O_{12} = 2C_4H_6O_2$ and $4CO_2$.

1122. The fermentation which yields these products is distinguished from fermentations which yield other substances by being termed the *vinous*. All liquids which have undergone the vinous fermentation yield alcohol when distilled, but it passes over diluted with water. In illustration of this, and of the processes by which it is rectified, the following experiments may be tried:—

1. A glass or more of port or sherry wine is distilled in a retort till two-thirds have passed over.

2. The diluted spirit thus procured is placed in a small bottle, and a teaspoonful of recently-fused carbonate of potass added to it. The bottle is then corked, and briskly shaken. On letting it stand at rest, the liquid within will arrange itself in two strata or layers: the upper is pretty strong

alcohol; the lower is a solution of carbonate of potass in the water which previously diluted the spirit.

3. The upper liquid is drawn off by a pipette (see fig. 70), and placed in a small retort, along with as much unslaked quicklime, in powder, as will completely absorb the liquid, so as to appear dry. The lime slakes itself in the water of the spirit, and thus withdraws the former, so that if a gentle heat be applied to the retort, absolute or anhydrous alcohol will distil over.

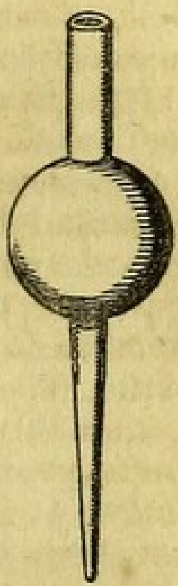
Fig. 70.

1123. Absolute alcohol is a colourless, highly inflammable liquid, which cannot be frozen. It has the density 794 (water = 1000), and the composition $C_4H_6O_2$. It boils at 173°. The spirit of wine of the shops, which has a density of about 840, contains about 80 per cent. of absolute alcohol; that of 890, 62 per cent. of true spirit. These form the alcohol which is burned in the spirit-lamp. Brandy, gin, and whisky, contain from 40 to 50 per cent. of absolute alcohol.

1124. All the intoxicating liquors, such as wine, beer, rum, arrack, &c. contain alcohol. Those which have not been distilled, such as wine and beer, possess also colouring matter, gum, sugar, albuminous matter, &c. derived from the fruits or other vegetable products from which they are prepared. Those which are effervescent, as beer and champagne, contain carbonic acid, which increases their intoxicating power; and all of the fermented liquors in ordinary use contain small quantities of essential oils and ethers, which confer upon them their peculiar flavour, fragrance, and bouquet.

Ether and Compounds of Ethyle.

1125. When equal weights of alcohol and oil of vitriol are distilled together, a volatile, fragrant liquid passes over, which has long gone by the name of sulphuric ether. This appellation has reference to the employment of sulphuric acid in the preparation of ether, not to the presence of sulphur in it. It contains the same elements as alcohol, but less hydrogen and oxygen—its formula being C_4H_5O. Its derivation from alcohol may be explained as follows, although its production is attended by several complicated reactions, the consideration of which is here omitted.

1126. Alcohol, which is $C_4H_6O_2$, may have its formula written $C_4H_5O + HO$, which represents it as differing from ether by containing an atom more of water. The oil of vitriol may be considered as combining with this atom of water, and becoming thereby diluted, whilst it converts the alcohol into ether. If a greater quantity of oil of vitriol be heated with alcohol, a second atom of water is withdrawn, and the alcohol becomes olefiant gas, C_4H_4, as mentioned under that substance.

1127. Ether is a transparent, limpid liquid, having a strong peculiar odour and taste. Breathed in small quantity, it acts as a powerful stimulant; but if continuously inhaled, it produces total but transient insensibility. Bodies which possess the latter power are called *anæsthetics* (from two Greek words, signifying to deprive of sensibility). They are now largely employed in medicine as a means of alleviating pain.

1128. The density of ether is 735. It boils at 97°, evaporates quickly at common temperatures, and, like other volatile liquids, produces great cold during its evaporation.

1129. It is highly combustible, and its vapour forms an explosive mixture with air and oxygen. It requires, accordingly, to be prepared cautiously, and the receiver in which it is condensed must be kept very cool. It dissolves a great variety of substances, but is inferior as a solvent to alcohol and water. It has a peculiar power, however, of dissolving fatty and oily matters, to which purpose it is largely applied in analysis.

1130. Ether is believed to contain a body resembling in functions ammonium, NH_4. It is named *ethyle*, and ether is its oxide. Ethyle has the composition C_4H_5, and cannot be isolated. It can act, however, like a metal, as ammonium can, uniting with salt-radicals to form compounds resembling salts, and with oxygen to form a compound resembling a metallic oxide. This oxide, by combination with water, forms a hydrate (alcohol); and by union with the oxacids and organic acids, bodies resembling the salts which these acids form with metallic oxides (compound ethers).

1131. Ethyle signifies literally ethereal essence, or principle of the ethers. The name is derived, as all the similar terms are, from the Greek υλη, *yle*, first or basic principle. It belongs to the class of bodies distinguished as the *salt-basyles*, and which, resembling metals in their function, are exactly contrasted with salt-radicals, such as chlorine.

1132. The following table will illustrate this:—

Compound Ethers.

Ethyle,	C_4H_5
Oxide of Ethyle (Ether),	C_4H_5,O
Hydrate of the oxide of Ethyle (Alcohol),	C_4H_5O,HO
Nitrate of the oxide of Ethyle (Nitric Ether),	C_4H_5O,NO_5
Chloride of Ethyle (Chloric Ether),	C_4H_5Cl

1133. The salts of ethyle are generally called *ethers*—as nitric ether, chloric ether, acetic ether. These compound ethers are produced by heating together the acid, whose ether is wished, with alcohol. They require to be cautiously prepared, owing to their combustibility.

1134. The following ether, the acetic, may be prepared as a characteristic specimen of its class, and no difficulty or danger attends its production.

1135. Equal measures of strong acetic acid, $C_4H_3O_3+HO$, and alcohol are distilled together, the condensing receiver being kept very cool. The acetic acid unites with the oxide of ethyle in the alcohol, forming acetic ether, $C_4H_5O,C_4H_3O_3$. Or E being taken as the symbol for ethyle, $EO,C_4H_3O_3$. The liquid in the receiver is shaken with water, to separate unaltered alcohol; then allowed to stand upon chalk, to neutralise any free acid; and afterwards shaken with fused chloride of calcium, to remove water. It is then distilled a second time. Acetic ether is a volatile, limpid, colourless liquid, having an aromatic taste, and very grateful odour.

1136. When a hydracid, such as hydrochloric, acts upon alcohol so as to convert it into an ether, the hydrogen of the acid combines with the oxygen of the oxide of ethyle to form water, and the salt-radical (in the case supposed, the chlorine) combines with the ethyle directly. Thus chloric ether is ECl.

Acetic Acid.

1137. If alcohol, diluted with water, be mixed with a ferment, such as yeast, and exposed to the air at, or a little above, its ordinary temperature, it is rapidly converted into vinegar or acetic acid. The change is accompanied by the absorption of oxygen, 2 atoms of which combine with as many of hydrogen to form water, whilst other 2 take the place of the hydrogen which has become water, so that acetic acid is produced from alcohol by the substitution of 2 atoms of oxygen for 2 of hydrogen. Thus alcohol is $C_4H_6O_2$. If we take from this 2 atoms of hydrogen, and add 2 of oxygen, it becomes $C_4H_4O_4$. But from the mode in which acetic acid acts when it combines with bases, it is certain that one of the equivalents of hydrogen and one of oxygen are united as water, so that the formula of acetic acid is $C_4H_3O_3 + HO$.

1138. The change which alcohol undergoes, when it becomes acetic acid, may be expressed in symbols shortly thus:—

$$C_4H_6O_2-H_2+O_2=C_4H_4O_4,\text{ or }C_4H_3O_3+HO.$$

1139. A striking experiment may be made illustrating the mode in which alcohol is converted into acetic acid. If slightly-diluted alcohol be dropped upon *platinum-black* (see par. 1011), the oxygen condensed in that substance acts with great energy on the spirit, and acetic acid is evolved in vapour. Here the whole office of the platinum is to determine the oxygen of the air, and the hydrogen of the alcohol to unite. In the commercial processes for manufacturing vinegar, some vegetable substance containing nitrogen (one of the albuminous principles) takes the place of the platinum-black, and determines the same change.

1140. In this country weak beer is simply exposed to the air. Its yeast acts like the platinum, and the beer soon acidifies.

1141. In grape countries the weaker wines are in the same way converted into vinegar by simply exposing them to the air. It is now manufactured also both in this country and on the continent by an interesting method called the 'quick process.' A large barrel is filled loosely with wooden shavings, and pierced at the sides, so as to allow air to circulate freely through it. Diluted spirit, or beer mixed with a very little yeast, or a little of the vinegar of a previous process, is warmed to the temperature of 70°, and allowed to trickle downwards through apertures in the lid of the cask. The liquid, spreading over the shavings, exposes a large surface to the air, and absorbs oxygen in consequence so freely, that it is converted into vinegar with great rapidity.

1142. Large quantities of acetic acid are also prepared by another process than the oxidation of alcohol. This is the destructive distillation of wood, oak and beech being preferred. The wood is heated in retorts like those used in the manufacture of coal-gas, and yields a very great variety of products; among the rest acetic acid. It is purified by neutralising it with lime, and afterwards converting the resulting acetate of lime into acetate of soda, which is fused at a temperature sufficiently high to destroy the tar and other impurities which originally accompany the acetic acid. From the acetate of soda, mixed with three times its weight of oil of vitriol, concentrated acetic acid is obtained by distillation in a retort.

1143. It is not known in the anhydrous form. In its most concentrated state it contains an equivalent of water, $C_4H_3O_3 + HO$. When it combines with metallic oxides, they take the place of the water; acetate of soda, for example, consisting of anhydrous soda and anhydrous acetic acid, $NaO,C_4H_3O_3$.

1144. Concentrated acetic acid is a crystalline solid below 60°, but above that temperature, up to 248°, its boiling-point, it is a limpid, colourless, highly-volatile liquid, possessing a peculiar characteristic odour. It blisters the skin, like muriatic acid, and its vapour is combustible.

1145. The wine vinegar of France, and that prepared by the quick process, has a peculiarly pleasant flavour, owing probably to the presence of a little acetic ether.

1146. The salts of acetic acid are numerous and important, and are largely used in the arts. The most important is the acetate of lead, already referred to. Acetic acid is believed to contain a peculiar basyle, C_4H_3, which is named acetyle. The following table will illustrate its chief compounds:—

Acetyle,	$C_4 H_3$	
Oxide of acetyle,	$C_4 H_3 O$	unknown
Hydrate of oxide of acetyle,	$C_4 H_3 O + HO$	aldehyde
Acetous acid,	$C_4 H_3 O_2 + HO$	aldehydic acid
Acetic acid,	$C_4 H_3 O_3 + HO$	

Chloroform.

1147. When alcohol diluted with water is distilled along with chloride of lime, it yields the remarkable compound, chloroform. To prepare it, the following proportions may be taken:—Spirit of wine, sp. gr. 840, three quarters of an ounce; chloride of lime, four ounces; water, twenty-four ounces. These are placed in a roomy retort, to prevent frothing over, and slowly raised to the boiling-point. The chloroform comes off as soon as the liquid begins to boil, and forms a layer at the bottom of the water which accompanies it. The contents of the receiver are shaken with three or four times their bulk of water containing a little carbonate of soda. The water is then drawn off by a siphon or pipette, and the chloroform is distilled a second time from unslaked lime or chloride of calcium.

1148. Pure chloroform has the composition C_2H,Cl_3. It is a colourless liquid, nearly half as heavy again as water, its specific gravity being 1·498, or, according to some, 1·500. It has an agreeable, ethereal, fruity odour, and a pleasant sweet taste. It boils at 140°, and is not inflammable. Breathed in small quantity, it acts as a stimulant, but if rapidly inhaled, it produces insensibility. A much smaller quantity than is requisite of ether suffices to produce this effect. It is now preferred to all other bodies as an anæsthetic. It should on no account be taken or given for the sake of experiencing or producing its effects on the living system, unless in the presence of a medical man, as fatal results may occur in the hands of unprofessional persons.

1149. The word chloroform refers to the fact, that when the compound under discussion is mixed with a strong solution of potass, its chlorine combines with the metal of the alkali, producing chloride of potassium, whilst the oxygen of the potass takes the place of the chlorine, producing the compound C_2H,O_3. This body was known to chemists long before chloroform, and received the name of *formic* acid, because it was first prepared from a species of ant, the Latin name of which is *formica.* Formic acid and chloroform are believed to be compounds of a peculiar basyle, called formyle, C_2H, of which formic acid is the teroxide, and chloroform the terchloride.

Formyle,	C_2H
Formic acid,	C_2H,O_3
Chloroform (terchloride of formyle),	C_2H,Cl_3

VEGETABLE ACIDS.

1150. A large number of acids are derived from vegetables, exhibiting all the characters of the bodies of their class in great perfection—that is, possessing a sour taste, the power of changing vegetable colours, and that of completely neutralising the strongest bases. Three are here selected as examples—namely, tartaric, citric, and malic acids.

Tartaric Acid, formula $C_8H_4O_{10} + 2HO$.

1151. This acid occurs in the grape, the tamarind, the pineapple, and other fruits and vegetables. It is obtained from the grape, in which it occurs in combination with potass and water, as the familiar salt, cream of tartar. The latter separates from the grape juice during its fermentation in the wine vat, precipitating in proportion as alcohol is developed, owing to its insolubility in that liquid. It carries down with it a good deal of the colouring matter, and is known in its crude state by the name of *argol.* This is purified by solution in water, and digestion with animal charcoal, and forms, when free from colour, the cream of tartar, or bitartrate of potass, of the shops. From this tartaric acid is obtained, by neutralising the cream of tartar with chalk, which converts it into tartrate of lime, and decomposing this by sulphuric acid, which forms the slightly-soluble sulphate of lime, and liberates the tartaric acid. The latter is purified by repeated solutions in water. It is generally sold in powder, but it may be obtained in large crystals.

1152. It is distinguished from the other vegetable acids by the precipitate it gives with salts of potassium, for which it is used as a test, as mentioned under the alkalis. It has an agreeable sour taste, and is largely used in the preparation of effervescing powders.

1153. Tartaric acid is bibasic—that is, it always unites with two atoms of base at a time, like pyrophosphoric acid. The following table of salts will illustrate this, the formula for tartaric acid being represented by $\overline{T}$:—

Tartrate of potass,	$KO,KO,\overline{T}$
Cream of tartar,	$KO,HO,\overline{T}$
Tartrate of potass and soda,	$KO,NaO,\overline{T}+10HO$
Tartrate of potass and iron,	$KO,Fe_2O_3,\overline{T}$
Tartrate of potass and antimony,	$KO,SbO_3,\overline{T}$

Citric Acid, $C_{12}H_5O_{11} + 3HO$.

1154. This acid occurs in the juice of the orange, lemon, lime, citron, currant, gooseberry, &c. It is prepared from lemon or lime juice by neutralising it with chalk. An insoluble citrate of lime is formed, which is washed and decomposed by diluted sulphuric acid. The liquid is filtered from the sparingly-soluble sulphate of lime, and yields, when sufficiently concentrated, crystals of citric acid, which are transparent, of a pleasant sour taste, and very soluble in water.

1155. Citric acid is distinguished from tartaric by not precipitating salts of potassium, and from the vegetable acids in general by forming a transparent solution with lime-water, which becomes turbid when heated, owing to the formation of insoluble citrate of lime.

1156. Citric acid is tribasic, like common phosphoric acid. The citrate of silver, for example, is $3AgO,C_{12}H_5O_{11}$; or taking $\overline{Ci}$ as the symbol of citric acid, $AgO,AgO,AgO,\overline{Ci}$.

Malic Acid, $C_8H_4O_8 + 2HO$.

1157. This acid receives its name from the Latin word for apple (*malum*), in allusion to its occurrence in that fruit when unripe. It is found also in the mountain-ash, or rowan-berry, and in the garden rhubarb.

1158. It is most conveniently prepared from the stalks of the latter, which are peeled, grated, and squeezed, so as to yield their juice. The liquid is neutralised whilst boiling hot with carbonate of potass, and then mixed with acetate of lime, which precipitates some oxalic acid present in the rhubarb, as insoluble oxalate of lime. Solution of acetate of lead is then added as long as it occasions a precipitate. This is the malate of lead, which is washed, stirred through water, and exposed to a current of sulphuretted hydrogen as long as it blackens. The filtered liquid is concentrated by evaporation, and set aside. The malic acid forms a crystalline mass. It has a sharp sour taste, is very soluble in water, and, like tartaric and pyrophosphoric acid, is bibasic.

VEGETABLE ALKALIS.

1159. The vegetable alkalis form a class of most interesting substances, found pretty widely diffused in nature, and occurring generally in poisonous plants. They all contain nitrogen, in combination, in the majority, with carbon, oxygen, and hydrogen. Their atomic weights are high, owing to the number of equivalents of each of their constituent elements present in them. They resemble hydrated ammonia, or the oxide of ammonium, in being powerful bases which can neutralise the strongest acids, and in the effect they produce on vegetable colours. The taste of the vegetable alkalis is almost invariably intensely bitter. In small doses, they are among our most useful medicines, and in large doses, deadly poisons.

1160. They occur in plants in combination generally with peculiar vegetable acids, and by union with them, as well as with the mineral acids, form a large series of beautiful crystallisable salts.

1161. Morphia, one of the characteristic alkalis of opium, and quinine, one of those in Peruvian bark, are here taken as examples:—

Morphia or Morphine, $C_{35}H_{20}O_6N$.

1162. Morphia occurs in opium, the inspissated juice of the poppy, in combination with a peculiar vegetable acid, called from the Greek name for the poppy, the *meconic*. To obtain morphia, opium is cut in small pieces, and boiled in a glass or porcelain vessel with water, till a dark-brown solution is procured. This contains, besides many other compounds, the morphia and meconic acid combined together as meconate of morphia. A solution of chloride of calcium is added to the infusion of opium, which is left at rest till it has ceased to deposit a copious precipitate. This consists of the meconic acid in union with lime (meconate of lime), whilst hydrochlorate of morphia remains in solution. The liquid is filtered, concentrated by evaporation, and left at rest. The hydrochlorate of morphia separates as a crystalline mass, which is strongly compressed between folds of flannel or filtering paper, to get rid of colouring matter and other impurities. The squeezed mass is then dissolved in hot water, and crystallised from it again; and this process is repeated, with the assistance, the last time, of a little animal charcoal, till the salt of morphia is obtained in colourless crystals.

1163. The pure hydrochlorate is then dissolved in hot water, and ammonia added to supersaturation. As the liquid cools, the morphia separates as a snow-white crystalline powder, which may be obtained in regular crystals from its solution in boiling alcohol.

1164. Morphia, as well as its hydrochlorate, may be had to purchase from the druggist or manufacturing chemist, and the student will find it more convenient to obtain them in this way than to attempt to prepare them on the small scale for himself. They must be handled cautiously, and not carelessly exposed, as less than a grain of either would be a dangerous if not a deadly dose.

1165. Morphia forms hard transparent lustrous crystals, which are sparingly soluble in cold water, alcohol, or ether, but dissolve in spirits of wine if raised to its boiling-point. Solutions of morphia have a bitter taste, and an alkaline action on colouring matter. It forms crystallisable salts with the acids.

1166. Morphia is distinguished by the brown colour which it communicates to iodic acid when it decomposes it (see iodic acid), by the orange colour it communicates to nitric acid (see nitric acid), and by its producing a blue liquid when added in fine powder to a solution of the perchloride of iron. The salts of morphia, especially the hydrochlorate and acetate, are largely used in medicine to allay pain and produce sleep. The similar virtues of laudanum are chiefly dependent on the morphia it contains.

Quina or Quinine, $C_{20}H_{12}O_2N$.

1167. This alkali occurs in Peruvian or Cinchona bark, in combination partly with sulphuric acid, partly with a vegetable acid called the *Kinic*. To procure it, the bark in powder is boiled with water and hydrochloric acid. The decoction is filtered, and mixed with milk of lime, and the precipitate which falls is then boiled with alcohol, and filtered hot. As it cools, crystals separate, consisting of another alkali also contained in the bark, and called *Cinchonine*. Quinine remains in solution, and may be obtained in crystals by evaporating the alcohol. The experimenter will find it more convenient to purchase the sulphate of quinine, which is largely prepared for medicinal use, to dissolve it in water with the aid of a little sulphuric acid, and supersaturate the liquid with ammonia. The quinine will precipitate in white, uncrystalline flocks, but may be crystallised from its solution in alcohol. It is very bitter, distinctly alkaline, sparingly soluble in water, and highly soluble in alcohol. Most of its salts with the acids are readily crystallisable, and all are excessively bitter. The sulphate is the most important, and is largely used in medicine as a tonic, and to cure intermittent fever.

OILS AND FATS.

1168. Oils and fats shade away insensibly into each other; their difference in consistence implying only a different relation to temperature, not necessarily a distinction in chemical qualities. An oil may be called a liquid fat, or a fat a solid oil. The same body, such as butter, by a slight alteration in temperature, changes from a solid to a liquid without alteration in its essential properties. What the Africans call palm oil, and know only as a liquid, we call palm butter, because in this country it is a solid.

1169. Oils are obtained both from the animal and vegetable kingdom, and are divisible into two well-marked classes:—*Fixed* oils, which cannot be distilled without decomposition; and *volatile* oils, which admit of distillation. Olive oil is an example of the former, and oil of turpentine of the latter.

1170. Fixed oils are readily distinguished from those which are volatile by their effect on paper. Each produces a greasy stain; but when it is occasioned by a volatile oil, it disappears on the application of heat, whereas the stain of a fixed oil is permanent.

1171. The fixed and volatile oils are quite distinct in properties, and must be considered apart.

Fixed Oils.

1172. The fixed oils are divided into two classes—*drying* oils, and *fat* oils. The drying oils are those which, when exposed to the air, especially after being heated, dry up into solid transparent bodies like varnishes. They are the oils used in painting. Linseed, rapeseed, poppy, and walnut oil, are examples of this class. Olive oil, palm butter, and ordinary butter, are examples of fat oils. The latter thicken a little, and grow rancid by exposure to air, but never consolidate into hard masses.

1173. The fixed oils show all degrees of consistence, from the most limpid olive or almond oil, to solid lard and tallow. They are all mechanically separable into a less and a more fluid portion. Reduction in temperature effects this separation also. Thus olive oil, which in summer is quite liquid, in winter becomes quite thick, from the separation of crystals which consist chiefly of a solid fat called *margarine*. The thinner or more limpid portion, which may be separated by filtration from the margarine, is distinguished by the name of *elaine* or *oleine*. Lard or tallow, if exposed to pressure between folds of dry flannel or blotting-paper, yields its oleine to the envelope, and its solid portion is left as a crystalline cake. This consists partly of a substance like margarine, partly of another solid called *stearine*.

1174. The consistence of fatty bodies is determined by the relative proportion in which these solid and liquid constituents occur in them. Oleine predominates in the more liquid oils; margarine or stearine, or both, in those which are solid.

1175. When the fixed oils are boiled with caustic alkalis, such as potass or soda, they are converted into soaps. When the solution is dilute, these remain in solution; but on concentrating the liquid by evaporation, the soap becomes insoluble, and rises to the surface. It is drawn off in a semifluid condition, and received into moulds, where it consolidates on cooling. Potass soaps, such as 'black soap,' never harden, owing to the deliquescence of their alkali. The ordinary hard soaps contain soda.

1176. Potass and soda soaps are soluble in pure water, or in water containing a small amount of salts; but soaps of lime are quite insoluble in water, and have no cleansing qualities; hence hard waters, especially those containing carbonate, sulphate, or other salts of lime, are unsuitable for washing, as they convert the soda and potass soaps into a lime soap, so that much of the former is wasted, and only the excess of it over what the lime in the water decomposes is useful. The hardness, in fact, of water is now estimated by the quantity of alcoholic solution of soap which it can precipitate.

1177. More than one of the plasters used in medicine, such as surgeon's adhesive plaster, is a kind of soap, made by boiling a metallic oxide with oil. Thus sticking-plaster is prepared by boiling litharge or white lead with olive oil and water till combination occurs.

1178. A soap is a true salt, or mixture of several salts—that is, it consists of a metallic oxide, such as potass, soda, or oxide of lead, united with one or more acids. When a soap is digested with sulphuric acid, this unites with the oxide present, and the fatty acids separate. They are solid, crystalline bodies, acting strongly on colouring matter when melted, and forming salts like other acids, with bases.

1179. Soap made from tallow or the fixed oils yields as many as three fatty acids, which are named respectively *stearic*, *margaric*, and *oleic* acids. They exist in the oil in combination with a remarkable sweet substance called, in consequence of its taste, *glycerine*, from the Greek adjective for sweet. It has the composition $C_6H_7O_5+HO$, and is the hydrate of the oxide of a peculiar basyle called *glyceryle*, C_6H_7. The fat oils and tallow thus appear to be mixtures, in variable proportion, of the oleate, stearate, and margarate of the oxide of glyceryle (glycerine).

1180. When an oil is saponified, the alkali, or other metallic oxide, combines with the fatty acids to the exclusion of the glycerine. Thus when oxide of lead is boiled with olive oil and water, the lead-soap or plaster produced (see par. 1177) is an insoluble combination of the fatty acids of the oil and the metallic oxide, whilst the glycerine (oxide of glyceryle) dissolves in the water. After purification, it forms a colourless, inodorous, uncrystallisable, viscid liquid. It has a very sweet taste, and is not fermentable. The following are the formulæ of the three most important fatty acids:—

Stearic acid, ...	$C_{68}H_{66}O_5$
Margaric acid, ...	$C_{68}H_{66}O_6$
Oleic acid, ...	$C_{36}H_{33}O_3$

They all contain carbon and hydrogen in great excess, which accounts for the marked combustibility of oils and fats. The stearine, margarine, and oleine into which the fixed oils are mechanically separable, consist of these acids united to glycerine. Stearine, for example, is the stearate of the oxide of glyceryle, or stearate of glycerine; margarine is the margarate, and oleine the oleate, of the same base.

Volatile Oils.

1181. The volatile, called also the essential oils, or essences, are obtained from different fragrant plants, and are the chief cause of the odour characteristic of so many products of the vegetable kingdom.

1182. They are generally obtained by distilling the plant with water. The oil accompanies the steam, and is found in the condenser, floating, in the majority of cases, on the surface of the water, but not unfrequently below it, owing to its greater density.

1183. The volatile oils are not unctuous to the touch, and do not saponify when heated with dissolved alkalis. Some of them are colourless; a greater number pale yellow; a few red or brown; and one or two blue or green. They have all a powerful, generally agreeable odour. At ordinary temperatures, the majority are liquids, but they may be frozen by cold. Several of them, when thus treated, separate, like the fixed oils, into a more solid and a less fixed substance. This is well seen in oil of anise, which becomes filled with crystals during winter.

1184. The more solid portion, which resembles stearine, is called *stearopten;* and the liquid portion resembling the elaine, *elæopten.*

1185. Camphor is a natural stearopten; and the stearoptens in general are frequently spoken of as the camphors of the volatile oils.

1186. The volatile oils are divisible into three classes:—*1st,* Those consisting only of carbon and hydrogen; *2d,* Those containing carbon, hydrogen, and oxygen; and *3d,* Those which, in addition to these elements, contain sulphur and nitrogen.

1187. To the first class belong oil of turpentine, oil of juniper, of lemons, of limes, of cedrat, of black pepper, and several more. They all contain carbon and hydrogen in the proportion C_5H_4, or a multiple of this, such as $C_{10}H_8$, or $C_{20}H_{16}$. Among oils of the second class are oil of cloves, cinnamon, anise, bitter almonds, roses, lavender, rosemary, marjoram, basil, thyme, nutmeg, &c. Camphor also is a solid oil of this group. As specimens of the composition of oils of this division, the following may be taken:—

Oil of cinnamon, ...	$C_{20}H_{11}O_2$
Oil of peppermint, ...	$C_{10}H_{10}O$
Camphor, ...	$C_{10}H_8O$

1188. Hops, assafœtida, onions, horse-radish, garlic, and black mustard seed, yield, when distilled with water, volatile oils containing sulphur. Oil of mustard has the composition $C_8H_5S_2N$.

1189. Many of the volatile oils, such as turpentine, exude from plants in combination with resins. Such natural mixtures of a volatile oil and a resin are called balsams. The most familiar example of these is Venice, or crude turpentine, which, when distilled, yields oil of turpentine, and leaves behind common resin.

COLOURING MATTERS.

1190. A great variety of colouring matters is derived from the vegetable and animal kingdoms. Some of them are too fugitive to be of service in the arts. Those which are more permanent are largely employed by the painter and dyer. Under the head of chlorine, the process of bleaching, or destroying organic colours, has been discussed; and under alumina, the method of fixing colours in dyeing has been explained. It now remains to give an example of each of the three primary colours, Red, Blue, and Yellow, as derived from organic bodies.

Blue.

1191. The most important blue colouring matter, and perhaps the most important vegetable dye, is indigo. It is obtained from a variety of plants, in the juice of which it exists as a soluble colourless compound. When the plant is steeped in water, this substance is dissolved from it; and by exposure to the air, becomes dark-blue, and at the same time insoluble, so that it deposits as a sediment in the vessels containing the indigo juice. As it occurs in commerce, indigo is a dark-blue powder, insoluble in water. Its composition is $C_{16}H_5O_2N$.

1192. Indigo admits of being deprived of its colour, and thrown into a soluble condition, such as it presents in the indigo plant. To effect this, it is reduced to a fine powder, mixed with slaked lime, and placed, along with solution of the protosulphate of iron, in a bottle provided with a tight-fitting stopper. The bottle is occasionally well shaken, and kept in a warm place. The indigo gradually loses colour, and dissolves in the lime-water; the change being determined by the protoxide of iron in the sulphate, which changes during the process into peroxide. If the alkaline solution of *white indigo*, as it has been called, be exposed to the air, it recovers its colour, and precipitates as insoluble blue indigo.

1193. Cloth is dyed blue by steeping it in such a solution of indigo as we have described, and then exposing it to the air. The indigo, as it recovers its colour, combines with the fibre of the cloth, and becomes fixed there, so as to be unaffected by water.

1194. White or insoluble indigo has the composition $C_{16}H_6O_2N$.

Red.

1195. The finest red dye is cochineal, a colouring matter obtained from the cochineal insect, or *coccus cacti*, so called from its feeding on a species of cactus, or prickly pear, which is cultivated for this purpose in South America. The cochineal of commerce is the dried body of the insect. Water and alcohol dissolve from it a rich red colouring matter, which may be obtained in crystals. Carmine is a *lake* consisting of this, combined with alumina or oxide of tin. The costliness of cochineal limits its use.

1196. The red dye stuff most largely employed is madder, the root of the *rubia tinctorum*, which is cultivated in France, Holland, and the Levant. Several crystallisable colouring matters can be procured from it. The most important is called *alizarine;* it is orange-red, and has the composition $C_{37}H_{12}O_{10}$.

Yellow.

1197. One of the most useful yellow dyes is obtained from quercitron bark (*quercus tinctoria*). It is crystalline, and has the composition $C_{16}H_8O_9 + HO$. Another is fustic, or yellow wood (*morus tinctoria*). Arnotto, or annotto, used in dyeing butter and cheese, is obtained from the seeds of the *bixa orellana.* The roots of the turmeric, carrot, and rhubarb plants, as well as the petals of saffron and safflower, all yield yellow colouring matters.

1198. Gamboge is the dried juice of the gamboge-tree (*Garcinia gambogia*).

COMPOUND SALT-RADICALS.

Cyanogen and its Compounds.

1199. Under the head of ammonium, as well as of ethyle and the other basyles, compounds have been described which resemble metals as to the function which they perform in combination.

1200. The substances now to be considered are as numerous and as important, whilst they are exactly the opposite of compound basyles and the metals in function, and resemble the salt-radicals, chlorine, bromine, iodine, &c. in characters. They are termed, accordingly, the *organic radicals,* or *compound salt-radicals.*

1201. The most interesting example of this class of substances is called *cyanogen,* from two Greek words signifying to generate or produce blue, in allusion to its being one of the ingredients of prussian blue.

1202. Cyanogen and its compounds are prepared, directly or indirectly, from a salt much used in the arts, and already referred to as a test for iron and for copper—namely, the ferrocyanide of potassium, or yellow prussiate of potass. This salt is obtained by heating together dried animal matters, such as the parings of skins, hair, horns, woollen rags, &c. &c. with carbonate of potass and iron. The fused mass is afterwards digested in water, and from the solution the ferrocyanide of potassium is obtained in bright yellow crystals. During the fusion of the animal matter with the alkaline carbonate, the carbon and nitrogen of the former combine in great part together to form cyanogen, which is a bicarburet of nitrogen, C_2N. This unites with potassium derived from the potass, and produces the cyanide of potassium, K,C_2N, and when the fused mass is dissolved in water, a similar combination is formed between the cyanogen and the iron. The yellow salt may be represented as consisting of two equivalents of the cyanide of potassium, K,C_2N, and one of the cyanide of iron, Fe,C_2N, besides three atoms of water. Cyanogen, considered as a salt-radical, is expressed by the symbol $Cy(=C_2N)$. The composition, accordingly, of the yellow salt may be written thus: $KCy,KCy,FeCy + 3HO$. The salt, if gently heated, loses its water of crystallisation, and becomes $2KCy,FeCy$.

1203. If the dried ferrocyanide be pulverised, and mixed with corrosive sublimate in powder, the mixture, on being heated, will yield cyanogen as a gas. This gas can be still more easily prepared by heating the cyanide of mercury, $HgCy$, or that of silver, $AgCy$, which are resolved in greater part into cyanogen and their constituent metal; but neither of these salts can readily be had to purchase, and the mixture first described will on that account be more suitable. Its fumes, when heated, should be avoided, as they are poisonous.

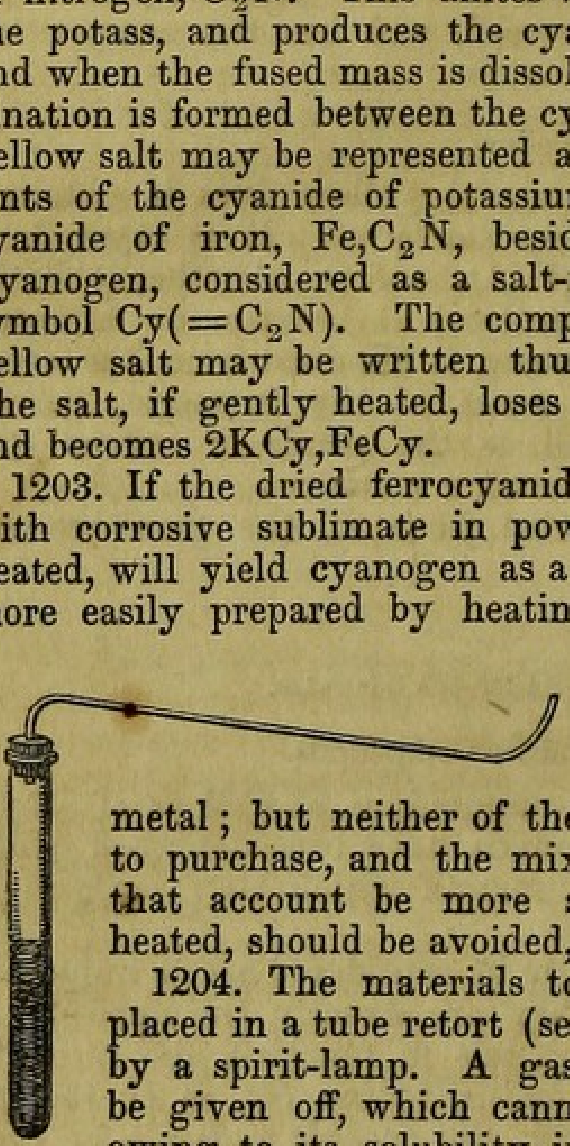

Fig. 71.

1204. The materials to yield cyanogen should be placed in a tube retort (see fig. 71), and gently heated by a spirit-lamp. A gas, which is cyanogen, will be given off, which cannot be collected over water, owing to its solubility in that liquid, but may be sufficiently examined as it issues from the beak of the retort. It has a powerful, peculiar odour, resembling that of peach blossoms and of prussic acid, is colourless, has a peculiar odour, and is poisonous. It is soluble in alcohol, as well as in water.

1205. Cyanogen is inflammable, and burns in air or oxygen with a beautiful pale purple or rose-coloured flame, a good deal resembling that of potassium. During combustion, its carbon forms carbonic acid, and its nitrogen is evolved. The density of cyanogen as a gas is 1806; its atomic weight 26. It can be condensed into a colourless transparent liquid.

1206. The compounds of cyanogen are exceedingly numerous, and most of them equally interesting and important:—

1207. HYDROCYANIC OR PRUSSIC ACID, HCy, Eq. 27.—Prussic acid, the most formidable of known poisons, can be prepared in a variety of ways. The most convenient, on the whole, is to distil four parts of the ferrocyanide of potassium with eighteen of water and two of oil of vitriol, whilst twenty more parts of water are placed in the condensing receiver. The change which occurs in the retort may be represented as exactly analogous to that which happens when common salt is distilled with sulphuric acid in the process for hydrochloric acid. The cyanide of potassium of the ferrocyanide alone suffers decomposition. Its cyanogen unites with the hydrogen of the water of the oil of vitriol, forming hydrocyanic acid, which distils over. Its potassium combines with the oxygen, forming potass, which, by union with the sulphuric acid, forms sulphate of potass. The other changes which occur are complicated, and do not require to be stated in order to account for the evolution of prussic acid. The decomposition mentioned previously may be expressed thus:—

$$\begin{tikzcd}
\mathrm{K} \arrow[r, dotted, dash] \arrow[dr, dash] & \mathrm{Cy} & = & \mathrm{HCy} \\
\mathrm{H} \arrow[r, dotted, dash] \arrow[ur, dash] & \mathrm{O}, + \mathrm{SO}_3 & = & \mathrm{KO,SO}_3
\end{tikzcd}$$

The proportions given above yield hydrocyanic acid largely diluted with water. If it be wished anhydrous, about half the weight of the yellow salt employed should be taken of water, and as much oil of vitriol. The condensing arrangement in this case should be very complete, and the acid which comes over must be shaken with chloride of calcium, and distilled again before it is obtained anhydrous and pure. In this condition, however, it is so formidable a poison (a single drop sufficing to occasion instant death), and its vapour is so volatile, that it should on no account be prepared in its state of greatest concentration, especially in a private dwelling. All its properties can be sufficiently examined with the diluted acid.

1208. Anhydrous prussic acid is a colourless, limpid liquid, boiling at the comparatively low temperature of 79° F., so that it is scarcely possible in summer to preserve it as a liquid. Its vapour occasions, even in small quantity, headache and faintness, and would cause death if largely inspired. It has a powerful, peculiar odour, generally compared to that of the peach blossom or of bitter-almond oil; its taste is pungent and cooling, but not sour. It must be observed with the acid only after it has been very much diluted. The necessity for the latter precaution will be understood from the fact, that the strongest medicinal acid used in Great Britain does not contain in a hundred grains more than three grains of the pure or anhydrous prussic acid, and of this diluted acid a drop is a dose, which must be given warily. Hydrocyanic acid, in truth, must be prepared and handled very cautiously. It should not be placed in unlabelled bottles, or indeed kept in private dwellings. The experimenter will do well, as soon as he has sufficiently examined the properties of prussic acid, to throw away what remains of the specimen he has prepared.

1209. One of the most efficacious antidotes to poisoning with prussic acid is the affusion of cold water, such as the shower-bath would supply. Dogs and other animals apparently quite dead have been recovered by dashing cold water upon them. Another antidote is ammonia (spirits of hartshorn), held near the nostrils.

1210. Hydrocyanic acid is identified by the following tests, which will also serve to exhibit its most striking properties:—

1. A portion of the diluted acid is placed in a test-glass, and its peculiar odour noticed. Nitrate of silver is then added, as long as it occasions a white precipitate. This is the cyanide of silver, AgCy. It is distinguished from the chloride of silver, which it resembles, by its solubility in boiling nitric acid. A more decisive test of the precipitate having been occasioned by prussic acid, is to collect the cyanide on a filter, wash it, dry it, and place it in a small test-tube, which is afterwards drawn out near its open extremity, at the blowpipe flame, into a narrow canal or jet; or it may be placed in a tube-retort. On heating the shut end of the tube by a spirit-lamp, cyanogen will be given off, and may be kindled as it escapes. It will burn with its characteristic beautiful flame.

2. To a portion of prussic acid in a second glass is added a solution of sulphate of iron, which will serve all the better if it has been prepared for some time, and is partially peroxidised. This is followed by a little caustic potass, and lastly muriatic acid. A permanent precipitate of Prussian blue is produced.

3. A portion of prussic acid is boiled with hydrosulphuret of ammonia and a few grains of sulphur, till all odour of sulphuretted hydrogen is gone. A few drops of perchloride, or any other persalt of iron, are then added. A blood-red tint spreads through the liquid. This results from the conversion of the hydrocyanic acid into sulphocyanic acid, which forms a red solution when added to dissolved persalts of iron. The change is explained under sulphocyanogen (par. 1224).

1211. When hydrocyanic acid acts on a metallic oxide, the resulting salt is a cyanide of the metal. The cyanide of mercury, $HgCy$, which is convenient for yielding cyanogen, is obtained by dissolving the red oxide of that metal in excess of prussic acid, and then concentrating the liquid till crystals form.

1212. The cyanide of potassium, KCy, which is now used in several of the arts, is most conveniently prepared by heating the dried ferrocyanide of potassium in a shut crucible or iron bottle, communicating with the outer air by a small aperture. The cyanide of iron, FeC_2N, in the ferrocyanide, gives off its nitrogen, and becomes bicarburet of iron, whilst the cyanide of potassium suffers no change, and may be dissolved out of the crucible after it has cooled, by a little cold water, or, still better, alcohol. This salt reduces the great majority of metallic compounds, setting free their metals. It is very serviceable, accordingly, in blowpipe experiments, and answers admirably for the reduction of arsenious acid, in testing for arsenic.

1213. OXIDES OF CYANOGEN.—There are three oxides of cyanogen, all acids, having the following composition:—

Cyanic acid,	CyO
Fulminic acid,	Cy_2O_2
Cyanuric acid,	Cy_3O_3

1214. CYANIC ACID, CyO.—If dried ferrocyanide of potassium be heated in an open, instead of a nearly close vessel; if, for example, it be spread out on an iron plate or saucer over a fire, the cyanide of iron will be converted into peroxide, and the cyanide of potassium will absorb oxygen, so that its potassium will become potass, KO, and its cyanogen, cyanic acid, CyO. The resulting cyanate of potass, KO,CyO, may be dissolved out by alcohol, and obtained in crystals. If sulphuric acid be poured on these, the cyanic acid is liberated, and undergoes in greater part immediate decomposition; but a portion escapes destruction, and may be recognised by its peculiar odour, resembling that of strong acetic acid.

1215. The most interesting compound of this acid is one which it forms by union with hydrated ammonia. It is identical in every property with a remarkable animal product named urea. This is one of the few organic bodies which can be prepared artificially.

1216. FULMINIC ACID, Cy_2O_2, is an important substance. It receives its name from the explosive compounds which it forms by combination with the oxides of silver and of mercury (fulminating silver, and fulminating mercury).

1217. Fulminate of the black oxide of mercury, which is the substance used in percussion caps, is prepared by dissolving one part of mercury in twelve of nitric acid, and mixing this with an equal quantity of alcohol. Heat is applied cautiously, and soon gives rise to an abundant effervescence, which, if it become too violent, must be moderated by withdrawing the light, and pouring in a little cold alcohol. A fragrant, very dense vapour is given off, which is indebted for its odour to the presence of aldehyde and nitrous ether. It may be poured from the neck of the flask like a liquid into jars, and decanted from one vessel into another. It presents the appearance of a fog or mist, which disappears in a moment, with a pale flame, when a light is applied. Whilst this vapour is escaping, crystals are separating from the liquid. These consist of the fulminate of the black oxide of mercury. The fulminate of silver is prepared by a similar process. Both these salts detonate when rubbed or struck, and explode when a light is applied. The detonation is exceedingly violent in the case of fulminating silver, which must be taken in very small quantity. The reaction which attends the production of these salts is exceedingly complicated. It may suffice to say that the carbon of the alcohol, by combination with the nitrogen and oxygen of the nitric acid, forms fulminic acid, which afterwards unites with the metallic oxide. Fulminic acid is bibasic, and cannot be procured uncombined.

1218. If fulminating silver or mercury be prepared by the student for himself, the process must be conducted on a very small scale, and with every precaution. Dangerous accidents and loss of life have occurred, even to practised chemists. The fulminate should be collected in small quantities, on several different filters, each of which should be dried separately, and folded up with its contents. The folded papers are best kept in a bottle closed with a cork, and not with a stopper, for the friction of the latter against the neck of the bottle would be quite sufficient to detonate the powder.

1219. CYANURIC ACID, Cy_3O_3.—This is a substance of much less interest than the two preceding. It is most conveniently prepared by heating the peculiar compound of cyanic acid and ammonia, already referred to as *urea*, till it ceases to evolve ammonia. It leaves a whitish solid mass, which, when purified, forms colourless crystals of cyanuric acid. It receives its name from its relation to cyanogen and urea.

1220. FERROCYANOGEN, $FeCy_3$, or Cfy.—The ferrocyanide of potassium has been heretofore referred to as if it contained cyanide of potassium and cyanide of iron, but it does not act with the tests of prussic acid, or of iron, as it should do if this were the case; and the name by which it is known is given to it in connection with a theory which supposes it to contain a salt-radical still more complex than cyanogen, and to which the name of ferrocyanogen is given. It consists of three atoms of cyanogen and one of iron, and is *bibasylous*, or unites with two atoms of a metal or a basyle at a time. Thus the ferrocyanide of potassium consists of one equivalent of ferrocyanogen and two of potassium. When this is added to a salt of copper, it throws down a brown precipitate (ferrocyanide of copper), in which the two atoms of potassium are replaced by two of copper. Acetate of lead gives a precipitate (ferrocyanide of lead) consisting of two atoms of lead and one of ferrocyanogen, and if this be decomposed by sulphuretted hydrogen, crystals are obtained of hydroferrocyanic acid, consisting of two atoms of hydrogen and one of ferrocyanogen. The following table will illustrate this:—

Ferrocyanogen, ...	$FeCy_3$ or Cfy
Ferrocyanide of potassium, ...	$2K+Cfy$
Ferrocyanide of copper, ...	$2Cu+Cfy$
Ferrocyanide of lead, ...	$2Pb+Cfy$
Hydroferrocyanic acid, ...	$2H+Cfy$

1221. FERRIDCYANOGEN, Fe_2Cy_6, or Cfdy.—When chlorine is passed through a solution of ferrocyanide of potassium, till the liquid ceases to precipitate a persalt of iron, a reddish-green solution is procured, which yields ruby-red crystals.

1222. The new salt is called the ferridcyanide of potassium, or red prussiate of potass, and has been referred to already under the tests for iron. It has the composition $Cy_6Fe_2K_3$, and is named on the supposition that it contains a composite salt-radical, consisting of the elements of two equivalents of ferrocyanogen, and named ferridcyanogen. This radical (Cy_6Fe_2, or Cdfy) is *tribasylous*, or unites with three atoms of metal at a time, so that the ferridcyanide of potassium is $3K + Cdfy$; ferridcyanide of lead $3Pb + Cdfy$; ferridcyanide of hydrogen $3H + Cdfy$.

1223. The ferrocyanide and ferridcyanide of potassium are largely consumed in dyeing, calico-printing, and the preparation of pigments. The former gives one variety of Prussian blue with the persalts of iron, the latter another with the protosalts, as explained under the tests for iron.

1224. SULPHOCYANOGEN, CyS_2, or CSy.—When the dried ferrocyanide of potassium is melted in a crucible with half its weight of sulphur, each of the equivalents of cyanogen contained in the former combines with two atoms of sulphur, forming a compound salt-radical, *sulphocyanogen*, which remains in combination with the potassium and iron of the salt, so that it is changed into a mixture of sulphocyanide of potassium and sulphocyanide of iron. The fused mass is digested in water, and carbonate of potass added so long as it occasions a precipitate of oxide of iron. The solution then contains nothing but sulphocyanide of potassium, which is concentrated by evaporation, and deposits crystals much resembling those of nitre in appearance and taste.

1225. Sulphocyanogen, the radical of this salt, is *monobasylous*, so that the sulphocyanide of potassium is KCsy; hydrosulphocyanic acid is HCsy. The sulphocyanide of potassium or sodium is contained in the saliva. Soluble salts of this radical are known by their producing, when added even in very small quantity to persalts of iron, a blood-red liquid (sulphocyanide of iron), the colour of which is destroyed by the addition to it of solution of corrosive sublimate. The test (3) for hydrocyanic acid, given at par. 1210 (3), depends on the fact, that when prussic acid is heated with sulphur and hydrosulphuret of ammonia, it becomes the sulphocyanide of ammonium, NH_4Csy, which acts with the persalts of iron like other sulphocyanides.

⁂ There are many other compound salt-radicals besides those described in this section, such as Mellon, C_6N_4, Cobaltocyanogen, Platinocyanogen, and the like, which contain the elements of cyanogen united to the metals cobalt, platinum, &c. None of these, however, are so important, or so accessible, as those described in the text.

Ferrocyanide and ferridcyanide of potassium (yellow and red prussiate of potass) can be purchased from any druggist or drysalter, and are not costly. From them, and in truth from the first alone, all the substances described in the text can be directly or indirectly prepared, with the exception of fulminic acid. Thus the ferrocyanide of potassium, if heated in a nearly close vessel, yields the cyanide of potassium; heated in an open vessel, it yields cyanate of potass; and melted along with sulphur, it furnishes the sulphocyanide of potassium. A solution of ferrocyanide of potassium may be converted into one of ferridcyanide by passing a current of chlorine through it till it ceases to give a precipitate of Prussian blue with a persalt of iron.

Again, if the ferrocyanide of potassium be distilled with sulphuric acid, it yields hydrocyanic or prussic acid. If a solution of nitrate of silver is added to this, cyanide of silver is procured; and if red oxide of mercury is dissolved in the prussic acid, it yields, on evaporation, cyanide of mercury. From either of these cyanides, cyanogen itself is liberated as a gas, when the metallic compound is heated. The cyanate of potass, in its turn, if dissolved in water, and added to a solution of sulphate of ammonia, yields the body called *urea*, which, when heated, furnishes cyanuric acid. The materials for fulminic acid are easily procured.

ELECTRO-CHEMISTRY.

1226. Electricity is far too extensive a subject to be discussed otherwise than very briefly in an elementary work on chemistry. We notice it here, as we did heat, only in its relations to chemistry.

1227. Two views are entertained concerning the nature of electricity—some conceiving that electrical phenomena are the result of a certain condition or state of matter; others that they are occasioned by a peculiar form or kind of matter. In the present state of our knowledge, it is impossible to determine which of these views is the more probable; but we shall, in discussing electricity, take for granted, for convenience' sake, that the latter view is the just one.

1228. Electricity, then, is to be conceived of as a highly-attenuated, imponderable substance, which in ordinary bodies is latent, or, as it were, buried in them; but when they exhibit electrical phenomena, becomes sensible, and like some infinitely light elastic fluid, envelops them, or flows over them or through them. This electricity is invisible, but gives rise to phenomena cognisable by all the senses. The only electrical phenomena, however, we notice are those of a chemical character. We confine ourselves, accordingly, to *voltaic* or *galvanic electricity*, called also *galvanism*.

1229. Galvanism—which receives its name from the Italian philosopher Galvani, as it does its other term of voltaic electricity from a still more distinguished Italian, Volta—is that modification or variety of electricity which is evolved when two dissimilar solids, generally metals, are connected in a liquid which dissolves only one of them.

1230. The more dissimilar the metals are in chemical relations, the greater the intensity and quantity of the electricity produced.

1231. Thus the more prone the one metal is to unite with oxygen and bodies like it, and the less prone the other is to combine with these, the better the galvanic arrangement. Theoretically, potassium on the one hand, which oxidises spontaneously in air, and with the greatest rapidity in water, and on the other platina and gold, which do not oxidise in air or water, which are with difficulty made to combine with oxygen, and part with it when it has been united to them, with great readiness, are the metals most suitable for galvanic batteries. The cost, however, of those metals limits their use, and potassium is in many respects unmanageable. Instead of the latter, accordingly, zinc, and occasionally iron, are employed. The cost of platina does not forbid its use in small batteries. Silver also is employed, but chiefly copper, as well as charcoal, which, except as crystallised in the diamond, resembles in electrical relations a slightly-oxidable metal.

1232. We shall suppose, in the following statements, that the metals selected are zinc and copper. To produce electricity from them, they are placed in contact, or connected by a wire or band of metal, and dipped into a liquid which can furnish oxygen, chlorine, or some other salt-radical, to the more oxidable metal. The liquid in which the metals are dipped may be sulphuric, nitric, or hydrochloric acid. For simplicity's sake, we shall suppose diluted sulphuric acid taken. It will be remembered (see Hydrogen) that when zinc decomposes diluted sulphuric acid, it combines with the oxygen of the water of the oil of vitriol, HO,SO_3, and liberates its hydrogen. During this decomposition electricity is evolved, provided the zinc be connected with copper, or some other slightly-oxidable metal. The following experiment will illustrate this:—A plate of sheet-zinc is washed with diluted sulphuric acid to clean it, and a little quicksilver is then rubbed over its surface. The mercury combines with the zinc, forming an alloy or amalgam, so that the latter metal is said to be amalgamated. A piece of sheet-copper is also taken of

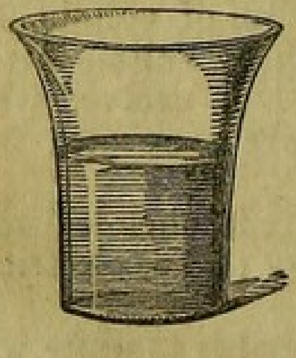

Fig. 72.

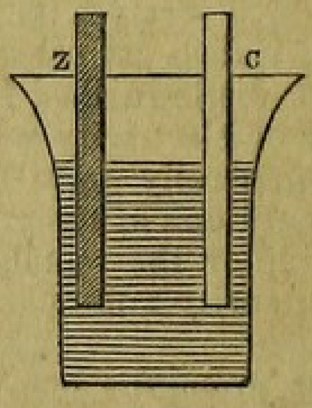

Fig. 73.

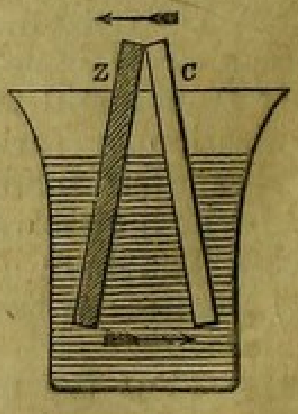

Fig. 74.

the same size as the plate of zinc, and the two metals are placed side by side, without touching, in a glass tumbler or beaker containing diluted sulphuric acid (see fig. 72). They need not be immersed to more than half their length.

1233. So long as the copper and zinc do not touch each other (see fig. 73), the liquid remains quiescent, for amalgamated zinc does not dissolve in diluted sulphuric acid, with the evolution of hydrogen, as the ordinary metal does. If, however, the upper ends of the metallic plates above the surface of the liquid be made to touch (see fig. 74), decomposition of the acid immediately begins. The zinc combines with the oxygen, forming oxide of zinc, and that with the acid produces sulphate of zinc; the hydrogen is set free; and at the same time electricity is developed. The production of the latter is recognised chemically as follows:—A copper wire is soldered to each plate, and to the free extremity of the former a short wire of platina is attached. A piece of filter-paper is then soaked with a solution of iodide of potassium, and laid on a sheet of glass. If the platina wires are now pressed down on the paper close to each other, but not touching, a brown spot will appear where the wire from the copper rested on the paper, owing to the decomposition of the salt and separation of the iodine. The nature and cause of the decomposition will appear more fully further on.

1234. If the phenomena be closely watched, the following appearances are noticed:—1. The zinc dissolves only when metallically connected with the copper; 2. Electricity appears only whilst the zinc dissolves; 3. The oxygen of the water combines with the zinc; 4. The hydrogen of the water rises in bubbles solely from the copper, no effervescence appearing around the zinc or in the space between the two plates.

1235. The electricity which is developed at the zinc plate flows through the liquid to the copper plate, and from the copper returns to the zinc. The electricity developed at the copper plate flows in the opposite direction through the liquid to the zinc, and from it back to the copper. The arrows in the accompanying figure show the direction of one of these currents of electricity—namely, that from the zinc to the copper in the liquid, and from the copper to the zinc out of it. The plates are connected by a wire, instead of simply touching.

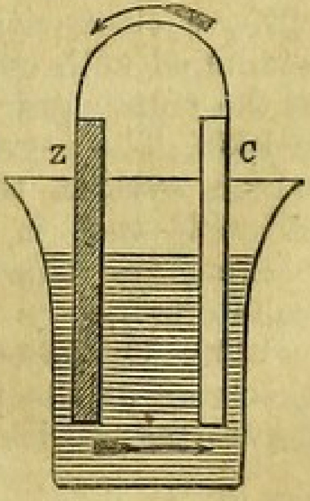

Fig. 75.

1236. There are thus, it will be observed, two opposite currents of electricity. That commencing at the zinc is termed *positive* electricity; that beginning at the copper, *negative* electricity.* They are exactly equal in power, and possess the same properties. When they meet each other, they combine, and all manifestation of either electricity ceases. Whenever electricity is developed, it displays itself in this twofold way; as much positive electricity being exhibited in one direction as of negative electricity in another. In this respect electricity exactly resembles magnetism. A magnet, for example, such as a compass-needle, exhibits certain powers of attraction and repulsion, &c. at its northern extremity or pole; and exactly similar and equal powers, but acting in a different direction, at its southern pole; so that there are two magnetisms, a northern and a southern, as there are two electricities, a positive and a negative. In discussing a magnet, however, reference is generally made only to one of its poles, as in northern latitudes like our own, to the north pole—it being taken for granted that every one is aware that, if a compass-needle point with one pole to the north, it must point with the other to the south. In like manner, in describing electrical phenomena, the positive electricity alone is generally denoted, it being all the while implied that negative electricity is simultaneously developed.

1237. An arrangement such as we have described is called a galvanic or voltaic pair or circle. One of its solid constituents is called its positive element; the other its negative element. The term positive is used in a twofold sense—namely, 1*st*, To indicate the metal at which the positive electricity is evolved; and also, 2*d*, In a more restricted sense to indicate the body which undergoes a positive change whilst the production of electricity is proceeding. Thus the zinc which evolves the positive electricity, and which is positively affected—that is, combined with oxygen, and dissolved—is the positive element of the voltaic pair we have described.

1238. The negative element, on the other hand, is the solid which evolves the negative electricity, and is negatively affected—that is, not oxidised or dissolved. Copper, silver, platina, and charcoal or coke, are the negative elements of voltaic pairs.

1239. The association of a positive and negative element in a solvent of the positive element, renders more intense their contrasted positive and negative characters. Thus diluted

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* The beginner must guard against supposing that the one of these electricities has a more *positive* or *real* existence than the other. The names are quite arbitrary, and might be reversed, so far as the characters of the two electricities are concerned. They are equally real and powerful.

nitric acid can dissolve copper as well as zinc, but the latter more readily than the former. If the metals, however, be connected metallically, as in fig. 75, and plunged into the acid, the copper does not dissolve at all, whilst the zinc dissolves much more rapidly than if not connected with a more negative metal.

1240. It was on this principle that Davy sought to protect the copper-sheathing of ships. Copper dissolves in sea-water; but if small pieces of zinc be attached to its surface, it totally ceases to dissolve, and the zinc alone suffers waste. Iron, in the same way, is protected from rusting by a thin coating of zinc. In virtue of the same law, the thinnest sheets of platina or silver may be employed in voltaic batteries, as they undergo no solution; whilst the zinc plates require from time to time to be renewed.

1241. A voltaic pair or circle consists generally of one zinc and one copper plate. To each a wire is soldered; and the pair of wires may be considered as the halves of the continuous wire-bridge or saddle, which we have hitherto supposed to connect the plates together. The free ends of these wires are named the poles of the circle, because, like the ends of bar-magnets, they possess certain powers of attracting and repelling. They are also, and still better, named *electrodes;* a term of Greek origin, which signifies electrical path or way, in reference to their being the gateways or passages by which the electricity developed by the voltaic arrangement passes into, or out of, substances. The ends of the wires are generally tipped, or terminated, by pieces of platina when chemical decomposition is to be effected, so that most circles have platina poles or electrodes. The one of these—that, namely, which proceeds from the copper—is termed the positive pole or electrode; and that from the zinc, the negative pole or electrode; for the positive electricity which originates at the zinc plate passes through the liquid to the copper, and the negative electricity originating at the copper passes through the liquid to the zinc.

1242. The electricity developed by a single voltaic pair, however large, is much too feeble in intensity to produce chemical decomposition to any great extent. To effect this, it is necessary to make use of a series of pairs arranged together. Such an arrangement, which admits of many modifications, goes by the name of a voltaic or galvanic battery.

1243. If we suppose, as before, a number of pairs of copper and zinc taken, with the zinc and copper of each connected by a wire or metallic bridge, we have all that is requisite for a voltaic battery. The pairs are arranged, to the number of two, three, or four hundred, in tumblers or beakers of acidulated water, as exhibited in fig. 76. The zinc of one pair, it will be observed, stands in the same vessel as the copper of the next pair, and is connected by a wire with a plate in the adjoining glass. We have thus, beginning at the one end, a zinc plate, and at the other end a copper plate, which stand alone in the glass at either extremity of the arrangement. To provide each of these solitary plates with one of the opposite metal, one of the pairs with which the battery has been arranged is, as it were, cut in two. Its zinc element is placed in the glass containing the solitary copper plate, and its copper in the vessel containing the solitary zinc plate (see fig. 77). To each of these single terminal plates a copper wire is soldered, to the free end of which a plate of platina is attached. The pieces of platina, as in the single battery, are the poles or electrodes; that connected to the copper plate is the positive electrode, and that to the zinc the negative electrode (see fig. 78).

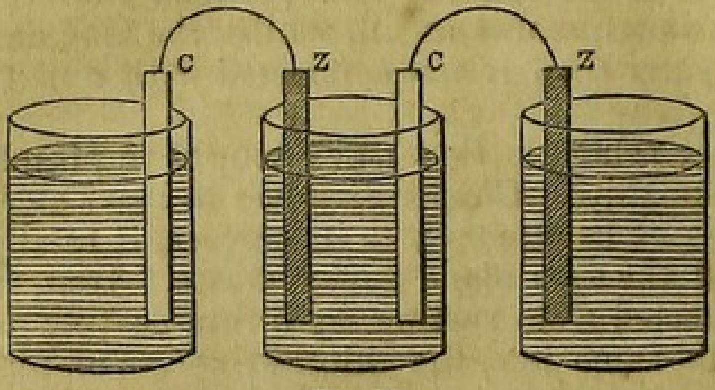

Fig. 76.

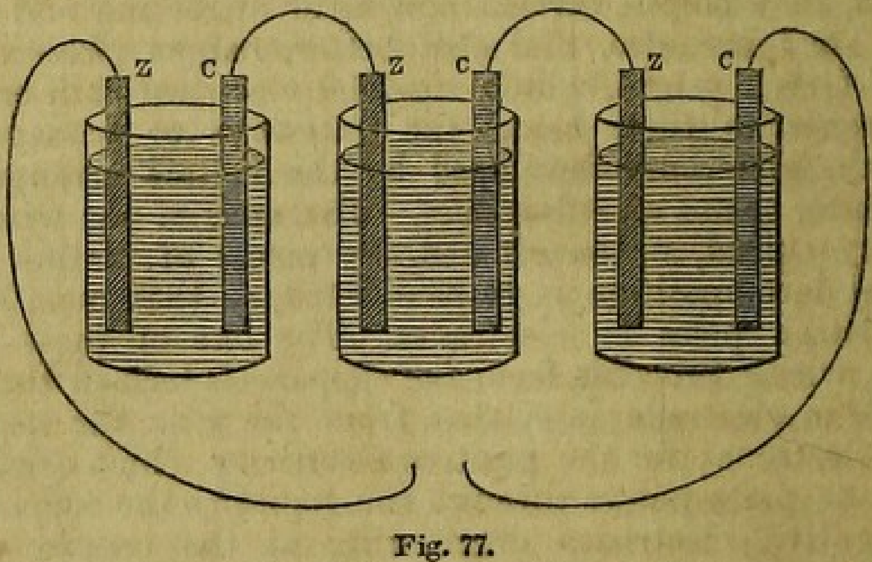

Fig. 77.

1244. Such an arrangement as we have described gives off no greater quantity of electricity than one of its pairs would evolve; but the intensity of the electricity is much greater than that of a single pair, and, in particular, its power to effect chemical decomposition is much exalted.

1245. The principle of the voltaic battery is the same as that of the simple circle. No solution of the amalgamated zinc occurs in either, and no electricity is developed unless a channel of conveyance, or conducting medium for the electricity, is provided. It is not necessary, however, that the bond of connection should be metallic. Thus in the decomposition of solution of iodide of potassium by a single pair, referred to previously (par. 1233), the metallic bridge is cut across. The solution of the iodide, however, fills up the gap, and can conduct electricity, which traverses it accordingly, and whilst so doing, decomposes it. Fig. 79 illustrates this, the solution of the iodide being represented as contained in a vessel, not as soaking filter-paper.

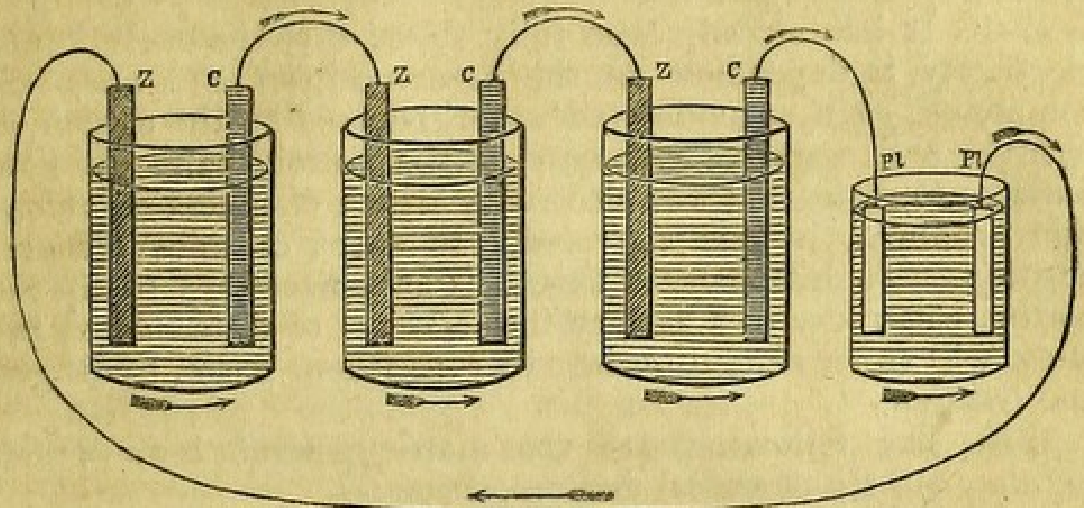

Fig. 78.

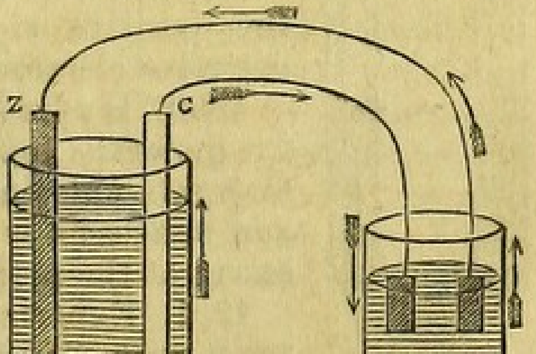

Fig. 79.

1246. In the battery (fig. 77), if amalgamated zinc be used, no metal is dissolved, no hydrogen evolved, nor any electricity developed, so long as no communication exists between the last zinc at one end and the last copper at the other. If the wires soldered to these terminal plates be twisted together, they quickly grow hot, each zinc plate dissolves, and hydrogen rises from each copper one. Electricity at the same time is evolved, and travels through the arrangement in an unbroken circuit. The arrows in fig. 78 show the direction in which the positive electricity set free at each zinc plate moves.

1247. If the terminal wires, instead of being placed in contact, are dipped into a liquid which electricity can decompose, it is evolved, and circulates exactly as if the gap had been filled up by a bridge of metal, only it decomposes the liquid as it passes. In fig. 78 this is shown, the wires being terminated in pieces of platina.

1248. It has already been fully stated that the evolution of electricity is dependent on the decomposition of a chemical compound, such as acidulated water, effected by the conjoined positive and negative elements of the voltaic pair. It now remains to state that the electricity which chemical combination produces, is able conversely to effect chemical decomposition. To demonstrate this, it is only necessary to dip the platina electrodes of a battery into a vessel of water, when the latter will suffer resolution into its constituent gases, hydrogen and oxygen.

1249. The following are the more general laws which regulate electro-chemical decomposition :—

1. Electricity does not decompose compound gases, however susceptible of decomposition by other agencies.

2. It does not decompose compound solids.

3. It decomposes liquids, but only those which conduct it.

4. It decomposes only such conducting liquids as consist of two elements in single equivalents, like water, or which may be represented as similarly made up of halves, like protosalts.

5. When it decomposes such primary or secondary binary compounds as we have indicated, it separates them into their two elements or halves, the one of which manifests itself at the positive electrode, and the other at the negative electrode.

1250. Hydrogen, metals, oxides, and bases in general, appear at the negative electrode. Oxygen, chlorine, the other salt-radicals, acids, and non-basic bodies in general, manifest themselves at the positive electrode.

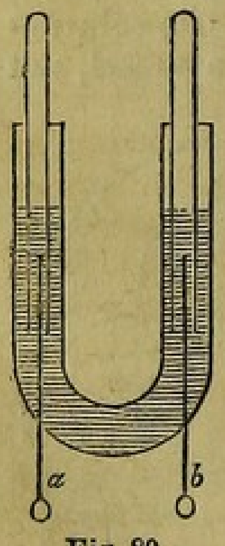

Fig. 80.

1251. Experiments in proof of this are best tried with the apparatus shown in fig. 80. It consists of an inverted glass siphon or U-shaped tube, provided with platina wires, *a b*, passed through apertures in the glass, which they exactly fit, so that the tube is water-tight. In default of such an arrangement, a glass tube may be bent into the shape of a U or V (see fig. 81), and the platina electrodes pushed down so that one shall lie in each limb.

1252. The most beautiful perhaps of all decompositions is that of water. To observe this, the U tube should be filled with water containing in solution sulphate of soda, which increases its conducting power for electricity. Whilst the siphon is kept below the surface of water, a test-tube full of the same liquid is inserted with its mouth downwards into each limb, as shown in fig. 80. The whole is then lifted out of the liquid, and, whilst supported by a convenient stand, is placed in metallic connection with the battery, by attaching each wire from the latter to one of the platina wires fixed into the glass, or by dipping the electrodes, which must be of platina, into each limb of the siphon. Bells of gas will immediately be seen to ascend from each wire, and, rising into the tube above it, will accumulate there. At the same time, it will be observed that no bubbles of gas show themselves in the space below and between the electrodes. The gas which collects above the negative electrode will exceed in volume that in the tube above the opposite electrode, and if tried by a light, will be found to burn with the flame of hydrogen. The gas above the positive electrode, which, if some of it were not retained in solution by the water, would occupy exactly half the space filled by the hydrogen, is the oxygen of the water. If this gas be tried with a red-hot match, it will kindle the latter into full combustion. The gases from each tube may be mingled, and the mixture fired, and it will explode, producing water.

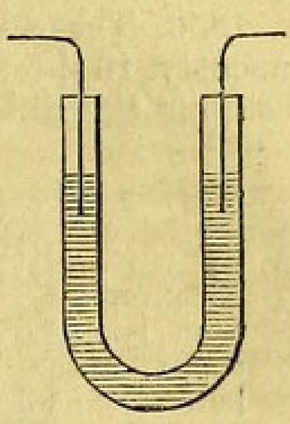

Fig. 81.

1253. If the test-tubes are now removed, and infusion of purple cabbage added to the solution of sulphate of soda contained in the siphon, the Glauber's salt will be decomposed into sulphuric acid and soda. The acid collecting round the positive electrode will redden the liquid there, whilst the soda accumulating at the negative electrode makes the liquid around it green. In the bend of the siphon the original purple will be retained.

1254. If the wires or electrodes be now shifted, so that the limb of the siphon, which contained the positive electrode, shall have the negative one within it, and *vice versâ*, the reddened liquid in the one limb will first become purple, and then green, and the green liquid purple, and then red. The shifting of the electrodes determines the sulphuric acid, and the soda respectively, to pass to the limb opposite to that in which they became free before, so that the change in tint of the colouring matter is exactly reversed.

1255. This experiment may be repeated with solution of sulphate of soda coloured with litmus, when the contents of the one limb will become red, and those of the other blue. If the solution of Glauber's salt be coloured with turmeric, the liquid round the positive electrode will be yellow, round the negative brown.

1256. The whole three effects may be observed simultaneously, if three plain siphons, or the U tubes, be taken, containing the different-coloured solutions of sulphate of soda, (see fig. 82). The middle one is connected to those on either side by a platina wire, bent like a hair-pin, and one of the electrodes is placed in each of the outer limbs of the external siphons. Decomposition will proceed contemporaneously in each tube in the way mentioned already, the connecting wires acting like the battery electrodes.

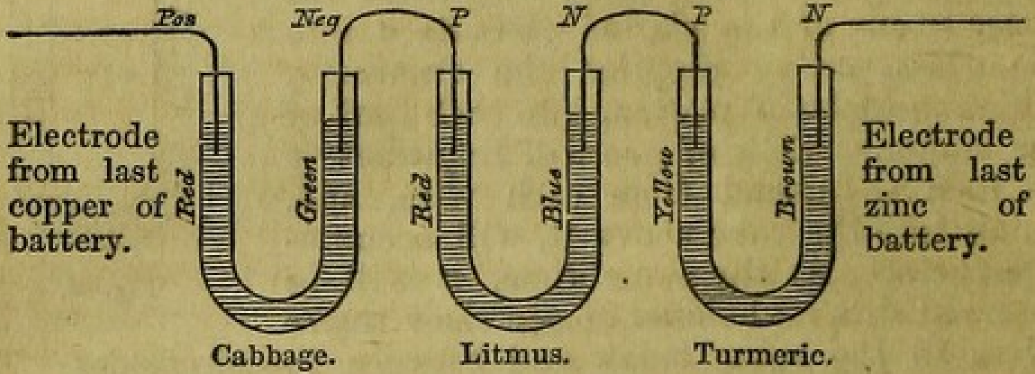

Fig. 82.

1257. If a solution of iodide of potassium, containing gelatinous starch, be placed in the U tube, the iodine will be separated at the positive electrode, and colour the starch blue.

1258. If a solution of sulphate of indigo, acidulated with hydrochloric acid, be employed, the chlorine of the acid will be evolved at the positive pole, and render the liquid colourless by bleaching the indigo. Instead of the U tube, two test-glasses may be used (see fig. 83). They are connected by a piece of lamp-wick, soaked in the solution to be decomposed by the electricity. The positive electrode is placed in the one glass, and the negative in the other.

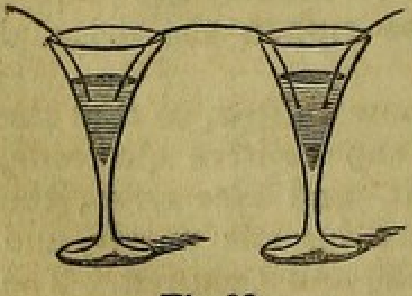

Fig. 83.

1259. If a solution of sulphate of copper, nitrate of silver, or acetate of lead, be placed in a test-glass, and the electrodes dipped into it, the metal will crystallise around the negative electrode.

1260. The decomposition of chemical compounds by electricity in the way illustrated by the experiments described above is called *electrolysis*, a term which signifies *chemical analysis effected by electricity.* Substances which can be analysed in this way are named *electrolytes.*

1261. The only electrolytes, as stated already (par. 1249), known to us are those liquids or compounds in a state of solution which consist of equivalent halves, such as a salt-radical and a basyle, or an acid and a base.

1262. Many other bodies may be decomposed by directing against them powerful electrical discharges from a large friction machine, or by exposing them to lightning strokes. This, however, is not electrolysis, but appears to be owing to the intense heat and violent disruptive action of electricity of great intensity.

1263. At one time electrolysis was supposed to be occasioned by certain attractive and repulsive forces resident in the poles of a battery. The oxygen, for example, of water was supposed to separate at the positive pole, because it attracted the particles of the gas towards it, whilst the negative pole was simultaneously attracting the hydrogen of the water, and each pole, moreover, was regarded as repelling the element which it did not attract. Each half of an electrolyte was thus supposed to be powerfully repelled by the one pole, and powerfully attracted by the other. This view is now altogether abandoned. No proofs of attraction and repulsion can be given. No motion of the separated elements of an electrolyte towards either pole can be shown. On the other hand, electrolysis can be effected without solid poles, or the employment of any surface answering to these, which can be supposed to possess attractive or repulsive powers. Thus if a piece of paper soaked in a solution of iodide of potassium, and pointed like a compass-needle at both ends, be balanced on an inverted wine-glass, and placed opposite to a friction electrical machine, with one of its ends near to the prime conductor, but not touching it, whilst the other end of the slip of paper is opposite, but not touching the extremity of a wire connected with the ground; on turning the machine, a current of electricity will traverse the paper, and whilst so passing, decompose the iodide of potassium. In this arrangement, however, there are no poles. A space filled with air constantly in motion separates the paper, at the one end from the machine which supplies the electricity, and at the other from the wire which carries it away. From this simple experiment, and from many others, it appears that all that is essential to electrolysis is the passage of a current of electricity through an electrolyte. The electricity, however, of the largest voltaic battery has not sufficient intensity to traverse air as that from the friction machine can. It is necessary, accordingly, with the former apparatus to make use of plates or 'poles' of platina to conduct the voltaic electricity into the body it shall decompose. Inasmuch, however, as the so-called poles are in reality only channels or doorways for the entrance and exit of the electricity, they are now named electrodes—that is, literally, electrical gateways.

1264. Friction electricity, as stated in the preceding paragraph, can find its way into electrolytes more readily than voltaic electricity can ; but the quantity of the former evolved per minute or hour is so very small, that the amount of decomposition it can effect is quite insignificant, compared with the electrolytical power of the latter.

1265. The subject cannot be pursued further. In the special treatise on Electricity which forms one of the volumes of the Educational Course, the science is treated at length; and in the larger text-books on chemistry the laws of electrolysis will be found discussed in full.

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