Chemistry / by Alex. Crum Brown.

CHAMBERS'S
SCIENCE MANUALS

CHEMISTRY

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ELEMENTARY SCIENCE MANUALS.

CHEMISTRY

BY

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W. & R. CHAMBERS
LONDON AND EDINBURGH
1880

Edinburgh :
Printed by W. and R. Chambers.

PREFACE.

THE vital importance of diffusing some knowledge of the leading principles of Science among all classes of society, is becoming daily more widely and deeply felt; and to meet and promote this important movement, W. & R. CHAMBERS have resolved on issuing the present Series of ELEMENTARY SCIENCE MANUALS. The Editors believe that they enjoy special facilities for the successful execution of such an undertaking, owing to their long experience—now extending over a period of forty years—in the work of popular education, as well as to their having the co-operation of writers specially qualified to treat the several subjects. In particular, they are happy in having the editorial assistance of ANDREW FINDLATER, LL.D., to whose labours they were so much indebted in the work of editing and preparing *Chambers's Encyclopædia.*

The Manuals of this series are intended to serve two somewhat different purposes:

1. They are designed, in the first place, for SELF-INSTRUCTION, and will present, in a form suitable for private study, the main subjects entering into an enlightened education; so that young persons in earnest about self-culture may be able to master them for themselves.

2. The other purpose of the Manuals is, to serve as TEXT-BOOKS IN SCHOOLS. The mode of treatment naturally adopted in what is to be studied without a teacher, so far from being a drawback in a school-manual, will, it is believed, be a positive advantage. Instead of a number of abrupt statements being presented, to be taken on

trust and learned, as has been the usual method in school-teaching; the subject is made, as far as possible, to unfold itself gradually, as if the pupil were discovering the principles himself, the chief function of the book being, to bring the materials before him, and to guide him by the shortest road to the discovery. This is now acknowledged to be the only profitable method of acquiring knowledge, whether as regards self-instruction or learning at school.

For simplification in teaching, the subjects are divided into sub-sections or articles, which are numbered continuously; and a series of Questions, in corresponding divisions, are appended. These Questions, while they will enable the private student to test for himself how far he has mastered the several parts of the subject as he proceeds, will serve the teacher of a class as specimens of the more detailed and varied examination to which he should subject his pupils.

NOTE BY THE AUTHOR.

It will be observed that in the present sketch of the Science of CHEMISTRY, various systems of nomenclature and notation of salts are employed. This has been done purposely, in order that the student may become familiar with all the systems in common use; and as the relations of these systems to one another are fully explained, the teacher who prefers to adhere to one system, will have no difficulty in translating the names and formulæ so as to make them uniform throughout.

EDINBURGH,
June 1875.

CONTENTS.

PRINCIPLES OF THE SCIENCE.

THE FACTS OF CHEMISTRY.

ORGANIC CHEMISTRY.

CHEMISTRY.

PRINCIPLES OF THE SCIENCE.

INTRODUCTORY.

1. CHEMISTRY is a department of physical science, and therefore treats of the properties and changes of matter.

As the division of physical science into various departments depends more upon the various methods which we use in observing the phenomena of nature, than upon any real natural distinction, it is impossible to give a logically complete definition of any of these departments; and what now belongs to one, it may be found, at some future time, more convenient to transfer to another. It is not, therefore, necessary, either to quote any of the numerous definitions of chemistry already given, or to add one to the number. The reader will be able to form an idea of its scope and purpose from the outline of the facts and principles of the science contained in the present sketch.

2. *Matter of Various Kinds.*—Matter, whether as it occurs in nature, or as modified by art, is obviously of various kinds, and any specimen of matter that we may examine is either all of one kind, or a mixture of several different kinds. There are various means by which we can determine whether a specimen of matter is pure (that is, all of one kind) or not.

3. We can often prove that a substance is a mixture by simple inspection. Thus, any one who looks at a piece of granite at once sees that it consists, not of one substance, but of a mixture of several, the particles of each being large enough to be distinctly visible. The smaller the particles, and the more intimate the mixture, the more difficult does it

become to distinguish it, by simply looking at it, from a pure, single substance. Where the eye cannot settle the question, we must resort to other means. These may be described generally as ways of "taking samples." If samples taken in many different ways agree with one another, and with the original substance, we conclude that we have to deal with a pure body; if, on the contrary, the samples differ from one another, we learn that the substance is a mixture, and, further, find out how to separate it into its several ingredients. A few of these "tests of purity," or ways of taking samples, may be here described.

4. *Separation of Mixed Substances—Elutriation.*—In the first case let us suppose that we have a substance, no part of which dissolves in water, and which consists of very small particles of two or more bodies of different specific gravity. The substance is reduced to a fine powder, and stirred up with water. This is left for a time at rest, and gradually a part of the powder separates—if heavier than water, as a sediment at the bottom; if lighter than water, as a scum at the top. The scum is then removed, or the muddy water poured off from the sediment and again left at rest, when a further portion separates; and by repeating this process, we obtain a series of samples differing from one another in the rate of deposition. If the substance were all of one kind, these samples would only differ from one another in the *size* of the particles, the largest separating most rapidly; but if we have a mixture, we find that (supposing the particles of the different ingredients to be of the same average size) the particles which are denser than water go down the faster the denser they are, and the particles lighter than water rise to the surface the faster the lighter they are, so that the first sample differs in kind from the last. This method of "elutriation" (Lat. *washing out*) is exemplified in the washing of ores; the lighter clay or earth with which the ore is mixed, falling slowly through the water is washed away as mud, while the heavier ore falls quickly to the bottom of the vessel in which the washing is performed, and is thus retained.

5. *Solution.*—Some substances, such as sugar, salt, etc., dissolve in water; others, such as sand, charcoal, etc., do

not. We can therefore detect a mixture of a soluble and an insoluble substance, and separate them from one another, by treating the mixture with water until no more will dissolve: we have then the insoluble substance left, and can recover the soluble one from the liquid by evaporating away the water. This process, sometimes called "lixiviation," is used in extracting saltpetre from earth containing it, in obtaining potash from wood-ashes, and in many other important operations. Other liquids besides water may be used for such a purpose, a liquid being selected which will dissolve some of the ingredients in the mixture and leave others undissolved. The solution is separated from the insoluble residue, either by allowing the latter to settle and then decanting, or by filtration.

6. *Filtration* is a process in which solid particles are separated from a liquid by means of a filter, *i.e.*, a porous substance which allows the liquid to run through but retains the solid particles. Various substances are used for this purpose—on the large scale, water is filtered through "filter-beds" of sand and gravel; in the chemical laboratory, muslin, calico, and "filter paper" are used. Filter paper is a very pure unsized paper, and is almost always used in operations on a small scale, and in analytical processes.

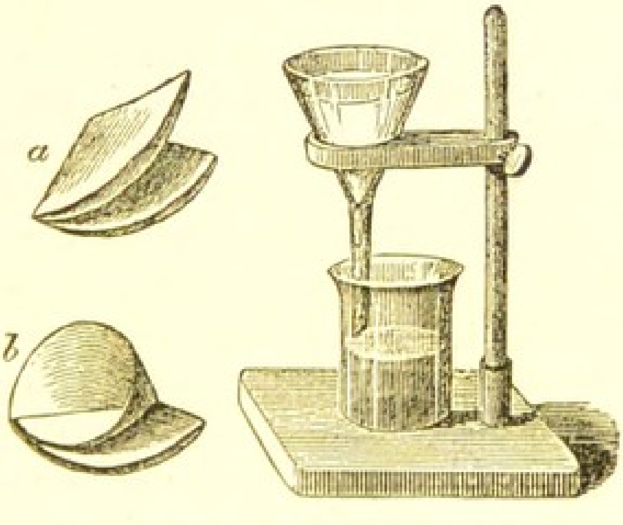

Fig. 1.—Paper Filter.
a, *b*, Method of folding the paper.

7. *Crystallisation.*—Substances soluble in water require

very various proportions of water to dissolve them; thus 100 parts of water will, at the ordinary temperature, dissolve 33 parts of Epsom salts, 20 parts of washing-soda, 10 parts of bicarbonate of soda (common "baking-soda"), and about one-third of a part of plaster of Paris. If, then, a mixture of soluble substances be dissolved in water, and the water gradually evaporated, the least soluble of the substances will separate first; and by collecting separately the successive crops of crystals, we shall have a series of samples, the first consisting almost exclusively of the least soluble, the last of the most soluble. Such a method of separation is seldom perfect, each crop generally containing some admixture of the ingredients prevailing in the crop before and in that after it. It is in this way that common salt is obtained from sea-water. Sea-water contains, besides common salt, smaller quantities of various other salts. Of these the least soluble is sulphate of lime, and this is the first to appear on evaporating the water; the common salt crystallises next; and the "mother-liquor," as the solution left after the common salt has been removed is called, contains salts of magnesia, which are very soluble.

8. *Dialysis.*—If a solution of common salt be securely tied up in a bladder, and the bladder be hung in a vessel filled with pure water, it will be found after a time that the water outside the bladder is as salt as that within; and if the water outside be frequently renewed, the whole of the salt can be removed from the bladder. If instead of a solution of salt, we take a solution of glue (weak enough to prevent it *setting* as a jelly), we find that practically none of the glue escapes into the outer vessel. If a mixture of salt and glue be treated in this way, the two substances will be separated—the salt passing through the bladder, and the glue remaining behind. Many substances, especially those which crystallise, behave like salt, and pass through the bladder; while many other substances, especially those, which like glue, do not crystallise but form jellies, and when dried, appear as horny masses, pass extremely slowly through the bladder. The late Mr Graham, Master of the Mint, who discovered this method, called the first set of bodies "crystalloid"—that is, crystal-

like; and the second "colloid"—that is, glue-like bodies. Dialysis (Gr. *separation*) is used in detecting poisons in animal fluids, such as the contents of the stomach. Most of the important poisons are crystalloid; while most of the animal fluids that interfere with the detection of poisons are colloid, so that the two can be separated by this means.

9. *Fusion.*—A mixture of a fusible and an infusible substance may be resolved into its ingredients by heating it till the fusible body melts, and then pressing it, or allowing it to drain away from the infusible residue. The same method may be employed to separate from one another two substances of different degrees of fusibility, by heating the mixture to a temperature higher than the fusing-point of the one, and below the fusing-point of the other.

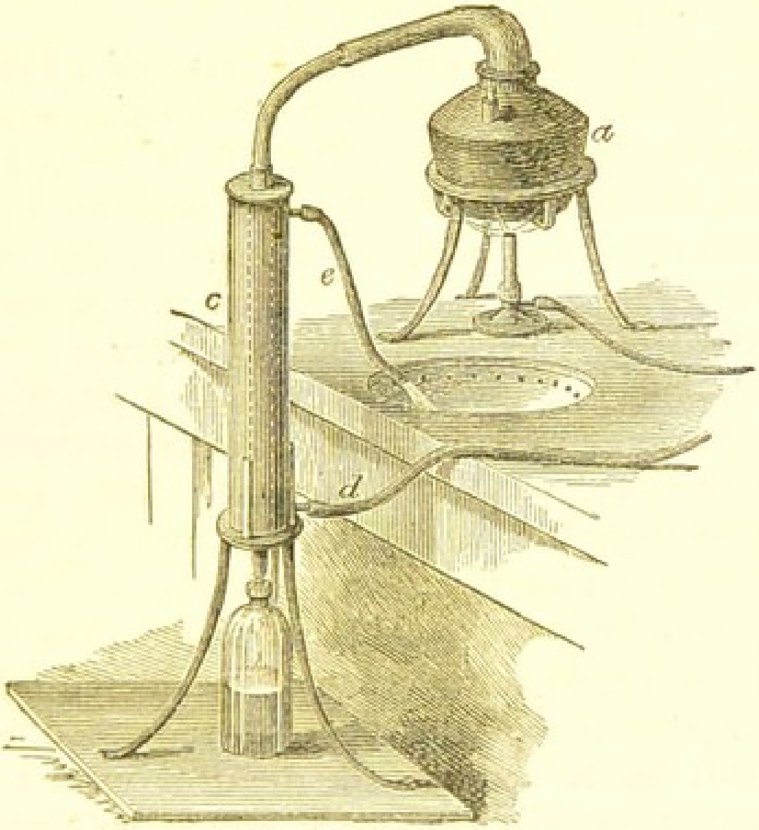

Fig. 2.—STILL.
a, Retort; *c*, condenser; *d*, cold water entering condenser; *e*, warm water issuing.

10. *Distillation.*—Some substances are *volatile*—that is, can be converted by the action of heat into vapour, which,

when cooled, is condensed, or restored to the liquid or solid state. By distillation we can separate volatile from non-volatile bodies. The mixture is heated in a vessel (retort or still), to which a tube is adapted, to convey the vapour to the "condenser," where it is cooled. The volatile substance distils over, while the non-volatile ingredient remains in the retort or still. By what is called *fractional distillation*, it is possible to separate, more or less completely, substances of different degrees of volatility; the first portion of the distillate contains a larger proportion of the more volatile ingredient, and the last a larger proportion of the less volatile. Thus, when the "wash," or liquid formed by the fermentation of malt, is distilled, the first portion consists of a very volatile product called the "foreshot;" then alcohol mixed with water distils over; and lastly, a substance less volatile than alcohol, the "fousel oil."

11. *Diffusion of Gases.*—If a heavy gas and a light gas are placed together in a vessel, the heavy gas below and the light above, they slowly mix even when left at rest; but, when once mixed, they shew no tendency to separate; and however long the mixture is kept, the mixture at the top will be found to have the same composition as that at the bottom. It is, therefore, often necessary to apply a test, in order to determine whether a given specimen is a single gas or a mixture. Some of the methods already mentioned may sometimes be employed for this purpose. Thus, gases differ in their solubility, and in this way it may be shewn that atmospheric air is a mixture, one of its ingredients (oxygen) being considerably more soluble in water than the other (nitrogen). Again, some gases can be condensed into liquids by cold and pressure, and thus partially separated from those which cannot be so condensed. By this means Faraday discovered in oil gas the gas now known as butylene.

12. There is, however, a special method by which, in almost all cases, mixtures can be distinguished from single gases. The slow mixing of two gases, of which we have just spoken, and which is known as "diffusion" of gases, takes place not only when the two gases are in immediate contact, but also when they are separated by a porous septum (such as a

plate of unglazed earthenware), and in this case it is easy to measure the "rate of diffusion" by observing what quantity of gas passes through the septum in a given time. Now, different gases have different rates of diffusion—the lighter the gas, the faster does it diffuse.* If, then, a mixture of two gases of different density be allowed to diffuse through a porous plate, more of the lighter gas will pass out, and proof will be obtained that the specimen was a mixture, and not a single gas.

The various methods of which a general description has been given above are physical or mechanical modes of separating completely or partially the ingredients of a mixture, and thus, more or less perfectly obtaining pure substances. By these methods the ingredients are, if we may use the expression, *picked out* of the mixture, as the visibly different particles can be picked out of crushed granite; the ingredients are not in any way changed, and we have merely to mix them —that is, put the particles side by side—in order to reproduce the original mixture.

DECOMPOSITION OF COMPOUNDS—CLASSIFICATION.

13. Let us now consider some of the properties of these pure substances. For this purpose, it is necessary to classify them, or arrange them in groups. This may be done in several different ways. We may, for instance, distinguish them as, first, simple ; and second, compound. A compound substance is one which we can, by the application of some process, separate into two or more pure substances, different from each other and from the original substance. We shall give an instance, and shew how a compound differs from a mixture. White statuary marble is a pure body; it cannot, by any mechanical process, such as have been described above, be separated into ingredients—any such mechanical mode of sampling it, yields samples identical with one another. But if we weigh a piece of marble in a crucible the weight of which is known, and then raise it to a bright red-heat, we

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* Experiment has shewn, in complete accordance with theory, that the rate of diffusion is inversely proportional to the square root of the density of the gas.

find that, upon cooling, it weighs less than it did before. If we continue the heating until no further change of weight is produced, we find that one hundred parts of marble are reduced to fifty-six. Something must have been lost in this process, and it can be shewn that this something is a gas, or kind of air, which the marble gives off when strongly heated. By appropriate means we can catch this air, and shew that one hundred parts of marble give off exactly forty-four parts of it by weight. What is left in the crucible is not marble—it differs entirely from it in appearance and properties—it is quicklime. We have thus decomposed marble into two substances, quicklime, and a gas, which its discoverer, Dr Black, called "fixed air," because it had been in a fixed or solid condition in the marble. We shall afterwards see what this gas is—in the meantime we may call it fixed air. By heating marble we have then obtained from it two different substances, lime and fixed air: but it will be at once seen that this *decomposition* is quite another thing from the separation of a mixture into ingredients. Marble is not a *mixture* of lime and fixed air; it is a pure substance, having properties of its own; thus, lime and fixed air are both soluble in water, marble is not; marble is tasteless, while both of the bodies formed from it have well-marked tastes. The space occupied by a piece of marble is not the same as that occupied by the lime and fixed air which can be obtained from it. On the other hand, the properties of the ingredients of a *mixture* remain unchanged—that is, are the same in the separate and in the mixed state; and the space occupied by a mixture is the same as that occupied by the ingredients unmixed.

14. *Synthesis.*—A large number of substances can be directly decomposed by the action of heat, light, or electricity, and thus proved to be compounds, as we have seen is the case with marble; and in many cases we can reverse the process, and prove that a substance is compound by forming it from its components; thus, quicklime and fixed air unite and form a substance identical in chemical characters with marble.*

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* Sir James Hall has shewn that if this substance (*amorphous* or *uncrystallised carbonate of lime*) is heated under great pressure, it does not decom-

By this process of "synthesis" (Gr. *putting together*) we can often prove that substances which we are unable to decompose directly are really compounds. Thus, quicklime cannot be decomposed without the addition of some other substance, but we can prove it to be a compound by effecting its synthesis. The metal calcium, which can be obtained from lime by a series of processes which will be described further on, unites with oxygen gas, and the resulting compound is quicklime. The compound character of quicklime, and the nature of its components, are as clearly proved by this synthesis as they could be by the direct decomposition of quicklime into calcium and oxygen.

15. *Elements.*—There are, however, a considerable number of substances (sixty-three are at present known) which chemists have not as yet been able either to decompose, or to produce by synthesis. Such substances have, therefore, not been proved to be compound, and are provisionally styled "elements," or simple bodies. All compounds are composed of two or more of these elements united together; and compounds are sometimes classified as binary, ternary, quaternary, etc., according as they consist of two, three, four, etc., elements.

16. *Substances grouped in Families.*—A more generally useful system of classification of pure substances is to arrange them in groups or natural families according to their resemblances in chemical action. This system will be best illustrated by means of examples, and for this purpose five groups are here selected, which include the most important and useful substances, and the relations of which exhibit most strikingly the nature of chemical action. These five groups are (1.) Acids, (2.) Bases, (3.) Salts, (4.) Metals, and (5.) Salt-radicals.

As particular examples of these groups, the following substances may be mentioned—(1.) Acids: Sulphuric Acid (oil of vitriol), Nitric Acid (aquafortis), Hydrochloric Acid (spirit of salt), Acetic Acid (vinegar). (2.) Bases: Caustic Potash, Caustic Soda, Lime, Magnesia, Oxide of Lead

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pose, but fuses, and, on cooling, forms a substance in all respects the same as white marble.

(litharge), Ammonia (spirit of hartshorn). (3.) Salts: Sulphate of Soda (Glauber's salt), Sulphate of Magnesia (Epsom salt), Chloride of Sodium (common salt), Chloride of Ammonium (sal-ammoniac), Acetate of Lead (sugar of lead), Nitrate of Potash (salpetre). (4.) Metals: Potassium, Sodium, Calcium, Magnesium, Zinc, Iron, Copper, Silver. (5.) Salt-radicals: Chlorine and Iodine.

ACIDS, BASES, SALTS.

17. *Acids, Bases.*—If we examine the acids above mentioned, we find that they possess certain well-marked characters in common. They have all a sour taste; they all act in the same way upon blue and purple vegetable colours (such as the colouring-matter of the violet, or of the red cabbage, or the colouring-matter called *litmus*, obtained from certain lichens), turning them red. These two characters—the sour taste, and the "acid reaction," as the reddening of vegetable blue colouring-matter is called—belong to most acids which are soluble in water. The taste of the soluble bases is not so generally characteristic, although many of them have a peculiar so-called "alkaline" taste—resembling that of soap—well marked in potash, soda, and lime. The change which they produce upon the above-mentioned vegetable colouring-matters is exactly the reverse of that of the acids, and is called the "alkaline reaction." Thus, if we take a purple infusion of red cabbage, and add potash, soda, lime, or ammonia to it, it becomes green; if to this green liquid, we cautiously add an acid, it becomes purple, and then red; an addition of a soluble base (alkali) to this red liquid renders it first purple, then green. Similarly, blue litmus is reddened by acids, and reddened litmus has its blue colour restored by the addition of an alkali. Another substance which is used as a test for the alkaline reaction is the yellow colouring-matter of the turmeric root—this is rendered brown by alkalies, and the yellow colour is restored on adding an acid. These characters (taste and reaction) belong to well-marked acids and bases which are soluble in water; they do not belong to *all* acids and bases. The distinguishing character of these groups is *their action upon each other.*

18. *Salts.*—When an acid and a base are mixed, a salt is produced. Thus, if we gradually add a solution (in water) of hydrochloric acid to a solution (in water) of caustic soda, a point will be reached where the mixed solution has neither the alkaline reaction of the soda nor the acid reaction of the hydrochloric acid. Such a solution is said to be *neutral*, and, on examination, is found to contain neither acid nor base, but a new substance, different from either of them. In the case which we have taken, this neutral substance is common salt. A similar action takes place between every acid and every base, and the fact that salts are formed in this way has given rise to the nomenclature of salts which was till lately in almost universal use, and is still very frequently employed. This nomenclature will be best explained by a series of examples. Thus,

Sulphuric Acid	acts on	Soda,	producing	Sulphate of Soda.
Nitric Acid	,,	Soda,	,,	Nitrate of Soda.
Hydrochloric or Muriatic Acid	,,	Soda,	,,	Hydrochlorate or Muriate of Soda.
Sulphuric Acid	,,	Ammonia,	,,	Sulphate of Ammonia.
Acetic Acid	,,	Oxide of Lead,	,,	Acetate of Oxide of Lead.

Etc., etc.

In all these cases, the name of the acid ends in *-ic* (sulphur*ic*, nitr*ic*, etc.). There are, however, acids the names of which end in *-ous*, such as sulphur*ous* acid, nitr*ous* acid. In such cases,

Sulphurous Acid	acts on	Soda,	and produces	Sulph*ite* of Soda.
Nitrous Acid	,,	Potash,	,,	Nitr*ite* of Potash.

And so on.

Sulphur*ic* Acid produces sulph*ates*; Sulphur*ous*, sulph*ites*, etc.

When this characteristic action of an acid upon a base takes place, water is in most cases produced as well as the salt. This formation of water is of great theoretical importance, and will be adverted to again further on.

19. What we have now seen enables us to define acids and bases as substances opposed to one another in chemical character, and capable of acting upon one another, so that both the acid and basic properties are neutralised, and salts produced. It is necessary, however, to note that this distinction between acids and bases is one rather of degree

than of kind, some acids possessing the acid character, and some bases possessing the basic character, in a much more strongly marked manner than others. Thus, some substances act as acids with strong or well-marked bases, and as bases with the stronger acids ; for instance, white arsenic has decidedly acid properties, and forms salts with most bases, but acts like a base when treated with hydrochloric or tartaric acid. Alumina and green oxide of chromium are bases to most acids, but acids to some of the stronger bases, such as potash and lime. The salts formed from a strong acid and a weak base have, generally speaking, when soluble, an acid reaction ; those formed from a weak acid and a strong base have, under similar conditions, an alkaline reaction. Thus, sulphate of alumina has an acid reaction ; carbonate of potash has an alkaline reaction.

EQUIVALENTS.

20. A point of the very greatest importance is the relation between the *quantity* of acid and the *quantity* of base required to form a salt. This is most easily investigated in the case of strong acids and strong bases which form with one another salts neutral to vegetable colours, although the same principles apply equally to all other cases. To illustrate these principles, we shall examine the relations of the acids and bases mentioned above—namely, sulphuric, nitric, hydrochloric, and acetic acids ; and the bases, caustic potash, caustic soda, lime, magnesia, oxide of lead, and ammonia. Let us first take a certain weighed quantity of pure caustic potash (for reasons to be explained afterwards, we select the quantity 56 grains*), and find out how much of each of these acids is required to neutralise it and form a salt. The results are as follow :

56 grains of	Caustic Potash	are neutralised by	49	grains of	Sulphuric Acid.
„	„	„	63	„	Nitric Acid.
„	„	„	36½	„	Hydrochloric Acid.
„	„	„	60	„	Acetic Acid.

These quantities—49 parts of sulphuric acid, 63 of nitric

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* Instead of grains, it need scarcely be said, any other unit (ounces, pounds, or tons) may be used.

acid, 36½ of hydrochloric acid, and 60 of acetic acid—are said to be "equivalent" (Lat. *of equal value or power*) to one another—that is, they are equivalent as far as neutralising potash is concerned; and these numbers are called the "equivalents" of the acids. We further find that

49 grains	of Sulphuric Acid	neutralise	56	grains of	Caustic Potash.
,,	,,	,,	40	,,	Caustic Soda.
,,	,,	,,	28	,,	Quicklime.
,,	,,	,,	20	,,	Calcined Magnesia.
,,	,,	,,	111½	,,	Oxide of Lead.
,,	,,	,,	17	,,	Ammonia.

Similarly, these quantities of the various bases are said to be "equivalent" to one another, and these numbers are called the equivalents of the bases. Now, the remarkable fact in connection with these numbers (the first discovered of a series of similar facts, upon which the modern system of chemistry is based) is that *an "equivalent" of any acid is precisely the quantity required to act upon an "equivalent" of any base in order to produce a salt.* Thus, 63 grains of nitric acid neutralise 56 grains of potash, 40 of soda, and so on; 60 grains of acetic acid act upon 111½ of oxide of lead to produce sugar of lead, etc. It is thus only necessary to ascertain by experiment the proportion in which a new base unites with *one* known acid, in order to know in what proportion it will unite with any other acid the equivalent of which is known.

21. *Neutral or Normal Salts.*—The salts thus formed are often called "neutral salts," because, when an equivalent of a *strong* acid acts upon an equivalent of a *strong* base, the resulting salt has neither an acid nor an alkaline reaction; it is, however, better to call them "normal salts," because, as already mentioned, such of them as have a weak acid and a strong base are often alkaline, and those with a strong acid, and weak base are often acid in reaction upon vegetable colours. They are called "neutral" or "normal" salts, to distinguish them from two other classes of salts—acid salts and basic salts.

22. *Acid Salts.*—If we mix 49 grains (one equivalent) of sulphuric acid with water, and add 56 grains (one equivalent)

of caustic potash, we already know that the "normal" sulphate of potash will be produced. If, however, we add only 28 grains (½ equivalent) of caustic potash, and then dry off the water, we find, not, as we might expect, a mixture of neutral sulphate of potash, and unacted-on sulphuric acid, but a salt, called the "bisulphate of potash," or "acid" sulphate of potash, which has been formed by the action of one equivalent of sulphuric acid upon half an equivalent of caustic potash (or, what is the same thing, by the action of two equivalents of sulphuric acid upon one of caustic potash). It is in the case of only some acids that we obtain acid salts: thus, sulphuric, oxalic, tartaric, phosphoric, citric acids form acid salts; nitric and hydrochloric acids do not. As examples of acid salts, we may mention cream of tartar (acid tartrate of potash), salt of sorrel (acid oxalate of potash), baking-soda (bicarbonate of soda), super-phosphate of lime (acid phosphate of lime). In these, we have salts formed from one equivalent of potash, and two of tartaric acid; one of potash, and two of oxalic acid; one of soda, and two of carbonic acid; one of lime, and three of phosphoric acid. It will be noted that here also we have the proportion of acid and base occurring according to equivalents; and it will be well to remember, what will be more fully explained afterwards, that it is the acid which determines the formation of acid salts, some acids forming them, others not.* Most acid salts have an acid reaction; but where the acid is weak, the reaction may be neutral, or even alkaline.

23. *Basic Salts.*—Again, we have seen that if 60 grains (one equivalent) of acetic acid be treated with 111½ (one equivalent) of oxide of lead, a normal salt (acetate of lead, or sugar of lead) is produced. If this be dissolved in water, and the solution be shaken up with finely divided oxide of lead, it will dissolve 223 grains (two equivalents) more, and form a salt, which is called "basic" acetate of lead. A basic salt is formed by the action of one equivalent of an acid upon more than one equivalent of base; just as an acid salt is

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* There are some bases which seldom or never form acid salts, even with those acids which have the greatest tendencies to form them; thus acid salts of oxide of silver can scarcely be said to be known.

formed by the action of more than one equivalent of acid upon one of base: and as it is the acid that determines the formation of acid salts (some acids forming them, others not) so it is the base that determines the formation of basic salts; some bases, such as oxide of lead, oxide of bismuth, red oxide of iron, forming them; others, such as caustic potash, soda, oxide of silver, not.

24. *Double Salts.*—Another class of salts deserves mention here—namely, the "double salts." These may be regarded as compounds of two salts with one another. As examples, we may mention common alum, consisting of sulphate of potash, and sulphate of alumina; Rochelle salt, tartrate of potash, and tartrate of soda; dolomite, carbonate of lime, and carbonate of magnesia.

DOUBLE DECOMPOSITION.

We have now considered, pretty fully, the action of acids upon bases; let us specially turn to the action of acids upon salts, of bases upon salts, and of different salts upon one another.

25. *Action of Acids upon Salts.*—In order to understand the action of acids upon salts, we shall first examine what takes place when an equivalent of a base is mixed with an equivalent of each of two acids. It is obvious that one or other of three things may occur—First, the base may form a salt with *one* of the acids, the remaining acid being left as it was; or second, the base may be divided into two parts, one forming a salt with part of the one acid, the other with part of the other acid, the rest of both acids being left unacted on; or third, a double salt may be produced. In the first case, we shall have a mixture of *one* salt and *one* acid; in the second, a mixture of *two* salts and *two* acids. Thus if one equivalent (111½ grains) of oxide of lead be mixed with one equivalent (49 grains) of sulphuric acid, and one equivalent (63 grains) of nitric acid, the whole of the oxide of lead acts on the sulphuric acid, and the nitric acid is left altogether unacted on. Again, if one equivalent (20 grains) of magnesia be mixed with one equivalent of sulphuric, and one equivalent

of nitric acid, the magnesia acts on both acids, producing sulphate of magnesia, and nitrate of magnesia, while a part of both acids is left unacted on. Now, the same final result is produced whether the two acids are added at once (as in the cases we have just mentioned) or successively. In the first case, we might add to the oxide of lead, first, nitric acid, and obtain nitrate of lead ; and then to the nitrate of lead add sulphuric acid, when we should obtain sulphate of lead and nitric acid—the sulphuric acid turning out (if we may use the phrase) the nitric acid. If, on the other hand, we add the sulphuric acid first, we obtain sulphate of lead, and nitric acid does not act on this ; so that in either case we obtain the same final result—sulphate of lead and nitric acid.

In the second case, sulphuric acid will *partially* (at ordinary temperatures) drive out nitric acid from nitrate of magnesia, and nitric acid will also *partially* drive out sulphuric acid from sulphate of magnesia ; in either case, producing a mixture of sulphate of magnesia and nitrate of magnesia, sulphuric acid and nitric acid. We have said " at ordinary temperatures," and this leads us to a point of great theoretical and practical importance. It is obvious that the balance of the mixture will be destroyed—that is, the proportion in which the base is divided between the acids will be changed—if a portion of one of the acids be taken away. Thus, if, in the last-mentioned case of a mixture of sulphate of magnesia, nitrate of magnesia, sulphuric acid, and nitric acid, we take away some of the nitric acid, a rearrangement will take place ; the magnesia will be divided between the two acids in proportion to the quantities of them *now* present, a new quantity of nitric acid will be driven out by sulphuric ; so that, if we continue to remove the nitric acid as it is formed, the nitrate of magnesia will be *entirely* decomposed, and nothing but sulphate of magnesia will be left. Now, nitric acid is much more volatile than sulphuric acid ; therefore, by heating the mixture, we can remove the nitric acid as vapour, leaving the sulphuric acid in the mixture ; and thus, although at ordinary temperatures, below the boiling-point of nitric acid, sulphuric acid only partially decomposes nitrate of magnesia, at higher temperatures the decomposition is complete, the nitric acid passing off as vapour.

It is, of course, not necessary that one of the acids should be removed *as vapour;* the same result follows, in whatever way it is taken out of the mixture; thus, it may separate as a solid out of an aqueous solution—as, for instance, is the case when an aqueous solution of borax (borate of soda, the salt formed by the action of soda on boracic acid) is treated with sulphuric acid. Here the sulphuric acid drives out the boracic acid, and as the latter is only sparingly soluble in cold water, a large part of it crystallises out, and the borax is almost wholly decomposed. The consideration of the fact, that, as a general rule, a base is shared between the acids which, so to speak, compete for it; and that when one acid is partially removed, the one which is left gets a larger share, enables us to explain some apparently anomalous cases of decomposition. Thus, as we have seen, in a cold aqueous solution sulphuric acid decomposes borate of soda, driving out boracic acid, and forming sulphate of soda; but if we mix sulphate of soda and boracic acid, and heat the mixture strongly in a crucible, we find that the boracic acid drives out the sulphuric acid, and forms borate of soda: in the first case, the boracic acid is removed by becoming solid; in the second, the sulphuric acid is removed by being converted into a vapour.

The balance in such a mixture as we have been considering, may be disturbed, and a rearrangement necessitated, by the removal of one of the salts, as well as by the removal of one of the acids. Thus, if we mix an equivalent of nitrate of lime* with one equivalent of sulphuric acid, and a sufficient quantity of water to retain the whole in solution, the lime is divided between the nitric and the sulphuric acids, so that we have a mixture of sulphate of lime, nitrate of lime, sulphuric acid, and nitric acid. If to this mixture we add alcohol (spirit of wine), a change of conditions is produced, for sulphate of lime is insoluble in dilute alcohol. The result is, that the sulphate of lime is precipitated,† and the sulphuric

* By an equivalent of a *salt* we mean the quantity formed by the action of an equivalent of acid upon an equivalent of base.

† When the mixture of two liquids causes the separation of an insoluble solid substance, the solid is said to be "precipitated," and is called a "precipitate."

acid in the liquid acts upon the nitrate of lime, producing more sulphate of lime, which is also precipitated, and so on until the whole of the nitrate of lime is decomposed, and nothing is left but sulphate of lime as a precipitate and nitric acid in solution.

The action of acids upon salts is taken advantage of in the preparation of many acids. Thus, nitric acid is prepared by the action of sulphuric acid on nitrate of soda; hydrochloric or muriatic acid, by the action of sulphuric acid on common salt (which we may call muriate of soda);* tartaric acid, by the action of sulphuric acid on tartrate of lime, etc.

26. *Action of Bases upon Salts.*—The action of bases upon salts will be easily understood from what has just been said of the action of acids upon salts. The new base may—first, totally decompose the salt, driving out the original base; second, partially decompose it, the acid being shared between the two bases; or, third, produce no change; or, fourth, form a double salt; and as in the case of the acids, so here, a partial decomposition may be made complete by removing the base as it separates, or by removing the newly produced salt. It sometimes happens that the new base, taking part of the acid of the salt, leaves a basic salt; thus, when ammonia is added to nitrate of lead, nitrate of ammonia is produced, and basic nitrate of lead. The latter being nearly insoluble in water, is precipitated.

The action of bases upon salts is taken advantage of in the preparation of bases; thus, ammonia is prepared by the action of lime upon hydrochlorate of ammonia; caustic potash and caustic soda, by the action of lime upon carbonate of potash or carbonate of soda; oxide of silver, by the action of caustic potash upon nitrate of silver, etc.

27. *The Action of Salts upon Salts.*—Some salts may be mixed together without any action taking place. In the case of others, especially when one or both are in solution, an exchange of acids and bases takes place, which may be, as in the actions just described, either complete or partial. Thus, if we mix one equivalent of nitrate of lead and one

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* This nomenclature will be more fully explained further on.

equivalent of sulphate of soda, both dissolved in water, we obtain an equivalent of sulphate of lead and an equivalent of nitrate of soda. Such an action is called double decomposition. In this case one of the salts produced (sulphate of lead) is insoluble in water, and is therefore precipitated. When all four salts—namely, the two which are originally mixed, and the two which are or may be produced—are soluble in water, it is often difficult to make out whether double decomposition has taken place or not, and still more difficult to determine the exact extent of the change. As previously pointed out, a partial change may be rendered complete by the removal of one of the products, either as a precipitate, or in the form of vapour. Thus, in the example given above, the double decomposition is complete, the sulphate of lead being precipitated; and when carbonate of lime and muriate of ammonia are mixed, carbonate of ammonia and muriate of lime are produced, and the action is complete if the mixture be heated, because carbonate of ammonia is volatile, and is driven off as vapour.

Double decomposition is taken advantage of in the preparation of many salts, and also in chemical analysis.

WATER IN COMPOSITION.

28. In the sketch of the characters of acids, bases, and salts, and their relations to one another, just given, a very important point which must now be adverted to has been omitted; this is, the relation of *water* to these classes of bodies.

Water enters into combination with a great variety of substances, and in different ways. Thus, many substances dissolve in water, and the solutions so formed are weak compounds of water and the substances dissolved; weak compounds, because the components are easily separated, moderate heat driving off the water.* Again, many crystal-

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* Although solutions may be said to be *weak* compounds because easily decomposed, many soluble substances have such a strong attraction for water that they can remove it from moist air, and unite with it to form a solution; such substances are said to be "deliquescent," and are used for the purpose of drying gases.

line substances contain water as an essential constituent, without which they would either not crystallise at all, or crystallise in a different form; hence called "water of crystallisation." This water also is feebly held in combination, and is easily driven off. Many crystalline substances containing water of crystallisation, lose it on exposure to dry air, losing at the same time their crystalline form. This change is called "efflorescence," and crystalline substances which undergo this change are said to be "efflorescent." Washing-soda is a familiar instance. The clear, transparent crystals of washing-soda contain nearly 63 per cent. of water of crystallisation. On exposure to dry air, they lose water, and become white and powdery. All substances containing water of crystallisation do not lose it so readily, but a temperature a few degrees above the boiling-point of water is sufficient to drive it off in every case.

29. *Hydrates, Anhydrides.*—Now, there are soluble acids and soluble bases, there are crystalline acids and crystalline bases containing water of crystallisation, but acids and bases enter into combination with water in another and special way. It has been pointed out before that there are substances which may be said to be intermediate between acids and bases, which act as bases to strong acids, and as acids to strong bases. Now, water is such a substance. Water unites with many bases, forming substances called "hydrates," or "hydrated bases" (thus, "hydrate of lime," "hydrated oxide of lead," etc.); it also unites with many acids, forming substances called "hydric salts," or "hydrated acids" (thus, "hydric sulphate," or "hydrated sulphuric acid," etc.). This kind of combination of water with acids and bases was long confounded with one or other of the two kinds mentioned just before, and from this there has arisen a confusion in the nomenclature of acids, bases, hydrates, and hydric salts, which is very likely to prove perplexing to the beginner.

Thus, the term "sulphuric acid" is used to express two different things—(1.) Oil of vitriol, which, when as strong as it can be made, consists of nearly pure "hydric sulphate," or "sulphate of water;" and (2.) A white, solid substance, which is oil of vitriol without the water. This white solid, when put into water, unites with it, giving out a great deal of heat, and forming oil of vitriol, or "hydric sulphate."

In the case of many other acids, we have the same double meaning of the word; we have the "anhydrous" (that is, waterless) acid, and the compound of that with water—the hydrated acid, or hydric salt. Some chemists restrict the word *acid* to the hydric salt, and call the anhydrous acid the "anhydride;" others restrict the name acid to the anhydrous substance, and call the hydrated acid a hydric salt. Thus, we have the name sulphuric acid applied to two substances—anhydrous sulphuric acid, or sulphuric anhydride; and hydrated sulphuric acid, or hydric sulphate. And these differ from one another in that the latter is a compound of the former with water.

30. As all the processes described in the preceding pages in illustration of the action of acids on other substances, were assumed to take place in water, it was not necessary to allude to this ambiguity, and the acids taken as examples (sulphuric, nitric, hydrochloric, and acetic) were supposed to be in the state of hydric salts. The question, indeed, would be one of nomenclature only, if every acid existed in both forms. But there are some acids which occur *only* as hydric salts, others which occur *only* as anhydrous acids. Thus, carbonic acid gas dissolves in water, but does not combine with it to form a hydrated acid, or hydric carbonate. Again, oxalic acid cannot be obtained in the anhydrous form. If we try to drive off the water from hydrated oxalic acid (hydric oxalate), we find that the acid itself decomposes and breaks up into other substances. These relations will be further considered under the head of Salt-radicals.

As some acids (that is, anhydrous acids) unite with water to form hydrated acids, or hydric salts, compounds in which water acts as a base, so some anhydrous bases unite with water also, forming hydrated bases or hydrates in which water acts as an acid; and here also we are apt to get into confusion with the names. Thus, the word lime is generally used to mean quicklime—the anhydrous base, but not unfrequently for what is properly called slaked lime, the compound of lime and water (hydrate of lime).

COMPOSITION OF WATER.

31. Having considered in a general way the characters of acids and bases, we may now shortly examine their composition, for they are all compounds—that is, they can all be produced by the union of elements, and can all be decomposed or broken up by directly or indirectly separating these elements from each other. And first, we shall investigate the composition of water, which is, as we have seen, both an acid and a base—an acid in relation to the strong bases; a base in relation to the strong acids.

Water, as is well known, was long regarded as a simple or elementary substance. It is one of the four "elements" of the ancients—fire, air, earth, and water; and although we now know that water is decomposed in a great many chemical changes constantly taking place, and produced from its elements in some of the most familiar and frequent cases of chemical action, the real nature of these changes escaped the observation of chemists until a comparatively recent time. The discovery of the composition of water was made by Cavendish about the year 1781. He shewed that when hydrogen gas is burned in the air, water is formed; and that if, instead of common air (which contains about 21 per cent. of oxygen), pure oxygen is used, the hydrogen and oxygen disappear, and water is produced, and *that the weight of the water formed is the same as that of the hydrogen and oxygen which have disappeared.* He thus proved that water is formed by the union of hydrogen and oxygen—that it is a compound of these two gases. By measuring the quantity of each gas * he ascertained the proportion in which they unite, and shewed that one volume of oxygen unites with two volumes of hydrogen. As oxygen weighs bulk for bulk 16 times as much as hydrogen, the proportion by *weight* is 8 parts of oxygen to one of hydrogen; that is, 1 oz. of hydrogen in burning will use up and unite with 8 oz. of oxygen, and pro-

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* When the bulks of two or more gases have to be compared, they must be measured under the same pressure and at the same temperature, as a change of pressure or of temperature produces a change in the bulk of a gas.

duce 9 oz. of water; or 9 oz. of water can be decomposed into 8 oz. of oxygen and 1 oz. of hydrogen; and the 1 oz. of hydrogen will occupy a space twice as great as the 8 oz. of oxygen. The composition of water was discovered by the method of *synthesis*—that is, by forming it from its constituents. We can also prove it by analysis—that is, by decomposing it into its constituents. This may be done by passing through water a current of electricity, from a galvanic battery for instance, when the hydrogen will bubble up from the one wire (that connected with the zinc of the battery), and the oxygen from the other (that connected with the copper of the battery). The two gases can thus be collected separately, and measured, when it will be found that the hydrogen produced fills just twice the space filled by the oxygen.

Water is a compound of hydrogen and oxygen, or in chemical language, an *oxide* of hydrogen; the compounds of oxygen with other elements being termed "oxides." Now, a very large number of the anhydrous acids and anhydrous bases are oxides, and the anhydrous bases which are oxides are all oxides of metals. This brings us to the consideration of the fourth group or family of substances mentioned in p. 15—namely, Metals.

METALS.

32. *Physical Characters of the Metals.*—Like all the other groups which we have examined, the metals possess certain characters in common, by which they may be recognised as belonging to the group; some of these characters are physical, some are chemical. The most marked physical characters of the metals are, the "metallic lustre," and the readiness with which they conduct heat and electricity. The metallic lustre is the name given to the peculiar brilliancy of a polished metallic surface. All metals, when polished, shew this lustre; but some substances which are not metals shew it also. Thus, "black-lead," or plumbago, which is not a metal, and is in no way related to lead, but is a form of carbon, has a brilliant metallic lustre; and a considerable number of compounds shew it also, such as iron

pyrites and galena. The power of conducting heat and electricity is possessed to a greater or less extent by all substances ; by some, however, to such a small extent, that they are usually called "non-conductors ;" for instances, glass, resin, gutta-percha. The metals differ greatly from one another in "conductivity," or the power of conducting heat and electricity ; but they are, as a rule, much better conductors than non-metallic substances. In other physical properties, metals shew great variety—in fusibility, ranging from mercury, which is liquid at ordinary temperatures, and only freezes at about -40° Fahr., to platinum, which requires the highest temperature we can produce for its fusion ; and osmium, which has not yet been fused. Metals differ greatly in density ; the lightest known simple solid and the heaviest —lithium and osmium—being both metals. Some metals are malleable and ductile—that is, they can be beaten into thin plates or leaves, and drawn into wire, as is the case with gold, silver, copper, and iron : others are brittle, and can be pounded into a powder in a mortar ; this is the case with antimony and bismuth. Most metals are white or grey, but we have yellow gold and red copper. Some are very hard, others very soft. As examples among common metals, we may compare the hardness of iron with that of silver and that of lead.

33. *Chemical Characters of Metals—Their Oxides.*—Let us now turn to the chemical characters of metals. It has just been mentioned that all the anhydrous bases which are oxides are oxides of metals. We may now add further, that every metal has an oxide which is a base. It is possible, directly or indirectly, to obtain a compound of each metal with oxygen. Some metals, such as zinc, aluminium, and magnesium, unite with oxygen in only one proportion ; others, such as iron, copper, lead, mercury, form each more than one oxide, the various oxides containing the metal and oxygen in different proportions. In the former case, the oxide is a base ; in the latter case, at least one of the oxides is a base. Thus, the oxide of zinc, the oxide of aluminium, and the oxide of magnesium, are bases ; two of the three oxides of iron, both of the oxides of copper, one of the three oxides of

lead, and both of the oxides of mercury, are bases. A metal may therefore be defined as an element which forms in combination with oxygen at least one base. There are two general principles which may be mentioned here: (1.) The more readily a metal unites with oxygen, the more basic is the oxide; thus, sodium is more easily oxidised than magnesium, magnesium than zinc, zinc than copper, copper than silver; and soda (oxide of sodium) is a stronger base than magnesia (oxide of magnesium), magnesia than oxide of zinc; and so on. (2.) When a metal forms two basic oxides, we usually find that that which contains the least oxygen is the stronger base. Thus, two of the oxides of iron are bases: one (ferrous oxide) contains iron and oxygen in the proportion of 7 to 2; the other (ferric oxide) in the proportion of 7 to 3; and the former is the stronger base.

34. *Action of Acids and Salts upon Metals.*—The anhydrous acids, as a rule, do not act at all upon metals. There are some exceptions to this rule which cannot be conveniently considered here. The action of the hydrated acids or hydric salts on metals is quite analogous to that of other salts. If we take a clear colourless solution of nitrate of silver, and place in it a piece of bright clean copper, we see in a few minutes that the copper is covered over with a growth of what looks like soft white moss; this gradually increases, the liquid at the same time becoming blue. The white covering on the copper consists of small scales of silver, and the blue colour of the liquid is due to nitrate of copper. If we take enough copper, we can in this way decompose the whole of the nitrate of silver, separating the silver in the metallic state. Again, if we place a piece of clean iron in a solution of nitrate (or sulphate) of copper, metallic copper is deposited on the iron, the blue colour of the solution disappears, and we have a solution of nitrate (or sulphate) of iron.* Again, if we place a piece of iron in a solution of hydrated sulphuric acid (oil of vitrol), that is, hydric sulphate, we have hydrogen gas given off, and sulphate of iron remains

* This action may be taken advantage of to detect copper in a solution; thus, a clean steel fork, quite free from oil or grease, is covered with a red deposit of copper when it is dipped in a jar of pickles coloured green by means of copper.

in solution. In each of these cases we have one metal driving out another, and taking its place.* Copper drives out silver, iron drives out copper, and iron drives out hydrogen. In each such case, the metal which drives the other out is said to be "positive;" that which is driven out is said to be "negative." Thus, silver is negative to copper; copper is positive to silver, but negative to iron; iron is positive to copper; and so on. By means of a number of experiments of this kind, we can arrange the metals in a series, beginning with the most negative, and ending with the most positive. If we examine this series, we find that the more "positive" a metal is, the more basic is its most basic oxide. So that just as a strong base drives out a weak one, so the metal of a strong base drives out the metal of a weak one.

CONSTITUTION OF SALTS.

35. *Salt-Radicals.*—We have hitherto looked upon salts as compounds of acids and bases, but the reader will now see that they may also be represented in another way. Thus, we have spoken of sulphate of copper as a compound of

$$\underbrace{\begin{array}{c}\text{Oxide of Copper,}\\ \text{that is,}\\ \text{Copper and Oxygen,}\end{array}}_{\text{Base.}} \quad \text{and} \quad \underbrace{\text{Anhydrous Sulphuric Acid.}}_{\text{Acid.}}$$

But just as a strong base, such as potash, will decompose this salt, driving out the oxide of copper, and forming sulphate of potash, so a more positive metal than copper—for instance, zinc—drives out the copper, and forms sulphate of zinc, in which the base is oxide of zinc. Here it is the *metal* which is changed; all the rest remains as it was. We may therefore represent the salt as a compound of metal with all the rest of the salt, thus:

$$\underbrace{\text{Copper}}_{\text{Metal.}} \quad \text{and} \quad \underbrace{\text{Oxygen and Anhydrous Sulphuric Acid.}}_{\text{Salt-radical.}}$$

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* We here speak of hydrogen as a *metal.* Chemically it is so, for water (the oxide of hydrogen) acts as a base, and substances have been obtained which may be regarded as *alloys* of hydrogen.

The *rest of the salt*, that which in union with metal forms the salt, is called the "salt-radical." In the case of the sulphates, and indeed of the majority of salts, the salt-radical has not been obtained *in the free state*—that is, by itself, and is only known *in combination* with metals, forming salts, and with hydrogen, forming the hydric salt or hydrated acid, thus :

$$\begin{gathered}\overbrace{\text{Hydrogen and Oxygen}}^{\text{Water.}}\text{ and }\overbrace{\text{Anhydrous Sulphuric Acid.}}^{\text{Acid.}}\\ \phantom{\text{Hydrogen and }}\underbrace{\phantom{\text{Oxygen and Anhydrous Sulphuric Acid.}}}_{\text{Salt-radical.}}\end{gathered}$$

36. *Halogens.*—There are, however, a number of substances known, which, *in combination*, play exactly the part of the salt-radicals we have just been considering—that is, they unite with metals to form salts, and with hydrogen to form hydric salts, corresponding exactly in general properties to the hydrated acids. These substances are called "halogens" (Gr. *salt-producers*). We shall illustrate their characters by means of an example, and for this purpose select the most important of them—namely, chlorine. Chlorine is a simple substance—in other words, it has not been decomposed—and thus differs entirely from the salt-radicals of the sulphates, nitrates, etc., which consist of anhydrous acid and oxygen, and have not been obtained in the free state. Chlorine, in the free state, is a greenish yellow gas with an acrid smell. It readily unites with hydrogen, forming the substance known as muriatic acid gas, or, from its composition, hydrochloric acid gas. This is a true hydric salt, possessing all the general properties of the hydrated acids. It acts upon bases, producing salts and water ; it drives out weaker acids (in the hydrated form—that is, as hydric salts) from their salts. The salts thus formed have in the former pages been called "muriates," or hydrochlorates ; but we now see what they are : they are compounds of metals and chlorine, the oxygen of the metallic oxide (or base) uniting with the hydrogen of the hydrochloric acid to form water. They are hence called "chlorides." Thus, instead of "muriate of soda," we say "chloride of sodium ;" and so on. They are, however, true salts, undergoing all the changes

and reactions common to salts. It will be noticed that *all* salts can be represented as compounds of metal and salt-radical, while some salts (such as the chlorides) cannot be represented as compounds of acid and base. This has led to a modification of the old names of many salts; thus, we often use the names sulphate of sodium (or sodium sulphate) instead of the old sulphate of soda. It must not be supposed that sulphate of sodium means a compound of sodium and sulphuric acid; it is a compound of sodium *and oxygen* and sulphuric acid (anhydrous).

37. *Nomenclature of Salts.*—We may now place side by side the various names given to the same salt:

Sulphate of Soda	Sodic Sulphate	Sulphate of Sodium.
Hydrated Sulphuric Acid	Hydric Sulphate	Sulphate of Hydrogen.
Muriate of Soda	Sodic Chloride	Chloride of Sodium.
Hydrochloric Acid	Hydric Chloride	Chloride of Hydrogen.
Nitrate of Oxide of Lead	Plumbic Nitrate	Nitrate of Lead.
Etc.	Etc.	Etc.

Sulphate of soda means the salt formed by the action of sulphuric acid on soda; sulphate of sodium means the compound of sodium and the salt-radical of the sulphates; while sodic sulphate may be used to indicate the same substance without referring to either view of its constitution. For this, as well as for other reasons, the names in the middle column are to be preferred, although this system sometimes involves us in the use of novel and awkward adjectives, such as zincic, or bismuthous.

OXIDATION AND REDUCTION.

38. We have seen that many bases are oxides of metals, and we must now attend to the relation of the metals to their oxides. When a metal (or other substance) is made to unite with oxygen, it is said to be "oxidised;" when the oxygen is taken away from an oxide, and the original substance (whether metal or not) is reproduced, the oxide is said to be "reduced." We have thus two processes inverse to one another—the one undoing what the other does, oxidation and reduction. Thus, there is an important ore of iron called the magnetic oxide of iron; when this is smelted the oxygen

is taken from it, and we obtain metallic iron—this is a process of reduction. If we heat iron strongly in the air, it becomes covered with a crust or scale of a black, brittle substance, which breaks off when the iron is hammered—this is an oxide of iron, and is identical in composition with the magnetic iron ore—this is a process of oxidation. It is obvious that these two processes go in opposite directions.

39. *Combustion.*—Most processes of oxidation are accompanied by the giving out of heat, sometimes in a very marked degree; thus, when charcoal is strongly heated in air or oxygen (and it must be remembered that about one-fifth of the atmospheric air consists of oxygen), it unites with oxygen, forming an oxide (carbonic acid, Black's "fixed air"), and in doing so, gives out much heat. Such an oxidation we call a combustion, or burning. And although different processes of oxidation are accompanied by the giving out of very different quantities of heat, we may generalise the term, and call all such processes cases of "burning." Similarly, all processes of reduction may be grouped together as cases of "unburning."*

As in a case of "burning" or "oxidation," heat is given out, so in a case of "unburning" or "reduction," heat disappears, or is used up; and we find that exactly as much heat is used in effecting the unburning of an oxide as was given out in producing it. It will thus be seen that the greater the quantity of heat given out during an oxidation, the greater is the amount of *work* required to be done, in order to effect the corresponding reduction. Now, the difficulty of undoing a union, or of breaking up a combination, may be taken as a measure of its stability, so that the most stable oxides are those during the formation of which the most heat is given out.

40. *Oxidising and Reducing Agents.*—Many oxidations can be effected directly by the action of oxygen, and some reductions can be effected directly by means of heat or electricity; thus, hydrogen unites with oxygen, or is burnt, producing water; and water can be decomposed by heat or by

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* This is here stated generally; some of the few exceptions will be mentioned among the compounds of Chlorine and Oxygen.

electricity into hydrogen and oxygen. There are, however, many oxidations which cannot be effected by the direct action of oxygen, but require the use of an "oxidising agent" —that is, a substance or mixture containing oxygen in combination, and ready to part with it to a body capable of being oxidised. Thus, nitric acid contains a large quantity of oxygen, and readily gives up part or all of this oxygen to oxidisable substances; accordingly nitric acid is a powerful oxidising agent, and is used to oxidise bodies in cases where the action can either not be produced at all, or not so conveniently, by oxygen alone. As an instance of an oxidising agent which is a mixture, we may take the mixture of chlorine and water. This mixture will oxidise in many cases in which water alone would be without action—the tendency of chlorine to unite with the hydrogen of the water increasing the readiness of the oxygen to leave the hydrogen, and unite with the substance to be oxidised.

Just as we have oxidising agents, so we have also reducing agents—that is, substances or mixtures which remove oxygen: these are generally bodies having a tendency to combine with oxygen, in other words, they are oxidisable; and the most powerful reducing agents are, as might be expected, those which give out most heat in uniting with oxygen. By far the most practically important reducing agents are hydrogen and carbon, either singly as hydrogen gas, and as charcoal or coke, or combined, as they are in coals, coal-gas, wood, and other ordinary combustibles. A large number of metallurgical operations are cases of reduction, in which coal, or coke or charcoal, is used to take away the oxygen of a metallic oxide, and leave the metal uncombined. It is in this way that iron, tin, zinc, and some other metals are reduced from such of their ores as contain the metals as oxides.

THE DOCTRINE OF EQUIVALENTS, AND THE ATOMIC THEORY AND NOTATION.

41. *Equivalence.*—We have already seen what is meant by an "equivalent" of an acid, or of a base; we shall now

consider the question of "equivalence" somewhat more fully. As has been already stated, zinc can turn copper out of a salt, such as sulphate of copper, and take its place; this is technically called "replacement," and zinc is said to "replace" copper.* As the salts may be considered as compounds of sulphuric acid (anhydrous) with oxide of copper and with oxide of zinc respectively, it is evident that equivalents of these oxides contain the same quantity of oxygen, for the oxygen remains as it was, thus:

$$\begin{array}{l}\text{Before......}\\ \text{After........}\end{array}\overbrace{\underbrace{\left.\begin{array}{l}\text{Copper}\\ \text{Zinc}\end{array}\right\}\text{ and Oxygen}}_{\text{Oxide of Zinc.}}}^{\text{Oxide of Copper.}}\text{ and Sulphuric Acid.}$$

And in the same way it may be shewn, by means of other replacements, that an equivalent of any basic oxide contains the same quantity of oxygen. By an extension of the meaning of the word equivalent, this quantity of oxygen is called an equivalent of oxygen, and the quantity of metal united to it is called an equivalent of the metal. Those metals which form more than one basic oxide have of course more than one equivalent; and when we speak of *the* equivalent of a metal of this kind, we must state *which* basic oxide or which set of salts we are referring to. Thus, the black oxide of mercury contains twice as much mercury as the red oxide for the same quantity of oxygen; and therefore the equivalent of mercury in the black oxide and its salts is twice as great as the equivalent of mercury in the red oxide and its salts.

The phenomena of "electrolysis" furnish an excellent illustration of the equivalence of metals in their salts. When an electric current from a galvanic battery is passed through a solution of a salt, the salt is decomposed, the *metal* being deposited at the end of the wire coming from the zinc of the battery, and the *salt-radical* at the end of the wire coming

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* "Replace" is here used in the sense of the French *remplacer*, and not in its ordinary English sense: but as we have no one English word which can be used to mean "to be a substitute for," it seems better to keep the word at present in use, than to try another such as "displace" (as has been suggested), which expresses the meaning no better.

from the copper of the battery.* This decomposition, by means of an electric current, is called "electrolysis." Now, a very remarkable law of electrolysis is, that *a given amount of electricity decomposes (or electrolyses) equivalent quantities of different salts.* Thus, if a current from a battery be made to pass through a series of vessels, each vessel containing a solution of a salt, the quantity decomposed of any one salt will be equivalent to the quantity decomposed of any other. If, now, one of these vessels contain a solution of a salt of the red oxide of mercury, and another a solution of a salt of the black oxide of mercury, we shall find that twice as much mercury is separated in the second as in the first.

42. *Equivalence expressed in Numbers.*—In order to express these equivalent quantities in numbers, it is necessary, in the first place, to fix upon a number which shall, by convention, represent one of them, and then, by experiment, find out the relation between the equivalent of that substance and the equivalent of every other element, radical, or substance. For this purpose, it has been found most convenient to select hydrogen as the element with which to compare all others, and to fix the equivalent of hydrogen as unity. The equivalent of hydrogen is thus settled by convention to be 1, and by experiment we determine the equivalents of other elements or radicals. Thus, when hydric sulphate (hydrated sulphuric acid) acts on metallic zinc, for every grain of hydrogen set free we find that 32.5 grains of zinc are dissolved, and that, therefore, the *equivalent* of zinc is 32.5. Again, when sulphate of copper acts on metallic zinc, for every 32.5 grains of zinc dissolved we find that 31.75 grains of copper are separated—therefore, the equivalent of copper is 31.75. Once more, when nitrate of silver acts on metallic copper, for every 31.75 grains of copper dissolved we find that 108 grains of silver are separated; therefore 108 is the equivalent of silver. Now, 1 grain of hydrogen unites with 8 grains of oxygen to form 9 grains of water; 32.5 grains of zinc unite

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* Where the metal is one which acts on water (such as sodium), we have of course, not the metal itself separated, but the products of its action on water; and similarly if the salt-radical is incapable of separate existence, we obtain the products of its decomposition.

with 8 grains of oxygen to form 40.5 grains of oxide of zinc; 31.75 grains of copper and 108 grains of silver unite each with 8 grains of oxygen to form respectively 39.75 grains of black oxide of copper, and 116 grains of oxide of silver; therefore, the equivalent of oxygen is 8. In the same way, 1 grain of hydrogen, 32.5 grains of zinc, 31.75 grains of copper, and 108 grains of silver severally unite with 35.5 grains of chlorine to form respectively hydrochloric acid (hydric chloride), chloride of zinc (zincic chloride), chloride of copper (cupric chloride), and chloride of silver (argentic chloride); therefore, the equivalent of chlorine is 35.5.

43. *The Law of Multiples.*—In a similar way, the equivalent of any element or radical may be determined, it being always recollected that an element or radical has as many different equivalents as it forms series of compounds. Now, if we compare the different equivalents of the same element or radical, we find that they have a simple arithmetical relation to one another, that the one is a multiple of the other. Thus (taking the equivalent of hydrogen as 1), the equivalent of mercury in the red oxide of mercury and its salts is 100; in the black oxide of mercury and its salts, 200—that is, twice 100: the equivalent of copper in the black oxide of copper and in its salts is 31.75; in the red oxide of copper and in its salts, 63.5—that is, twice 31.75: the equivalent of iron in the ferrous salts is 28; in the ferric salts, 18.6—that is two-thirds of 28.

CHEMICAL NOTATION.

These two facts—1st, that the equivalent of an element remains the same through a series of compounds; and 2d, that the different equivalents of the same element have a simple arithmetical relation to each other—enable us to form a system of chemical notation by means of which the composition of compounds may be fully and distinctly expressed.

44. In this system of notation, which is known as the Atomic Notation, certain symbols are used, each of which represents a definite quantity of a particular element. The subjoined table contains the names of the elements with the symbol of each, and the quantity of the element which the

symbol represents. This quantity is called the "atomic weight" of the element, for reasons which will be afterwards stated.

TABLE OF ELEMENTS WITH THEIR SYMBOLS AND ATOMIC WEIGHTS.

Aluminium	Al	27.5
Antimony or Stibium	Sb	122
Arsenicum	As	75
Barium	Ba	137
Beryllium or Glucinum	G	9.3
Bismuth	Bi	210
Boron	B	11
Bromine	Br	80
Cadmium	Cd	112
Cæsium	Cs	133
Calcium	Ca	40
Carbon	C	12
Cerium	Ce	92
Chlorine	Cl	35.5
Chromium	Cr	52
Cobalt	Co	59
Copper (*Cuprum*)	Cu	63.5
Didymium	Di	96
Erbium	Er	112.6
Fluorine	F	19
Gold (*Aurum*)	Au	196
Hydrogen	H	1
Indium	In	113
Iodine	I	127
Iridium	Ir	197
Iron (*Ferrum*)	Fe	56
Lanthanum	La	92
Lead (*Plumbum*)	Pb	207
Lithium	Li	7
Magnesium	Mg	24
Manganese	Mn	55
Mercury (*Hydrargyrum*)	Hg	200
Molybdenum	Mo	96

Nickel	Ni	59
Niobium	Nb	97·5
Nitrogen	N	14
Osmium	Os	199
Oxygen	O	16
Palladium	Pd	106.5
Phosphorus	P	31
Platinum	Pt	197
Potassium or Kalium	K	39·1
Rhodium	Ro	104.3
Rubidium	Rb	85
Ruthenium	Ru	104
Selenium	Se	79·5
Silicon	Si	28
Silver (*Argentum*)	Ag	108
Sodium or Natrium	Na	23
Strontium	Sr	87.5
Sulphur	S	32
Tantalum	Ta	182
Tellurium	Te	129
Thallium	Tl	204
Thorium	Th	119
Tin (*Stannum*)	Sn	118
Titanium	Ti	50
Tungsten or Wolfram	W	184
Uranium	U	120
Vanadium	V	51.2
Yttrium	Y	61.5
Zinc	Zn	65
Zirconium	Zr	89·5

45. *Atomic Weight.*—If we compare the *atomic weights* as given in this table with the *equivalents* of the elements, we shall find that, even in the cases where each element has only one equivalent, that number has not always been chosen as the atomic weight of the element. Thus, the equivalent is the same as the atomic weight in the case of hydrogen, of potassium, of sodium, of rubidium, of cæsium, and of lithium. But the atomic weight is twice the equivalent in the case of

barium, of beryllium, of cadmium, of calcium, of magnesium, of oxygen, of strontium, and of zinc. Aluminium has only one equivalent, and the atomic weight of aluminium is three times its equivalent. Where an element has more than one equivalent, the atomic weight is sometimes equal to one of these equivalents, and sometimes not. Thus, the atomic weight of copper is equal to the equivalent of copper in the cuprous compounds (red oxide of copper and its salts); the atomic weight of mercury is equal to the equivalent of mercury in the mercurous compounds (black oxide of mercury and its salts); the atomic weight of silver is equal to the equivalent of silver in all its compounds except the peroxide, and the suboxide and the few salts derived from it, etc. The atomic weight of iron is twice the equivalent of iron in the ferrous salts, and three times the equivalent of iron in the ferric salts. In all cases, however, the atomic weight stands in a simple arithmetical relation to each of the equivalents.

CHEMICAL FORMULÆ.

46. The way in which this notation is used will be most easily explained by a few examples. Compound substances are represented by formulæ expressing the proportions by weight of their elementary constituents—thus, HCl means the compound of 1 part by weight* of hydrogen and 35.5 parts by weight of chlorine—that is, 36.5 parts of hydrochloric acid. Here the proportion in which the two elements combine is that of their atomic weights, and the symbols are simply placed one after the other. Again, H_2O means the compound of 2 parts by weight of hydrogen and 16 parts by weight of oxygen—that is, 18 parts of water. Here H_2 represents twice the quantity of hydrogen represented by H, so that as H stands for 1 part of hydrogen, H_2 stands for 2 parts of hydrogen. Again, sulphurous acid gas contains equal weights of sulphur and oxygen, and is represented by the formula SO_2, by which we mean the compound of 32

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* Instead of "part by weight" or "part," we may here and throughout read "grain," or "ounce," or "pound," or any other unit we please; we must, however, remember that, having once adopted a particular unit, we must adhere to it through all the formulæ which we wish to compare together.

parts of sulphur and twice 16 parts of oxygen—that is, 64 parts of sulphurous acid gas. In the same way, SO_3 means the compound of 32 parts of sulphur and three times 16 parts of oxygen, and this is 80 parts of anhydrous sulphuric acid. CuO means the compound of 63.5 parts of copper and 16 parts of oxygen—that is, 79.5 parts of black oxide of copper, or cupric oxide. Now, 18 parts of water unite with 80 parts of anhydrous sulphuric acid to form 98 parts of hydrated sulphuric acid (hydric sulphate). Similarly, 79.5 parts of black oxide of copper unite with 80 parts of anhydrous sulphuric acid to form 159.5 parts of cupric sulphate. These compounds may therefore be represented by the complex formulæ H_2O,SO_3 and CuO,SO_3 respectively; the comma placed between the formulæ indicating that the compounds may be regarded as composed, the one of water and anhydrous sulphuric acid, the other of cupric oxide and anhydrous sulphuric acid.

Further, if we place cupric sulphate, which is a white powder, in water, 159.5 parts of it at once unite with 18 parts of water, forming a blue powder, which may be represented by the formula CuO,SO_3,H_2O. This blue powder dissolves readily in water, forming a blue solution; and if we evaporate the water carefully, we obtain blue crystals, containing, in addition to the water previously in the blue powder, four times 18 parts of water—the crystalline substance (crystallised cupric sulphate, or blue vitriol) has therefore the formula $CuO,SO_3,H_2O,4H_2O$. Here $4H_2O$ means four times 18 parts of water (a large figure placed *before* a formula multiplying the whole formula up to the first comma). The water present in this salt occurs in two different forms of combination—(1.) Water of crystallisation, easily driven off by heat; of this there are four times 18 parts. (2.) Water retained with great force, requiring a high temperature to expel it, and called "water of halhydration;" of this there are 18 parts. In the same way, hydrated nitric acid, nitrate of potash, and nitrate of copper are represented by the formulæ H_2O,N_2O_5; K_2O,N_2O_5; CuO,N_2O_5 respectively, and crystallised nitrate of copper by $CuO,N_2O_5,3H_2O$. Again, 1 part of hydrogen unites with 35.5 parts of chlorine to form 36.5 parts of hydrochloric acid (or hydric chloride), and this is represented by the formula HCl; and similarly, chloride of sodium (sodic chloride, common salt) and cupric chloride have the formulæ NaCl and $CuCl_2$ respectively. Looking over these formulæ,

Hydrated Sulphuric Acid	or	Hydric Sulphate	H_2O,SO_3,
Sulphate of Soda	,,	Sodic Sulphate	Na_2O,SO_3,
Sulphate of Copper	,,	Cupric Sulphate	CuO,SO_3,
Hydrated Nitric Acid	,,	Hydric Nitrate	H_2O,N_2O_5,
Nitrate of Potash	,,	Potassic Nitrate	K_2O,N_2O_5,
Nitrate of Copper	,,	Cupric Nitrate	CuO,N_2O_5,
Hydrochloric Acid	,,	Hydric Chloride	HCl,
Chloride of Sodium	,,	Sodic Chloride	NaCl,
Chloride of Copper	,,	Cupric Chloride	$CuCl_2$,

we at once see that 2 parts of hydrogen (H_2), twice 23—that is 46 parts of sodium (Na_2), 63.5 parts of copper (Cu), and twice 39—that is 78 parts of potassium (K_2), are equivalent to one another—that is, are capable of playing the same part in a compound.

47. *Symbols of Radicals.*—The reader will remember that salts can be represented not only, as has been done above in the case of the sulphates and nitrates, as compounds of base and acid (anhydrous), but also as compounds of metal and salt-radical, the salt-radical consisting of the anhydrous acid and the oxygen of the base. A glance at the formulæ of the sulphates and nitrates given in the preceding table will shew how this view can be represented by formulæ. Thus:

Hydric Sulphate	H_2O,SO_3	or	H_2,SO_4.
Sodic Sulphate	Na_2O,SO_3	,,	Na_2,SO_4.
Cupric Sulphate	CuO,SO_3	,,	Cu,SO_4.

Here SO_4 represents the salt-radical of the sulphates—that is, the group of elements which along with a metal forms a sulphate. This, like many other radicals, cannot be (or at least has not as yet been) obtained as a separate substance, but may still be spoken of and reasoned about as *that which is common to all the sulphates*, that group which remains unchanged when we pass from one sulphate to another. Similarly, we may represent the nitrates thus:

Hydric Nitrate	H_2O,N_2O_5	or	H_2,N_2O_6.
Potassic Nitrate	K_2O,N_2O_5	,,	K_2,N_2O_6.
Cupric Nitrate	CuO,N_2O_5	,,	Cu,N_2O_6.

Here N_2O_6 is the salt-radical of the nitrates. But it will be at once observed that N_2O_6 can be divided by two, or that N_2O_6 is the same as $2NO_3$; we can therefore simplify the above formulæ thus: Hydric Nitrate, H,NO_3; Potassic Nitrate, K,NO_3; and Cupric Nitrate, $Cu,2NO_3$ or $Cu,(NO_3)_2$ (the group NO_3 between the brackets being multiplied as a whole by the small figure placed after it; in other words, a group of symbols placed within brackets is treated as a single symbol).

We can now compare the formulæ of the sulphates and nitrates with those of the chlorides:

Hydric Sulphate, H_2,SO_4; Hydric Nitrate, H,NO_3; Hydric Chloride, H,Cl.
Sodic Sulphate, Na_2,SO_4; Sodic Nitrate, Na,NO_3; Sodic Chloride, Na,Cl.
Cupric Sulphate, Cu,SO_4; Cupric Nitrate, $Cu,(NO_3)_2$; Cupric Chloride, Cu,Cl_2.

This comparison shews that NO_3 is equivalent to Cl, while SO_4 is equivalent to Cl_2 just as K is equivalent to H, and Cu equivalent to H_2, or that there is a difference in the *value* of the symbols of the salt-radicals in our system of notation similar to the difference in the *value* of the symbols of the metals. We shall see by-and-by why the atomic weights have been fixed so as to give rise to these differences; our object at present is to explain the use of the system as it is, not to give reasons why it has been made so. It is also obvious that the quantities of the salts above mentioned represented by the last formulæ are not equivalent to one another; the *equivalent* quantities being H_2,SO_4; Na_2SO_4; Cu,SO_4; $2[H,NO_3]$; $2[Na,NO_3]$; $Cu,(NO_3)_2$; $2[H,Cl]$; $2[Na,Cl]$; Cu,Cl_2.

48. *Molecular Weight.*—It is of the utmost importance that symbols or formulæ should *always* be used as representing definite *quantities* of the substances, and that the slovenly habit should be avoided of using them as contractions or synonyms for the *names* of the substances. When we use the words "water," "common salt," or "sulphate of potash," we do not indicate any particular quantities of these bodies; but when we write H_2O, NaCl, or K_2SO_4, we mean 18 parts of water, 58.5 parts of common salt, or 174 parts of sulphate of potash. Just as the quantity of an element represented by its symbol is called its atomic weight, so the

quantity of a substance represented by its formula is called its molecular weight.

49. *Monobasic, Dibasic, etc., Acids.*—Acids such as hydrochloric and nitric, which contain in one molecule *one* atom of hydrogen capable of being replaced by metal, are called "monobasic acids;" those that, like sulphuric acid, contain in one molecule *two* such hydrogen atoms, are called "dibasic acids." There are also "tribasic" and "tetrabasic" acids, containing respectively three and four atoms of replaceable hydrogen. All acids containing in one molecule more than one atom of replaceable hydrogen are called "polybasic;" and this polybasic character explains the occurrence of acid and double salts of such acids. Thus, in bisulphate of potash, K_2O,SO_3, H_2O,SO_3, or $HKSO_4$, we have *one* of the hydrogen atoms of sulphuric acid, H_2SO_4, replaced by potassium. Again, common phosphoric acid (p. 76) has the formula $3H_2O,P_2O_5$, or H_3PO_4, and is tribasic, so that we have such salts as Ag_3PO_4, Na_2HPO_4, NaH_2PO_4, etc.

50. *Chemical Equations.*—We can use formulæ not only to express the quantitative composition of substances, but also the action of substances upon each other, or generally, chemical changes. This is done by means of what are called "chemical equations." Let us take as an instance the action of sulphate of potash upon chloride of barium. Here we have 174 parts of sulphate of potash and 208 parts of chloride of barium before the change, and after it we have 233 parts of sulphate of baryta and 149 parts of chloride of potassium. We represent the change by the following equation:

$$K_2SO_4 + BaCl_2 = BaSO_4 + 2KCl.$$

The formulæ representing the quantities of the substances before the change are written first, connected by the sign + (which here is the same as "*and*"); then we write = (which here stands for "*become*" or "*are changed into*"); and lastly, the formulæ representing the quantities of the substances produced by the change, also connected by the sign +.

The above equation may then be read as follows: 174 parts of sulphate of potash and 208 parts of chloride of barium are changed into 233 parts of sulphate of baryta and

149 parts of chloride of potassium. We shall have frequent occasion to use such equations further on.

THE ATOMIC THEORY.

51. The system of atomic or symbolic notation, just explained, originated in the Atomic Theory of Dalton. According to this theory, matter is composed of exceedingly minute ultimate particles or atoms which are incapable of being divided. All the atoms of a given element are precisely similar to one another, but the atoms of one element differ not only in properties, but also in weight, from those of the others; and although we have not as yet been able to discover the actual weight of an individual atom, the theory assumes that we can discover the proportion existing between the weights of the atoms of different elements, and that these proportions are represented by the atomic weights. Thus, we do not know the weight of an atom of iron, but, if this assumption is correct, it is four times the weight of an atom of nitrogen—that is, in the proportion 56 : 14. In the same way, an atom of mercury is two hundred times as heavy as an atom of hydrogen; and so on.

52. *Molecules.*—The theory further supposes that when combination takes place, the atoms of the constituents go together to form groups or molecules; thus, when copper is heated in oxygen, each atom of copper attaches itself to one atom of oxygen to form a molecule of cupric oxide. The formula of a compound may thus be considered as a list of the number and kind of the atoms forming the molecule of the compound.

53. *Combination by Volume—Avogadro's Law.*—So far we have considered the proportions *by weight* in which constituents occur in compounds; we shall now look for a little at another way of measuring them—namely, by volume or bulk. We can measure the volume or bulk of a quantity of matter, whether it be solid, liquid, or gaseous, and express it by means of units; and just as we used the word "part" to indicate a unit of *mass* (which may be a grain, or a pound, or a ton), so now we use the word "volume" to indicate a

unit of bulk (which may be a cubic inch, or a cubic foot, or a gallon), only reminding the reader that here, as before, having once fixed *which* of these is to be our unit, we must adhere to it throughout.

Chemists have made some progress towards finding out the laws of combination according to volume in the cases of solids and liquids ; but this part of the subject is at present both too complicated and too speculative to be profitably discussed here. We shall therefore confine ourselves to the laws of combination of gases according to volume. The first step towards the discovery of these laws was made by Gay-Lussac, soon after the publication of Dalton's Atomic Theory; and it is a remarkable fact in the history of chemistry that Dalton, who had thrown so much light on the laws of combination according to weight, was inclined to doubt the accuracy of Gay-Lussac's views. These views were afterwards greatly extended and simplified by Avogadro ; and subsequent investigation and comparison have established what we may call "Avogadro's law" so fully, that it may be said to be as important a corner-stone of the chemical edifice as the Atomic Theory itself. Without entering into historical questions, we shall state this law, as it is at present held by the great majority of chemists, thus : *A volume of any gas contains the same number of* molecules *as the same volume of any other gas, the two being measured at the same temperature and pressure.** It follows at once from this law that the specific gravities of two gases (taken at the same temperature and pressure) are in the same proportion as their molecular weights ; and we have thus a means of determining the molecular weight of any substance which either is a gas at ordinary temperatures, or can be, without chemical change, converted into one by the action of heat, by comparing its specific gravity in the gaseous state with the specific gravity (at the same temperature and pressure) of some gas the molecular weight of which is known.

54. *Molecular Formulæ.*—By applying this method, we find that the molecular formula of a substance is not

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* This law is in complete accordance with the "Dynamical Theory of Gases," as at present held by physicists.

always the formula which most simply represents its composition.

Thus, let us assume that the formula of hydrochloric acid gas is HCl, and therefore its molecular weight 36.5, and from this let us deduce the molecular weight of some other gases. The specific gravity of hydrogen is to the specific gravity of hydrochloric acid almost exactly as 1 : 18.25, or as 2 : 36.5; therefore, if the molecular weight of hydrochloric acid is 36.5, that of hydrogen must be 2, and its formula H_2. Again, the specific gravity of hydrochloric acid is to that of nitrogen almost exactly as 36.5 : 28; therefore, the molecular weight of nitrogen is 28, and its formula N_2. In these cases, then (and the same is true of many other gases), the theory leads us to believe that the atoms are united in pairs, each pair being a molecule, and that, just as in hydrochloric acid each hydrogen atom is united with an atom of chlorine, so in hydrogen gas each atom of hydrogen is united with another atom of hydrogen. Again, the well-known substance benzol is a compound of carbon and hydrogen in the proportion of 12 parts of carbon to 1 of hydrogen; the simplest formula by which its composition could be represented is obviously CH. If this were its true formula, the specific gravity of its vapour should stand to that of hydrochloric acid gas (at the same temperature and pressure) as 13 : 36.5, but we find the proportion almost exactly 78 : 36.5—that is, 6 times 13 : 36.5. The molecular weight of benzol is therefore 6 times 13, and its formula C_6H_6. In considering individual substances, we shall meet many such cases, and need not, therefore, dwell longer on the subject here.

THE DOCTRINE OF ATOMICITY.

55. In order to illustrate what is called "the Doctrine of Atomicity," we shall give in a tabular form the molecular formulæ of a number of substances, selected so as to place this doctrine before the reader in the way in which it may be most easily understood:

Hydrochloric Acid	HCl.	Water	H_2O.
Hydrobromic Acid	HBr.	Sulphuretted Hydrogen	H_2S.
Hydriodic Acid	HI.	Seleniuretted Hydrogen	H_2Se.
Chloride of Sodium	$NaCl$.	Chloride of Calcium	$CaCl_2$.
Bromide of Potassium	KBr.	Bromide of Zinc	$ZnBr_2$.

Ammonia	NH_3.	Marsh Gas	CH_4.
Phosphuretted Hydrogen	PH_3.	Siliciuretted Hydrogen	SiH_4.
Arseniuretted Hydrogen	AsH_3.	Perchloride of Tellurium	$TeCl_4$.
Chloride of Gold	$AuCl_3$.	Perchloride of Tin	$SnCl_4$.
Terbromide of Phosphorus	PBr_3.	Bromide of Platinum	$PtBr_4$.

Looking at these formulæ, the reader will easily see that there are some elements, such as hydrogen, chlorine, bromine, iodine, sodium, and potassium, which unite with one another two and two to form compounds containing two atoms in the molecule, one of the one, the other of the other element. Such elements are called "monads." Again, there are elements, such as oxygen, sulphur, selenium, calcium, and zinc, which unite with monads to form compounds containing three atoms in the molecule, one atom of the element in question uniting with two monad atoms (as in the second group). Such elements are called dyads. Further, we have elements, such as nitrogen, phosphorus, arsenic, and gold, each atom of which unites with three monad atoms to form a molecule. Such elements are called triads. In the same way there are elements, such as carbon, silicon, tin, and platinum, which are called tetrads, each atom uniting with four monad atoms to form a molecule. These different modes of combination can be represented graphically by drawing lines uniting the symbols of the atoms forming the molecule, thus:

$H—Cl$

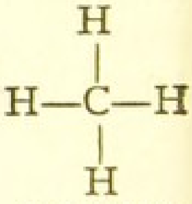
Hydrochloric Acid.

$H—O—H$

Water.

$$\begin{array}{c} H \\ | \\ H—N—H \end{array}$$

Ammonia.



$$\begin{array}{c} H \\ | \\ H—C—H \\ | \\ H \end{array}$$

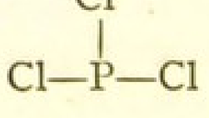
Marsh Gas.

$Na—Br$

Bromide of Sodium.

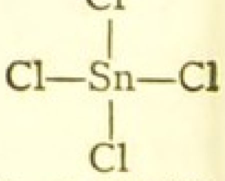
$Cl—Ca—Cl$

Chloride of Calcium.



$$\begin{array}{c} Cl \\ | \\ Cl—P—Cl \end{array}$$

Terchloride of Phosphorus.



$$\begin{array}{c} Cl \\ | \\ Cl—Sn—Cl \\ | \\ Cl \end{array}$$

Stannic Chloride.

In these *graphic formulæ* it will be observed that a monad atom is represented by its symbol with *one* line proceeding from it; similarly, *two* lines proceed from the symbol of a dyad atom; *three*, from that of a triad; and so on.

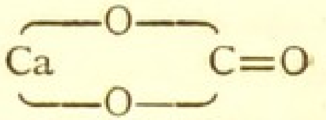
The property of combining with a definite number of monad atoms is termed "atomicity;" thus, the atomicity of hydrogen is one; of oxygen, two; of nitrogen, three; of carbon, four. More complex compounds can be represented in a similar way, thus:

$Ca=O$

Lime.

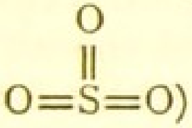
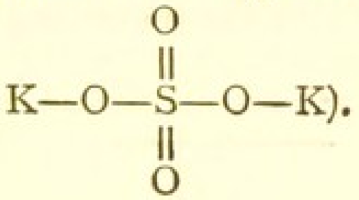
$O=C=O$

Carbonic Acid.



$$\mathrm{Ca}\begin{matrix}\diagup\!\!-O-\!\!\diagdown \\ \diagdown\!\!-O-\!\!\diagup\end{matrix}\mathrm{C}=\mathrm{O}$$

Carbonate of Lime.

Chemists are divided in opinion, as to whether an element always has the same atomicity—some holding that this is the case; while others consider that an element may have one atomicity in one set of compounds, and another in another set. The latter school regard, for instance, sulphur as dyad in sulphuretted hydrogen (H—S—H) and analogous compounds, tetrad in anhydrous sulphurous acid (SO_2; $O=S=O$), and hexad in anhydrous sulphuric acid (SO_3;  $O=\overset{\overset{O}{\|}}{S}=O$) and the sulphates, such as sulphate of potash (K_2SO_4;  $K-O-\overset{\overset{O}{\|}}{\underset{\underset{O}{\|}}{S}}-O-K$).

DULONG AND PETIT'S LAW.

56. We have hitherto considered the *atomic weight* of an element as a number adopted merely with a view to the simple, consistent, and convenient representation of the composition of the compounds of that element by means of formulæ. It has been found, however, that the atomic weights so selected have an important relation to some of the physical properties of the elements. The relation of the atomic weight to the *specific heat** of the elements has been most fully worked out,

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* The *specific heat* of a substance is the quantity of heat required to raise the temperature of one part by weight of it, by one degree, compared with the

and will alone be considered here. This relation is expressed by means of a proposition, called, from its discoverers, *Dulong and Petit's Law*. This is, that the specific heat of an element in the solid state is inversely proportional to its atomic weight; or, that the product of the atomic weight and specific heat in the solid state of an element is constant. This law is not absolutely true. The specific heat in the solid state of an element multiplied by its atomic weight is a number which, in the case of the great majority of elements, is 6·6, or very nearly this number, and this enables us in some cases to fix the atomic weight of an element where purely chemical evidence is doubtful; but as there are a few exceptional cases, and as even in those in which the product approximates to 6·6 the divergence is considerable, this law can only be regarded as an indication of a relation, not as an exact statement of it; it is, however, too important to be altogether passed over even in such a sketch of chemical principles as we have here endeavoured to give.

We have now gone over the main points of chemical principle: in order to give the reader a general view of the science, it is now necessary that we should append a short statement of chemical *facts*, to supplement what has necessarily been interwoven into the preceding exposition.

THE FACTS OF CHEMISTRY.

SHORT STATEMENT OF THE PROPERTIES OF THE ELEMENTS AND THEIR COMPOUNDS, OF THE METHODS OF PREPARING THEM, AND THEIR ACTION UPON EACH OTHER —OXYGEN.

57. Oxygen is a colourless, tasteless, odourless gas; its specific gravity (that of air being taken as unity*) is 1.1056.

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quantity of heat required to produce the same increase of temperature in one part by weight of water.

[*] Throughout this manual, when it is not otherwise stated, the specific gravity of a gas is referred to that of air as unity.

It is slightly soluble in water, 100 volumes of water, at ordinary temperatures and pressure, dissolving about 3 volumes of oxygen. It has not been reduced to the liquid state by any amount of pressure even at the lowest temperature hitherto attained.

58. It exists *free* in atmospheric air, of which it constitutes, by volume, about 20.9 per cent. It may be obtained pure—

(1.) By heating certain metallic oxides, such as oxide of silver (Ag_2O), oxide of mercury (HgO), which simply decompose into oxygen and metal; or peroxide of manganese (MnO_2), peroxide of barium (BaO_2), anhydrous chromic acid (CrO_3), which decompose into oxygen and an oxide of the metal containing less oxygen than the original substance—peroxide of manganese yielding oxygen and an oxide having the formula Mn_3O_4, containing two-thirds of the oxygen in the peroxide—peroxide of barium and anhydrous chromic acid losing half their oxygen, and leaving oxides having the composition expressed by the formulæ BaO and Cr_2O_3 respectively.

(2.) By the decomposition by heat of certain salts containing oxygen. The most practically important of these are: (*a*) *Chlorate of potash*, K_2O,Cl_2O_5 or $KClO_3$—this salt, when *strongly* heated alone (or by the action of a more moderate heat when mixed with a small quantity of peroxide of man-

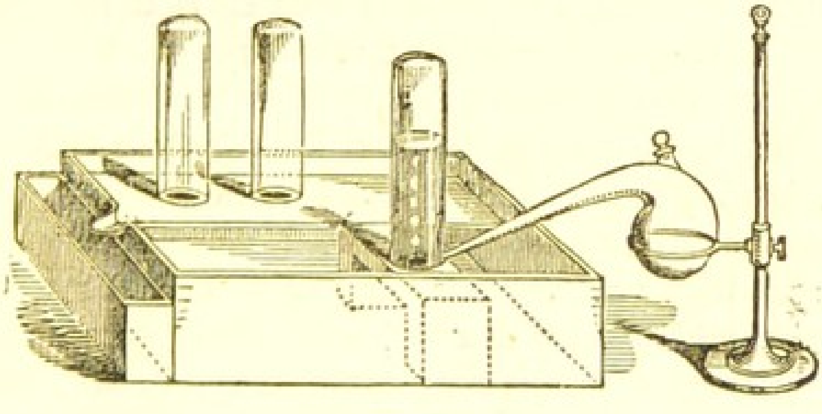

Fig. 3.

Collection of Oxygen Gas over Pneumatic Trough.

ganese, red oxide of iron, or black oxide of copper), decomposing into oxygen and chloride of potassium (KCl), thus yielding all its oxygen as oxygen gas ; (*b*) *Sulphate of zinc*, ZnO,SO_3 or $ZnSO_4$, which, when heated, yields oxide of zinc (ZnO), sulphurous acid gas (SO_2), and oxygen gas. As sulphurous acid gas is readily soluble in water, we can obtain the oxygen pure by washing the mixed gas.

(3.) By the *electrolysis* of water. See p. 37.

(4.) By the action of the green parts of living plants upon carbonic acid gas and water, under the influence of sunlight. This action cannot be conveniently used for the preparation of pure oxygen, but it plays a most important part in the economy of nature.

59. Oxygen is a *supporter of combustion;* that is, it enters into combination with combustible substances, and in doing so produces a great deal of heat. The conditions under which such combustions take place, and the products formed, will be given under the heads of the combustible substances themselves.

Oxygen is essential for the support of *animal life.* In the process of respiration, oxygen is absorbed by air-breathing animals in the lungs, by water-breathing animals in the gills from the oxygen dissolved in the water, in both cases the red colouring-matter of the blood entering into a feeble combination with oxygen. Oxygen is thus carried by the blood to all parts of the body, where it combines with the carbon and hydrogen of the tissues, producing carbonic acid and water. This combination is attended by the evolution of heat, and is thus the source of animal heat.

The compounds of oxygen have already been to some extent described, and will be further treated of under the elements of which they are oxides. Most common rocks, such as quartz, granite, limestone, trap, basalt, etc., are compounds of oxygen.

60. *Ozone* is a remarkable modification of oxygen. It has hitherto been obtained only mixed with a large proportion of common oxygen. Oxygen can be ozonised—that is, part of it converted into ozone—in various ways ; for instance, by passing electric sparks through it, or by the slow combustion

of various substances, as phosphorus. Oxygen prepared by electrolysis contains ozone. Ozone can be converted into common oxygen by heat, and also by contact with a great variety of substances. Ozonised oxygen occupies less space than the common oxygen from which it was prepared, and expansion takes place when ozone is reconverted into common oxygen, thus proving that ozone is denser than common oxygen. Experiments seem to prove that the density of ozone is to that of common oxygen as 3 : 2. If this is the case, the molecular formula of ozone is O_3, as that of common oxygen is O_2. Ozonised oxygen has a strong and peculiar odour, and acts as a bleaching and oxidising agent. It is usually present in small quantity in the air, and probably is of use in oxidising offensive and injurious organic matters.

HYDROGEN.

61. Hydrogen is a colourless, tasteless, odourless gas. Its specific gravity is 0.0693; in other words, 14½ volumes of hydrogen have the same weight as one volume of air. Light balloons filled with hydrogen, therefore, rise in the air. Hydrogen is very slightly soluble in water, 100 volumes of water dissolving less than 2 volumes of the gas. It has not been reduced to the liquid state.

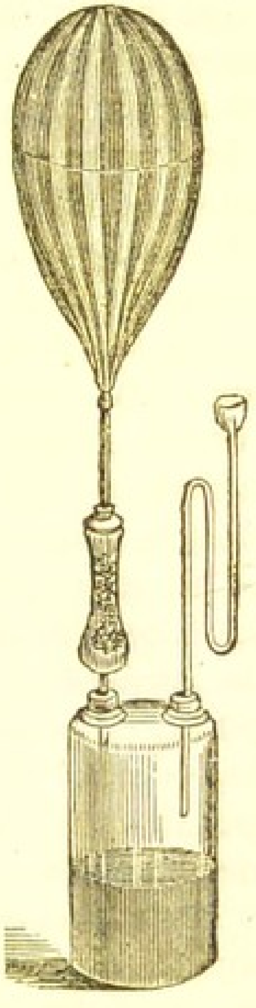
Fig. 4.

62. Hydrogen does not occur free in this planet, but spectroscopic observations prove that it exists in large quantity in the atmosphere of the sun. It forms one-ninth part, by weight, of water, and is an essential constituent of all animal and vegetable tissues. It may be obtained—(1.) By the electrolysis of water, or dilute acids (see p. 37). (2.) By the action of water on certain metals—as sodium, at ordinary temperatures, iron or zinc at a red-heat, the metal

uniting with the oxygen, and setting the hydrogen free. (3.) By the action of some hydrated acids (hydric salts) upon metals—as hydrochloric acid on zinc, iron, or tin; dilute sulphuric acid on zinc or iron; the metal simply replacing the hydrogen (see p. 31).

63. Hydrogen is inflammable—that is, it can be set fire to in air or oxygen. In order to set fire to it, the contact of a red-hot body is necessary. If a piece of spongy platinum is placed in a mixture of oxygen and hydrogen, the two gases condense in the pores of the platinum, unite there, and produce sufficient heat to render the metal red-hot, and this sets fire to the hydrogen. As already stated (p. 28), two volumes of hydrogen unite with one volume of oxygen to form water. If the two gases are mixed in this proportion, an explosive mixture is formed. When a flame or a red-hot body is applied to such a mixture, very rapid combination takes place, with violent explosion, caused by the sudden evolution of heat. Hydrogen at a high temperature is a powerful reducing agent. By far the most important compound of hydrogen and oxygen is water; its chief chemical properties have already been described.

64. The only other known compound of these two elements is the *peroxide of hydrogen.* This substance is formed when acids act on peroxide of sodium or peroxide of barium; thus, $BaO_2 + 2HCl = H_2O_2 + BaCl_2$. Its formula is H_2O_2, and it contains hydrogen and oxygen in the proportion of 1 : 16. It decomposes very readily into water and oxygen gas; a very slight rise of temperature is sufficient to effect this decomposition. In many cases it acts as an oxidising agent, because of the readiness with which it gives up half of its oxygen; but, curiously enough, it sometimes acts as a *reducing* agent. Thus, when brought in contact with oxide of silver, it not only gives off its own superfluous oxygen, and is reduced to water, but also, if we may use the expression, induces the oxide of silver to give up its oxygen too, so that metallic silver is produced.

NITROGEN.

65. Nitrogen is a colourless, tasteless, odourless gas. Its specific gravity is 0.972 ; 100 volumes of water dissolve at ordinary temperatures about 1½ volumes of the gas ; it has not been condensed to the liquid state. Nitrogen occurs in the atmosphere, of which it forms about 79.1 per cent. by volume. Atmospheric air consists essentially of nitrogen and oxygen, with comparatively very small quantities of other gases—carbonic acid, ammonia, and water-vapour. Nitrogen may be prepared from atmospheric air by removing the oxygen ; this can be done in various ways ; of these we may mention : (1.) Passing air through a long tube containing metallic copper, heated to redness ; the copper unites with the oxygen, forming cupric oxide, CuO, and the nitrogen passes on. (2.) Burning phosphorus (or allowing it slowly to oxidise) in air, the oxygen unites with the phosphorus, forming phosphoric (or phosphorous) acid (see p. 76), which can be removed by water, in which it is soluble.

Nitrogen gas is an eminently inactive substance, and does not readily enter into combination with other elements. In the air, its chief function is to act as a diluent of the oxygen. There are, however, a great many very important compounds of nitrogen which we obtain indirectly from one another. All animals and vegetables contain compounds of nitrogen ; and by the decomposition of dead animal and vegetable matters, and from the excreta of animals, other compounds of nitrogen are formed, which in their turn form part of the food of plants. Thus, there is a constant circulation of nitrogen from one state of combination to another, and with this circulation the great mass of free nitrogen in the air has very little connection. We shall here shortly describe the compounds of nitrogen with oxygen and with hydrogen.

66. *Compounds of Nitrogen and Oxygen.*—Of these there are five—namely :

Nitric Acid (anhydrous), N_2O_5, forming, with water, hydrated nitric acid or hydric nitrate, H_2O,N_2O_5 or HNO_3 ; and with bases, nitrates, as K_2O,N_2O_5 or KNO_3, nitrate of potash or potassic nitrate.

Peroxide of Nitrogen, NO_2.

Nitrous Acid (anhydrous), N_2O_3, does not form a stable hydric salt with water, but unites with bases forming nitrites, as K_2O,N_2O_3 or KNO_2, nitrite of potash or potassic nitrite.
Nitric Oxide, NO.
Nitrous Oxide, N_2O.

Nitrates and nitrites occur in the soil. The mode of their formation will be considered under Ammonia. *Hydrated nitric acid* can be obtained by heating any nitrate (most commonly, nitrate of soda—the cheapest nitrate—is used) with sulphuric acid (see p. 21). All the other oxides of nitrogen are most easily prepared from hydrated nitric acid. *Peroxide of nitrogen* is a reddish-brown vapour, having an extremely irritating action on the lungs when even a small quantity of it mixed with much air is breathed. It can be condensed to a brown liquid, nearly colourless when cooled to a low temperature. It is formed—(1.) By the reduction of nitric acid—as when hydrated nitric acid acts on tin, the tin unites with part of the oxygen, forming an oxide; and red fumes are given off, consisting of peroxide of nitrogen. (2.) By the decomposition of some nitrates by heat—for instance, nitrate of copper, CuO,N_2O_5, when heated, gives cupric oxide, CuO, which remains behind; while, instead of anhydrous nitric acid being given off, we have peroxide of nitrogen and free oxygen, $CuO,N_2O_5 = CuO + 2NO_2 + O$. (3.) By the union of nitric oxide and oxygen. Nitric oxide, NO, when mixed with oxygen, at once combines with it, forming peroxide of nitrogen.

67. *Nitrous acid* is produced in various reductions of nitric acid—for instance, when hydrated nitric acid acts on white arsenic, or on starch. It is a reddish-brown vapour, closely resembling peroxide of nitrogen. It can be condensed to a blue liquid. When nitrate of potash, K_2O,N_2O_5, or KNO_3, is strongly heated, it loses oxygen, and yields nitrite of potash, K_2O,N_2O_3 or KNO_2.

68. *Nitric oxide* is a colourless transparent gas, very sparingly soluble in water. It has not been condensed to the liquid state. It is formed by the reduction of nitric acid—for instance, when hydrated nitric acid acts on some metals (copper, lead, mercury, silver), an oxide of the metal is formed, which at once unites with nitric acid to form a

nitrate, and nitric oxide gas is given off. Its most remarkable character is its action on oxygen gas. When these two colourless gases are mixed, they instantly combine to form red fumes of peroxide of nitrogen.

69. *Nitrous oxide* is a colourless transparent gas, having a sweetish taste. Water, at ordinary temperatures, dissolves about its own volume of the gas. It can be condensed by cold and pressure to the liquid state, and may be frozen to an ice-like solid by very intense cold. This gas supports the combustion of most ordinary combustibles, such as wood, paper, wax, etc., the oxygen combining with the combustible, and the nitrogen becoming free. It cannot, however, support animal life, as the oxygen is too firmly held by the nitrogen to be given up to the red colouring-matter of the blood. At the same time, it is not directly poisonous, and can be breathed for a short time without injury. When so breathed, it produces insensibility, and is now used in minor surgical operations for the same purposes as chloroform or ether. In small quantities, it produces intoxication, whence its popular name, "laughing-gas." Its preparation will be described under Ammonia.

70. *Ammonia.*—The only known substance consisting solely of nitrogen and hydrogen is ammonia. Ammonia is a colourless transparent gas, having a peculiar pungent odour. Its specific gravity is 0.59. It is very soluble in water, one volume of water absorbing, at ordinary temperatures and pressures, between 600 and 700 volumes of the gas. Solution of ammonia is specifically lighter than water: it gives up the whole of the ammonia when boiled. This solution is what is sold as "liquor ammoniæ," or "spirit of hartshorn." The gas can be condensed by cold and pressure to a colourless liquid.

71. *Ammonia Salts.*—Ammonia is composed of 14 parts by weight of nitrogen, and 3 of hydrogen: its formula is NH_3. It unites with the hydrated acids or hydric salts to form ammonia salts. Thus, ammonia unites with hydrochloric acid to form the salt known as sal-ammoniac — $NH_3 + HCl = NH_3,HCl$ or NH_4Cl; with nitric acid to form nitrate of ammonia—$NH_3 + HNO_3 = NH_3,HNO_3$ or NH_4NO_3; with

sulphuric acid it unites in two proportions to form acid sulphate of ammonia, or bisulphate of ammonia, and normal sulphate of ammonia—$NH_3 + H_2SO_4 = NH_3,H_2SO_4$ or NH_4HSO_4, and $2NH_3+H_2SO_4=2NH_3,H_2SO_4$ or $(NH_4)_2SO_4$. These ammonia salts resemble very closely, in crystalline form and in many chemical characters, the corresponding potash salts; and if we compare the formulæ of the two sets of salts, we see that there is also an analogy in composition:

NH_4Cl;	NH_4NO_3;	NH_4HSO_4;	$(NH_4)_2SO_4$, etc.
KCl;	KNO_3;	$KHSO_4$;	K_2SO_4, etc.

72. *Ammonium.*—The reader will at once see that wherever we have in a potash salt K (that is, 39 parts of potassium), in the corresponding ammonia salt we have NH_4 (that is, 17 parts of ammonia and 1 of hydrogen). NH_4 is, therefore, a "compound radical" (see p. 44), and stands to K in a relation similar to that of NO_3 to Cl. This compound radical has received the name of *ammonium;* thus, sal-ammoniac, NH_4Cl, is chloride of ammonium, etc. There are some points where the analogy between potassium and ammonium breaks down. We may compare this analogy to that between a firm or corporation and an individual person. In buying and selling, in borrowing and lending, in suing or in being sued, a corporation or firm resembles an individual; but there are cases where this resemblance totally ceases—those cases, namely, which lead to the dissolution of the firm, or the surrender of the charter of the corporation. So in the case of ammonium and potassium, in a great many double decompositions the actions of the ammonium salts resemble those of the potassium salts—ammonium (NH_4) in the one case, and potassium (K) in the other, changing place with other metals; but sometimes the ammonium breaks up, and its constituents take each its separate course. It is by a reaction of this kind that pure ammonia is prepared. Anhydrous potash, K_2O, and hydrated or caustic potash, K_2O,H_2O (or KHO), are compounds of potassium which have no analogues in the ammonium set. There is no $(NH_4)_2O$, and no NH_4HO.* Every chemical

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* The formula NH_4HO and the name hydrated oxide of ammonium are sometimes used, but they do not refer to a definite substance, but merely to ammonia and water acting together.

change which might be expected to produce either of these bodies really yields ammonia and water—$(NH_4)_2O$ becoming $2NH_3 + H_2O$, and NH_4HO becoming $NH_3 + H_2O$. Thus, when an ammonia salt—say sal-ammoniac (chloride of ammonium)—is mixed with caustic potash (hydrate of potash), a change takes place, which is represented by the following equation :

$$NH_4Cl + KHO = KCl + NH_3 + H_2O.$$

The K takes the place of the NH_4, but the NH_4, not being able to take the place of the K, breaks up, and instead of NH_4HO, which might have been expected, we have $NH_3 + H_2O$. In preparing ammonia, slaked lime (hydrate of lime) is usually employed instead of caustic potash. The action is quite similar to that given above :

$$2NH_4Cl + CaO,H_2O = CaCl_2 + 2NH_3 + 2H_2O.$$

This operation is conducted in a retort ; and the ammonia, if required as a gas, may be dried by passing it through a tube containing fragments of solid caustic potash, which retains the water ; or if a solution of the gas (spirits of hartshorn) is wished, it is led into vessels containing water, which dissolves it.

If we attempt to isolate ammonium, it also breaks up, and ammonia and hydrogen are produced. Thus, if sodium amalgam, a compound of sodium and mercury, is covered with a strong solution of sal-ammoniac, the sodium and the ammonium change places, and we obtain chloride of sodium and ammonium amalgam. This, however, rapidly decomposes ; hydrogen and ammonia are given off, and mercury remains behind.

73. *Sources of Ammonia.*—The most important source of ammonia and ammoniacal salts is the decomposition of animal and vegetable matters containing nitrogen. Dead animals and vegetables, and animal excreta, yield ammonia in decomposing. When coal (the remains of dead plants) is distilled in the manufacture of gas, a considerable quantity of ammonia is produced, and it is from this source that the ammonia of commerce is chiefly obtained.

The following salts of ammonia deserve notice here. Sulphate, $(NH_4)_2SO_4$, largely used as a manure; sal-ammoniac, NH_4Cl; the nitrate, NH_4NO_3, is specially interesting, on account of the way in which it decomposes when heated, all of the hydrogen uniting with two-thirds of the oxygen to form water, while the nitrogen and the rest of the oxygen form nitrous oxide gas, thus: $NH_4NO_3 = 2H_2O + N_2O$. The nitrite, NH_4NO_2, undergoes a similar decomposition, yielding water and nitrogen gas, $NH_4NO_2 = 2H_2O + N_2$.

74. *Oxidation of Ammonia.*—It has been stated above that decaying animal and vegetable matters, when these contain, as they generally do, nitrogen, give off ammonia; now, if ammonia, or such ammonia-producing matters, are exposed to air in the presence of bases, especially if so exposed in a porous material, such as the soil, the ammonia undergoes oxidation, and in the first place a nitrite is produced, and this nitrite is converted into a nitrate, if the exposure to oxygen is long continued. What nitrite or nitrate is formed depends of course upon the base with which the ammonia was mixed. This is the origin of nitrates in the soil, and thus nitrate of potash is produced in Bengal, where the soil contains potash; nitrate of lime and nitrate of magnesia in this country, where the soil contains these bases. The nitrate of soda, found in extensive layers in Bolivia, appears to have had a different origin. Nitrates and nitrites are not unfrequently found in the water of shallow wells in towns and villages; in such cases, this usually indicates that decaying animal matters, drippings from dunghills, sewage, etc., have percolated through the soil, and found their way, more or less oxidised, into the well.

CARBON.

75. Carbon occurs free in nature in two perfectly distinct forms: (1.) As *diamond*, a colourless transparent solid, of specific gravity 3.5. It is the hardest substance known: it is found crystallised in forms derived from the cube. When strongly heated in air or oxygen, diamond burns, forming carbonic acid. (2.) As (*graphite*) plumbago, or blacklead, a black, opaque solid, with a metallic lustre, crystallised in hexagonal

plates. Graphite is seldom found quite pure, generally mixed with from one to five per cent. of iron, silica, and alumina. When strongly heated in air or oxygen, it burns, forming carbonic acid. In combination, carbon is very widely diffused; carbonic acid (CO_2) occurs in atmospheric air in the proportion of about four parts in 10,000. It is poured out in great quantity by volcanoes, and from cracks in the earth's surface; many mineral waters contain carbonic acid in solution; it is produced by the combustion and by the slow oxidation (decay) of animal and vegetable substances, all of which contain carbon; and forms a large part of the air expired by animals (p. 54). It is also produced in the alcoholic fermentation (see p. 98). Carbonates occur in great quantity in nature; carbonate of lime (marble, limestone, chalk, calcspar), carbonate of lime and magnesia (dolomite, magnesian limestone) being very abundant minerals, and forming the mass of many great mountain chains. Carbonate of iron (p. 86) is one of the most important iron ores. Carbon occurs in nature combined with hydrogen in marsh gas (CH_4), and is an essential constituent of all animal and vegetable tissues.

76. *Charcoal.*—From such tissues carbon may be obtained as charcoal by the action of heat. When animal or vegetable substances are heated to redness in such a manner as to exclude air or oxygen from them, the hydrogen and oxygen (and nitrogen and sulphur, if these elements are present) go off with *part* of the carbon as gases or volatile bodies, while the rest of the carbon remains behind as charcoal. This heating or charring may be conducted in either of two ways: (1.) The wood, coal, or other substance to be charred, may be set fire to in heaps so arranged that the access of air is limited, only so much being admitted as is necessary to burn a *part* of the combustible, and so furnish heat enough to char the rest. This process is adopted in charcoal-burning in countries where wood is abundant, and in coking-ovens for preparing coke for fuel. (2.) By heating the substance to be charred in cylindrical retorts heated by special furnaces outside the retorts; as in the manufacture of coal-gas. Charcoal varies greatly in character according to

the substances from which it is prepared; thus, we have wood-charcoal, peat-charcoal, coke (coal-charcoal), bone-charcoal, blood-charcoal, etc. These differ from one another in texture, being more or less dense, more or less porous, etc.; they also contain mixed with them all the mineral matter which may have been present in the substance charred. Nearly every kind of charcoal has a remarkable power of absorbing gases and vapours, and is therefore used for removing offensive vapours from air;* charcoal, especially animal charcoal, also absorbs many colouring-matters, and is accordingly used to decolorise solutions, as in sugar-refining. Charcoal, when heated in air or oxygen, burns, forming carbonic acid.

77. *Lampblack* is a form of carbon deposited from the flame of gaseous or volatile compounds of carbon. When compounds of carbon and hydrogen are burnt with a sufficient supply of air or oxygen, the hydrogen is burnt to water, and the carbon to carbonic acid; but if there is not enough oxygen for both, the carbon, or part of it, is deposited as smoke or lampblack. Lampblack is prepared by burning resinous matters in a furnace, the chimney of which opens into a large chamber where the lampblack settles. It always contains a considerable quantity of tarry matter. Charcoal and lampblack are "amorphous;" that is, are not crystalline. We have, then, three distinct forms of the element carbon, two crystalline—diamond and graphite—and one amorphous. These are called "allotropic" forms of carbon; and carbon is said to be "dimorphous," because it occurs in *two* different *crystalline* forms.

78. *Compounds of Carbon and Oxygen.—Carbonic acid* (anhydrous carbonic acid, carbonic anhydride) is composed of carbon and oxygen in the proportion of 3 to 8; its formula is CO_2. It is a colourless transparent gas, and has a pungent taste. Its specific gravity is 1.524. Water dissolves at ordinary temperatures about its own volume of the gas. It can be reduced by cold and pressure to the liquid state, and the liquid can be frozen so as to form a solid. When the gas is

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* When the offensive vapour consists, as it frequently does, of an oxidisable substance, it is oxidised by oxygen absorbed by the charcoal from the air.

produced in a vessel closed at the bottom, such as a brewer's vat or tan-pit, or poured from cracks or crevices into a well or mine, it remains—on account of its density being 1½ times that of air—as a layer at the bottom, only slowly mixing with the air by diffusion (p. 12), unless it be disturbed. Loss of life has frequently been caused by persons incautiously descending into such vats or pits, as carbonic acid not only does not support animal life, but is directly injurious. As already mentioned, atmospheric air contains normally about 4 parts in 10,000, and this proportion may be considerably increased without serious effects to animal life. Some authors assert, that air which contains one part of carbonic acid in 200 is dangerous; but there is no doubt that when the quantity reaches 2 or 3 per cent. death may be produced. Carbonic acid does not support combustion; a lighted candle is extinguished when plunged into a jar of the gas; it must, however, be remembered that a candle will burn in an atmosphere in which a man could not live, for air containing 2 or 3 per cent. of carbonic acid will support the flame of a candle, but not the life of a man.

79. *Carbonates.*—Carbonic acid (being an anhydrous acid) unites with bases to form carbonates—as normal carbonate of soda (washing-soda), Na_2O,CO_2 or Na_2CO_3 (this salt crystallises with 10 molecules of water of crystallisation); bicarbonate of soda (baking-soda), Na_2O,CO_2,H_2O,CO_2 or $NaHCO_3$; carbonate of lime (chalk, marble, limestone), CaO,CO_2 or $CaCO_3$. From carbonates we can easily obtain carbonic acid by the action of any strong acid, as hydrochloric acid, and as hydrated carbonic acid does not exist, we obtain by this action anhydrous carbonic acid and water, thus:

$$CaO,CO_2 + 2HCl = CaCl + H_2O + CO_2.$$

Other sources of carbonic acid have already been mentioned.

80. *Carbonic oxide* is composed of carbon and oxygen in the proportion 3 : 4—its formula is CO. It is a colourless transparent gas, of specific gravity 0.968, or almost exactly the same as that of nitrogen.* Carbonic oxide is very slightly soluble

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* It will be observed that the molecular weight of carbonic oxide is the same as that of nitrogen, $12 + 16 = 2 \times 14$. Their specific gravity should therefore be the same (p. 48). The slight discrepancy is no doubt due to the gases (as is

in water, and has not been liquefied. It may be prepared in various ways; of these we shall mention three. (1.) When carbonic acid is passed through a tube containing red-hot iron turnings, the iron takes half of the oxygen from the carbonic acid, and carbonic oxide is produced. (2.) When carbonic acid is passed through red-hot charcoal, it takes up carbon—thus $CO_2 + C = 2CO$. This mode of formation may be seen in a common fireplace, in which a clear red fire is burning; the air enters at the bottom of the grate, and its oxygen combines with carbon, forming carbonic acid; this gas passing upwards through the red-hot charcoal or cinders, is converted into carbonic oxide, which burns with a blue flame at the top of the fire. (3.) When *oxalic acid* is heated with strong sulphuric acid, it is decomposed into water, carbonic oxide, and carbonic acid, thus:

$$\underset{\text{Oxalic Acid.}}{H_2C_2O_4} = H_2O + CO + CO_2.$$

By passing the mixture of carbonic acid and carbonic oxide gases through a solution of caustic potash, the carbonic acid is absorbed, forming carbonate of potash, while the carbonic oxide passes through and may thus be obtained pure. Carbonic oxide is combustible, burning with a blue flame, and forming carbonic acid. It is an exceedingly poisonous gas, much more so than carbonic acid, and, along with the latter, is the cause of the deaths which have frequently been produced by breathing the air of a room where charcoal has been burnt without a chimney or proper ventilation.

81. *Compounds of Carbon and Hydrogen.*—These substances are called "hydrocarbons," and form a very large and important class of compounds. When we name as specimens of the class, paraffin oil, solid paraffin, benzine, oil of turpentine, oil of roses, india-rubber, it will be obvious to the reader that it is impossible here to describe the hydrocarbons in detail. We shall only enumerate some of their general characters, and describe two of the simplest hydrocarbons. All hydrocarbons are colourless (when pure), volatile and com-

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the case with all gases) deviating *slightly*, and not to the same extent, from Boyle's law.

bustible; when sufficient oxygen is supplied, they burn to form carbonic acid and water. If the supply of oxygen is insufficient, tarry matters and lamp-black are produced. The luminosity or brightness of the flame depends greatly on the proportion of carbon, the flame being generally brighter the more carbon is contained in the compound.

The two hydrocarbons which we shall here describe are marsh gas, and olefiant gas.

82. *Marsh gas* contains carbon and hydrogen in the proportion 3 : 1; its formula is CH_4. Of all known hydrocarbons it contains the largest proportion of hydrogen, and therefore gives the least luminous flame. It is a colourless transparent gas, scarcely soluble in water, and has not been liquefied. Its specific gravity is 0.558. It is the lightest gaseous hydrocarbon, and is often called "light carburetted hydrogen." It is produced by the decomposition of vegetable matter under water; the gas which bubbles up when the bottom of a pond is disturbed consists of marsh gas mixed with carbonic acid. It also occurs in cavities in coal-seams, and forms the "fire-damp" of our coal-mines; and it is produced by the distillation of many organic substances. It is one of the constituents of coal-gas. It is a combustible gas, and when mixed with the proper proportion of oxygen, forms an explosive mixture. The products of the combination are carbonic acid and water, $CH_4 + 2O_2 = CO_2 + 2H_2O$. From this equation it will be seen that one volume of marsh gas requires two volumes of oxygen for its combustion. As air contains about 20 per cent. of oxygen, one volume of marsh gas requires ten volumes of air for its complete combustion. The explosions which occur in coal-mines are caused by the ignition of such a mixture, and explosion takes place even when the two gases are not in the exact proportions given above. It has been found by experiment that no explosion takes place when there is less than three volumes, or more than eighteen volumes of air, to one of marsh gas. It will be remembered that a red-hot body will cause explosion of a mixture of hydrogen and oxygen—the temperature at which marsh gas takes fire is much higher—contact with a flame or white-hot body being necessary.

It is upon this fact that the efficacy of Davy's safety-lamp depends. In this lamp the flame is enclosed in a cylinder of wire-gauze. If such a lamp be placed in an explosive mixture of marsh gas and air, the mixture inside the cylinder, immediately in contact with the flame of the lamp, will burn; but this combustion will not extend to the mixture outside, as the gases, by passing through the meshes of the wire-gauze, are cooled down below the temperature necessary for kindling marsh gas. The enlargement of the flame due to the marsh gas burning inside the cylinder, is a warning to the miner of the presence of "fire-damp."

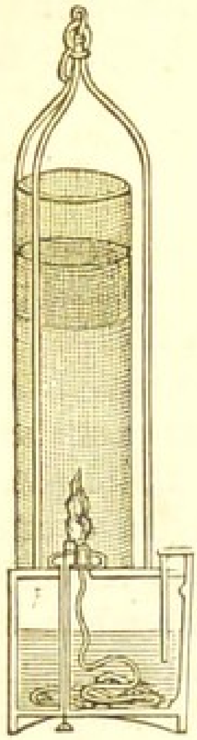
Fig. 5.

83. *Olefiant gas* contains carbon and hydrogen in the proportion 6 : 1; its formula is C_2H_4. It is a colourless transparent gas of specific gravity 0.978. It is inflammable, burning with a strongly luminous flame, and producing carbonic acid and water, $C_2H_4 + 3O_2 = 2CO_2 + 2H_2O$. It occurs in coal-gas, and the luminosity of coal-gas is to a great extent due to its presence. It can also be prepared by heating a mixture of four parts of strong sulphuric acid and one of alcohol; the action which takes place is represented by the following equation:

$$\underset{\text{Alcohol.}}{C_2H_6O} = \underset{\text{Water.}}{H_2O} + \underset{\text{Olefiant Gas.}}{C_2H_4}.$$

The sulphuric acid in this case acts as a dehydrating or water-removing agent.

CHLORINE.

84. Chlorine has been already spoken of (p. 33) as a simple or elementary "salt-radical." It occurs in nature in combination with metals, forming metallic chlorides. Of these the most important is *Chloride of Sodium* or common salt (NaCl). Common salt is by far the most abundant of the salts dissolved in sea-water, and is obtained from sea-water by spontaneous evaporation in shallow ponds or marshes in the

neighbourhood of the sea in warm countries. It also occurs in extensive beds as rock-salt, and in solution in many mineral waters. When acted on by sulphuric acid, it yields sulphate of soda and hydrochloric acid gas ($2NaCl + H_2SO_4 = 2HCl + Na_2SO_4$). *Hydrochloric acid* gas is a colourless transparent gas, of specific gravity 1.27. It is very soluble in water; at ordinary temperatures, water dissolves about 450 times its volume of the gas. The solution is denser than water, and the gas cannot be wholly expelled by boiling. The solution is generally called hydrochloric acid, or muriatic acid, or spirit of salt. Hydrochloric acid acts upon such metallic oxides as are bases, producing a salt and water; thus $CaO + 2HCl = CaCl_2 + H_2O$. But if we take an oxide, such as peroxide of manganese, which is not a base, and has no corresponding chloride, the action is different, thus: $MnO_2 + 4HCl = MnCl_2 + Cl_2 + 2H_2O$. Instead of obtaining $MnCl_4$, we have $MnCl_2$ *and* Cl_2; that is, free chlorine. It is in this way that chlorine gas is prepared.

85. Chlorine is a greenish yellow gas, of specific gravity 2.45, having a pungent smell. As it is much heavier than air, it may be collected by displacement, the tube from which it issues being led to the bottom of the receiving vessel. The chlorine collects at the bottom of the vessel, and gradually fills it, driving out the air (see fig. 6). It cannot be breathed unless very much diluted with air, and has a very irritating effect on the lining membrane of the air-passages. Water dissolves about twice its volume of chlorine gas. Chlorine

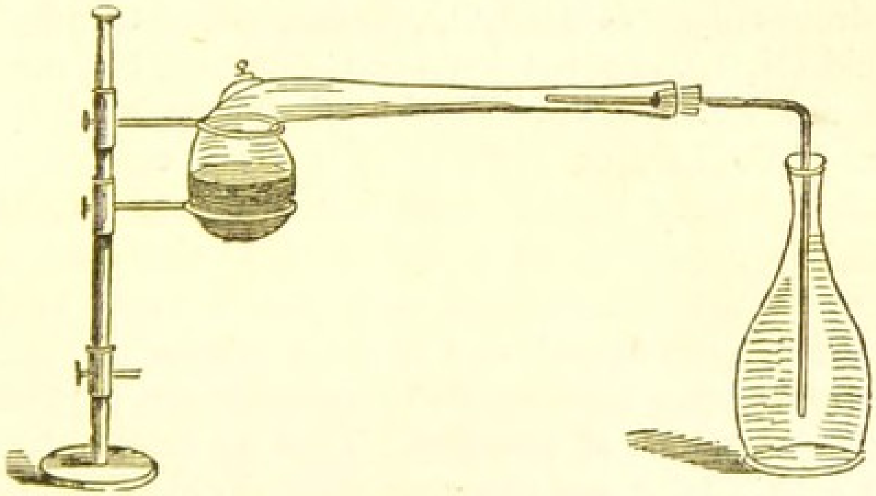

Fig. 6.

unites very readily with hydrogen ; a jet of hydrogen kindled in chlorine burns readily, forming hydrochloric acid. A mixture of equal volumes of hydrogen and chlorine can be kept for any length of time in the dark, but explodes violently when exposed to sunlight. In diffused light, the two gases combine more slowly. This tendency of chlorine to combine with hydrogen renders *wet chlorine*, or chlorine along with water, a very powerful oxidising agent ; the chlorine attracting the hydrogen of the water, the oxygen of which thus becomes more easily separated, and can therefore readily attack oxidisable substances.

It is in this way that chlorine acts as a bleaching and as a disinfecting agent. Many colouring-matters, and many offensive gases and vapours, are oxidisable, and can, by oxidation, be converted into colourless, or into inodorous bodies. In these cases, they are destroyed by wet chlorine—the chlorine taking the hydrogen of the water, while the oxygen oxidises the colouring or offensive substances.

86. *Compounds of Chlorine with Oxygen.*—Chlorine has only a very slight affinity for oxygen, so that the two elements do not directly combine ; and their compounds, when indirectly produced, decompose very easily into chlorine and oxygen, the decomposition usually taking place with explosive violence. In these decompositions, heat is given out.

Anhydrous chloric acid (Cl_2O_5), corresponding to anhydrous nitric acid (N_2O_5), has not yet been obtained, but many of its salts are well known. Hydrated chloric acid (hydric chlorate, H_2O,Cl_2O_5 or $HClO_3$) is a very explosive and powerfully oxidising liquid. *Chlorate of potash* (K_2O,Cl_2O_5 or $KClO_3$) is important as a source of oxygen, and as an ingredient in the composition with which some kinds of lucifer-matches are tipped, and in many fireworks.

Most of the other compounds of chlorine and oxygen also correspond to oxides of nitrogen. Thus we have anhydrous chlorous acid (Cl_2O_3) and chlorites, such as chlorite of potash (K_2O,Cl_2O_3 or $KClO_2$) ; peroxide of chlorine (ClO_2) ; anhydrous hypochlorous acid (Cl_2O), corresponding to nitrous oxide in composition, but uniting with strong bases to form unstable hypochlorites, such as hypochlorite of soda (Na_2O,Cl_2O or

NaClO).* These hypochlorites are formed along with the corresponding chlorides, when chlorine gas is passed into a *cold* solution of caustic potash or caustic soda. The action may be represented by the following equation :

$$2KHO + Cl_2 = KClO + KCl + H_2O.$$

87. *Bleaching-powder.*—If instead of caustic potash, slaked lime is taken, the compound known as bleaching-powder is formed. This may be regarded as a compound of chloride of calcium and hypochlorite of lime ($CaCl_2,CaO,Cl_2O$ or Cl—Ca—O—Cl). When a strong acid, such as sulphuric, is added to such mixtures or compounds of chloride and hypochlorite—the hypochlorite is first decomposed and hypochlorous acid produced ; but if enough sulphuric acid be present, the chloride is also acted on, and the hydrochloric acid and hypochlorous acid at once produce water and chlorine gas—thus

$$2HCl + Cl_2O = 2Cl_2 + H_2O.$$

So that bleaching-powder gives off hypochlorous acid or chlorine according as it is treated with a small or a large quantity of sulphuric acid.

When the solution of a hypochlorite is boiled, part of the salt loses and part gains oxygen, so that a chloride and a chlorate are produced—thus

$$3KClO = 2KCl + KClO_3.$$

It has already been mentioned (§ 58) that, when chlorate of potash is *strongly* heated it gives off all its oxygen and is reduced to chloride of potassium. A different action takes place when it is heated more moderately. A part only of the salt loses oxygen, and some of this oxygen is taken up by another part ($2KClO_3 = KCl + KClO_4 + O_2$), so that chloride of potassium, *perchlorate of potash*, and oxygen are formed. Perchlorate of potash ($KClO_4$ or K_2O,Cl_2O_7) is much less soluble in water than chloride of potassium ; the two salts can thus be easily separated.

When perchlorate of potash is strongly heated, it loses all its oxygen, and is reduced to chloride of potassium ($KClO_4 = KCl + 2O_2$).

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* Similar compounds of nitrous oxide have been obtained *indirectly* by the reduction of the nitrates.

BROMINE AND IODINE.

88. Bromine and Iodine are elements closely resembling chlorine in chemical character. They form bromides and iodides with metals, hydrobromic and hydriodic acids with hydrogen, and bromates and iodates corresponding to the chlorates. Their affinity for hydrogen and the metals is in the order chlorine, bromine, iodine; being greatest in the case of chlorine, least in that of iodine. Their affinity for oxygen is in exactly the opposite order; being greatest in the case of iodine, least in that of chlorine.

Bromides occur in small quantity in sea-water and many mineral springs, from the "mother-liquor" of which (or liquid left after the removal of the less soluble chloride of sodium) bromine is obtained. Compounds of iodine occur in extremely small quantity in sea-water, from which they are removed by sea-weeds. Iodine is obtained from the "kelp" or ash of such sea-weeds. Bromine is a volatile brown liquid; iodine, a volatile black solid, yielding a beautiful purple vapour when heated.

SULPHUR.

89. Sulphur occurs native in many volcanic districts, most of the sulphur of commerce being obtained from Sicily. It is purified by distillation, and is met with in commerce either as "flowers of sulphur"—that is, a fine powder produced by rapidly cooling the sulphur-vapour—or as roll-sulphur, cast in cylindrical moulds. When heated, sulphur fuses at a temperature of about 234° Fahrenheit, forming a mobile liquid of a brownish yellow colour. If this liquid is allowed to cool, it solidifies into an "allotropic" modification of sulphur. This form of sulphur differs from the usual one: in colour, it is brownish yellow, instead of bright yellow; in specific gravity, it is somewhat lighter than common sulphur; and in crystalline form. When kept, however, it changes back again to the common form. If fused sulphur is heated, it begins to become thick like treacle at a temperature very little above 250° F. The thickness increases as the tempera-

ture rises, until, at about 430° F., the vessel containing it can be inverted without any of the sulphur flowing out; about 640° F. it is again more liquid. If at this stage the sulphur is rapidly cooled by pouring it into water, it is obtained in a plastic form, elastic like india-rubber. This modification, when kept, passes back into the common form of sulphur.

90. *Compounds of Sulphur and Oxygen.*—When sulphur is burned in air or oxygen, it unites with oxygen, and forms anhydrous *Sulphurous Acid*, a colourless transparent gas, consisting of equal weights of sulphur and oxygen. Its formula is SO_2, its specific gravity is 2.25. It can easily be condensed to a colourless liquid, and dissolves readily in water; one volume of water dissolving about 30 volumes of the gas at ordinary temperatures. The gas has the pungent smell of burning sulphur, and cannot be breathed unless mixed with a large quantity of air. It unites with bases, forming *sulphites*, such as normal sulphite of soda (Na_2O,SO_2 or Na_2SO_3), acid sulphite of soda (Na_2O,SO_2,H_2O,SO_2 or $NaHSO_3$). Sulphurous acid and the sulphites act as reducing agents (p. 36), taking up oxygen to form sulphuric acid or sulphates. Sulphurous acid acts also as a bleaching agent, rendering certain animal and vegetable colouring-matters colourless, and is used for bleaching straw and woollen goods. Sulphurous acid is a weak acid, and the sulphites are decomposed by most strong acids.

91. Anhydrous *Sulphuric Acid* (SO_3) is a white crystalline solid, which when placed in water, unites with it, much heat being produced, to form hydrated sulphuric acid (H_2O,SO_3 or H_2SO_4). This is a colourless liquid, of specific gravity about 1.84 as compared with water. It is obtained by the oxidation of sulphurous acid. The operation is conducted in large leaden chambers, into which are introduced—(1.) Sulphurous acid, formed by burning sulphur or iron pyrites (a compound of sulphur and iron); (2.) Steam; (3.) Nitric acid; and (4.) Atmospheric air. The nitric acid oxidises the sulphurous acid to sulphuric acid, which unites with water from the steam—the nitric acid being reduced to nitric oxide (NO) (p. 58); this immediately takes up oxygen from the air, and forms peroxide of nitrogen (NO_2), which again oxidises more sulphur-

ous acid, and is reduced to nitric oxide. By a constant repetition of this process, a small quantity of nitric acid suffices for the oxidation of a large quantity of sulphurous acid. The sulphuric acid thus formed is concentrated by heat, which drives off much of the water, and leaves an acid nearly corresponding to the formula H_2O,SO_3 or H_2SO_4.

Hydrated sulphuric acid has a great attraction for water, and gives out much heat when mixed with it. It is a powerfully corrosive substance, destroying animal and vegetable tissues, and is sometimes used as a caustic in surgery. It is a very strong acid, decomposing the salts of most other acids, and is used for preparing hydrochloric, nitric, acetic, and many other acids. With bases it forms sulphates, such as normal sulphate of potash (K_2O,SO_3 or K_2SO_4); acid sulphate of potash (K_2O,SO_3,H_2O,SO_3, or $KHSO_4$); sulphate of lime (CaO,SO_3 or $CaSO_4$), etc. It is often called oil of vitriol, because it can be obtained by distilling green vitriol, or ferrous sulphate (FeO,SO_3 or $FeSO_4$). If the green vitriol be dry, anhydrous sulphuric acid is obtained. A mixture or solution of anhydrous sulphuric acid in hydrated sulphuric acid is known as Nordhausen or "fuming" sulphuric acid; it is used for dissolving indigo.

92. Sulphur unites with hydrogen, forming *Sulphuretted Hydrogen* (H_2S); this is a colourless transparent gas, of specific gravity 1.19. It can be condensed by cold and pressure to a colourless liquid. Water dissolves at ordinary temperatures about three times its volume of the gas. It has an extremely unpleasant smell, like that of rotten eggs, and acts as a poison upon animals and plants. It is inflammable, burning in air or oxygen with a blue flame, and producing water and sulphurous acid gas. It is most conveniently prepared by the action of dilute sulphuric acid on ferrous sulphide ($FeS + H_2SO_4 = H_2S + FeSO_4$). It acts upon many metallic salts, producing a metallic sulphide and a hydrated acid, thus:

$$\underset{\substack{\text{Sulphate}\\\text{of Copper.}}}{CuO,SO_3} + \underset{\substack{\text{Sulphuretted}\\\text{Hydrogen.}}}{H_2S} = \underset{\substack{\text{Hydrated}\\\text{Sulphuric Acid.}}}{H_2O,SO_3} + \underset{\substack{\text{Cupric}\\\text{Sulphide.}}}{CuS.}$$

All metallic salts are not thus acted on, and this difference of behaviour is taken advantage of in separating the metals from one another.

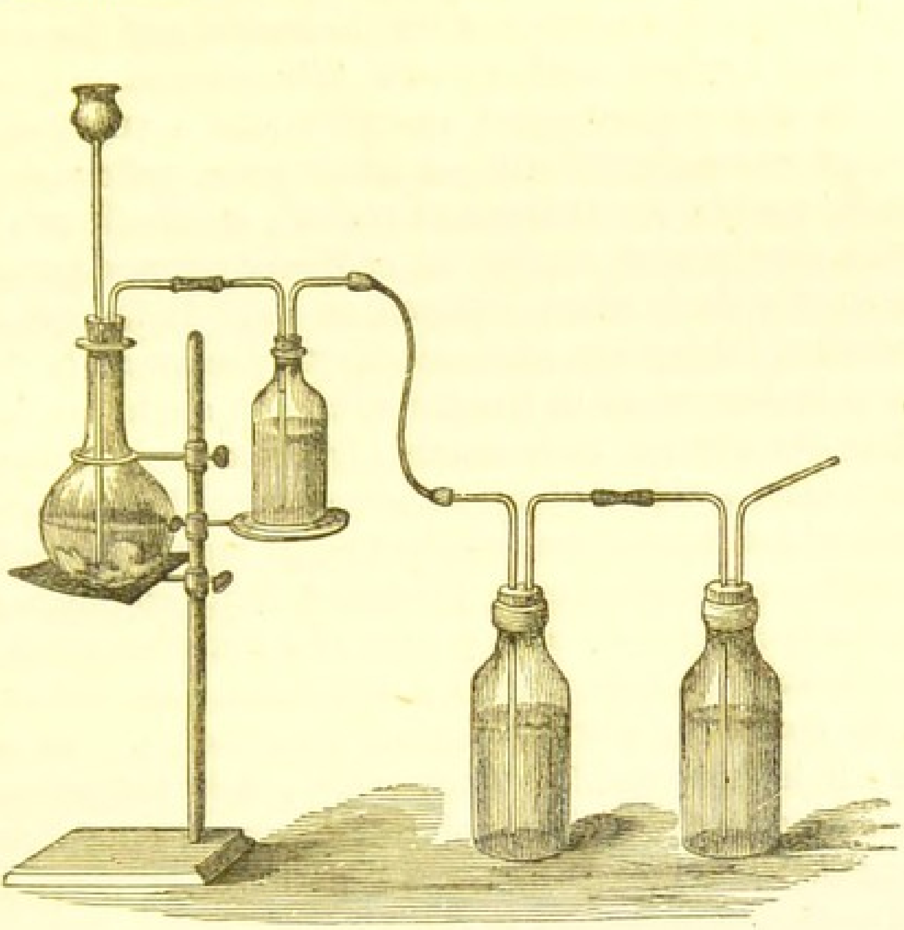

Fig. 7.

93. Sulphur unites with carbon when sulphur-vapour is passed over red-hot charcoal, forming *Bisulphide of Carbon* (CS_2), a very volatile liquid, used as a solvent of sulphur, phosphorus, and oils and fats. It is very easily set fire to, and burns with a blue flame, forming carbonic acid and sulphurous acid. As will be seen from its formula, it corresponds to carbonic acid (CO_2); and just as carbonic acid unites with basic *oxides* to form carbonates (such as Na_2O,CO_2), so bisulphide of carbon unites with the *sulphides* of positive metals to form *sulpho*-carbonates (such as Na_2S,CS_2).

PHOSPHORUS.

94. Phosphorus is an element very widely diffused in nature. Compounds of phosphorus are essential ingredients

in every fertile soil, are absorbed by plants, and pass from plants into animal bodies. The animal tissues containing large quantities of phosphorus are the bones, and the nervous tissues, brain, spinal cord, nerves. Phosphorus can be obtained in two "allotropic" modifications: (1.) Common, yellow, or waxy phosphorus—a translucent yellowish solid of specific gravity 2. It fuses at 112° F., and boils at 550° F. It unites slowly with oxygen at ordinary temperatures, and shines in the dark when exposed to air. It is very easily inflammable, taking fire when moderately warmed in the air, so that it is dangerous to handle it, and it ought to be preserved under water. It is extremely poisonous, and serious and even fatal accidents have occurred from children sucking the ends of lucifer-matches containing phosphorus. (2.) Red or amorphous phosphorus is produced from common phosphorus by keeping it for a long time at a temperature slightly below its boiling-point. It is a red solid, and differs very much in character from common phosphorus. It is not fusible; it is not readily inflammable; it is not poisonous. When heated to the boiling-point of common phosphorus, it is changed back into the latter, and therefore takes fire if heated to this temperature in the air.

95. *Compounds of Phosphorus and Oxygen.*—Phosphorus combines with oxygen in two proportions, forming, first, anhydrous *Phosphorous Acid* (P_2O_3), and second, anhydrous *Phosphoric Acid* (P_2O_5). When phosphorus is set fire to in air or oxygen, it burns with dazzling brilliancy, forming anhydrous phosphoric acid. This is a snow-white solid, which unites with the greatest readiness with water, giving out much heat. It forms with water three distinct hydrates or hydric salts:

$P_2O_5 + H_2O = H_2O,P_2O_5$............Hydric *Meta*phosphate.
$P_2O_5 + 2H_2O = 2H_2O,P_2O_5$............Hydric *Pyro*phosphate.
$P_2O_5 + 3H_2O = 3H_2O,P_2O_5$............Hydric *Ortho*phosphate.

If in these formulæ we put all the oxygen together, we find that the first and third are divisible by two, so that we have the following formulæ:

Hydric Metaphosphate (or Hydrated Metaphosphoric Acid)......HPO_3.
Hydric Pyrophosphate (or Hydrated Pyrophosphoric Acid).......$H_4P_2O_7$.
Hydric Orthophosphate (or Hydrated Orthophosphoric Acid, usually called Common Phosphoric Acid)........................H_3PO_4.

Corresponding to each of these hydrates, there are series of salts; thus, we have metaphosphate of lime (CaO,P_2O_5), metaphosphate of soda (Na_2O,P_2O_5), metaphosphate of silver (Ag_2O,P_2O_5), pyrophosphate of lime ($2CaO,P_2O_5$), pyrophosphate of soda ($2Na_2O,P_2O_5$), pyrophosphate of silver ($2Ag_2O,P_2O_5$), orthophosphate (or common phosphate) of lime ($3CaO,P_2O_5$), common phosphate of soda ($2NaO,H_2O,P_2O_5$), common phosphate of silver ($3Ag_2O,P_2O_5$). It will be observed that in common phosphate of soda we have, as in all common, or ortho-, phosphates, three equivalents of base to one P_2O_5, but only two of these are anhydrous soda, the other being water; this salt is, therefore, formally, an acid salt; it has not, however, an acid reaction, and the normal salt, $3NaO,P_2O_5$, is an unstable, highly alkaline body. When an orthophosphate containing basic water is heated, water is given off, and a pyrophosphate or metaphosphate is left; thus, when common phosphate of soda is heated, water is given off, and pyrophosphate of soda is left; $2Na_2O,H_2O,P_2O_5 = H_2O + 2Na_2O,P_2O_5$ or $2Na_2HPO_4 = H_2O + Na_4P_2O_7$; and when what is called acid phosphate of soda ($Na_2O,2H_2O,P_2O_5$), which is also an orthophosphate, is heated, water is given off, and metaphosphate of soda is left; $Na_2O,2H_2O,P_2O_5 = 2H_2O + Na_2O,P_2O_5$ or $NaH_2PO_4 = H_2O + NaPO_3$.

96. Common *Phosphate of Lime* ($3CaO,P_2O_5$ or $Ca_3(PO_4)_2$) is the most abundant mineral constituent of bones; and "bone-ash," the substance left when bones are burned white in an open fire, so as to destroy all the animal matters, consists chiefly of this phosphate. When treated with sulphuric acid and water, a partial decomposition takes place, which is represented by the following equation: $3CaO,P_2O_5 + 2(H_2O,SO_3) = CaO,2H_2O,P_2O_5 + 2(CaO,SO_3)$. The sulphate of lime ($CaO,SO_3$) being sparingly soluble in water, settles for the most part to the bottom of the vessel in which the decomposition is effected, while the acid phosphate of lime (superphosphate) remains in solution. This *Superphosphate* is largely used as a manure. When superphosphate of lime is heated, it loses water, and leaves metaphosphate of lime: $CaO,2H_2O,P_2O_5 = 2H_2O + CaO,P_2O_5$. From metaphosphate

of lime, phosphorus is obtained by heating it in earthenware retorts with charcoal. Two-thirds of the anhydrous phosphoric acid (P_2O_5) are decomposed, the charcoal taking the oxygen to form carbonic oxide, and thus setting the phosphorus free, while one-third remains with all the lime as common phosphate of lime : $3(CaO,P_2O_5) + 10C = 10CO + 4P + 3CaO,P_2O_5$.

97. Anhydrous phosphorous acid (P_2O_3), formed when phosphorus is heated with a limited supply of air or oxygen, also unites with water, forming hydrated phosphorous acid or hydric phosphite ($3H_2O,P_2O_3$ or H_3PO_3). From this substance other phosphites can be obtained. No phosphite is known in which more than two-thirds of the hydrogen of hydric phosphite is replaced by metal—thus we have sodic phosphite ($2Na_2O,H_2O,P_2O_3$ or Na_2HPO_3) calcic phosphite ($2CaO,H_2O,P_2O_3$), etc.

When hydrated phosphorous acid, or any of the phosphites is heated, phosphuretted hydrogen is given off, and phosphoric acid or a phosphate is left behind.

98. *Phosphuretted Hydrogen* (PH_3) is a colourless, transparent gas, having a disagreeable smell. It may be formed by heating phosphorus in a strong solution of caustic potash. As thus formed, it is spontaneously inflammable, taking fire at once on coming into contact with air or oxygen. The gas owes this spontaneous inflammability to the presence of a small quantity of the vapour of another compound of phosphorus and hydrogen (PH_2).

99. Phosphorus unites with chlorine and also with bromine in two proportions, corresponding to the two oxides—namely, PCl_3 ; PCl_5 and PBr_3 ; PBr_5. The terchloride and terbromide are volatile liquids ; the pentachloride and pentabromide are crystalline solids ; they all undergo decomposition when brought into contact with water, yielding hydrochloric or hydrobromic acid, and phosphorous or phosphoric acids : $2PCl_3 + 6H_2O = 6HCl + 3H_2O,P_2O_3$; $2PCl_5 + 6H_2O = 6HCl + 3H_2O,P_2O_5$.

FLUORINE.

100. Fluorine is an element the compounds of which resemble to a great extent those of chlorine. It occurs in nature combined with metals, forming salts called fluorides. The most important of these are *Fluorspar* (Derbyshire spar) or fluoride of calcium (CaF_2), and cryolite, which is a compound of fluoride of sodium and fluoride of aluminium ($3NaF,AlF_3$). From these fluorides, hydrofluoric acid (HF) can be obtained by the action of sulphuric acid: $CaF_2 + H_2SO_4 = CaSO_4 + 2HF$. *Hydrofluoric Acid* is a very volatile liquid, mixing readily with water. It acts very corrosively on animal tissues and produces severe wounds when applied to the skin. Its most striking chemical character is the way in which it acts upon glass (see Silica), and it is used in the arts for the purpose of etching glass.

SILICON.

101. Silicon, like carbon, can be obtained in three distinct "allotropic forms:" two of these are crystalline, corresponding to diamond and graphite; and one is amorphous. Silica, the oxide of silicon (SiO_2), corresponds in formula to carbonic acid, and, like it, is an anhydrous acid, uniting with bases to form *Silicates*. It differs, however, very greatly from carbonic acid in physical characters. It occurs in nature crystallised as rock crystal or quartz, and obscurely crystallised in flint and chalcedony. Opal is an amorphous form of silica, usually containing some water. Silica fuses at a very high temperature. When heated with bases it unites with them, forming silicates. Some of these silicates are of great importance. Thus, felspar (one of the ingredients of granite) is a compound of silicate of alumina and silicate of soda, potash, or lime; clay is a silicate of alumina; talc is a silicate of magnesia. Glass is formed of a mixture of silicates; of these, one must be the silicate of potash or silicate of soda: in crown-glass and plate-glass, the other is silicate of lime. In flint-glass, and the glass which is cut into ornaments, silicate of lead is present, sometimes in large proportion. Green bottle-glass owes its colour to silicate of iron.

102. The silicates of the alkalies (when not combined, as in glass, with other silicates) are soluble in water (water-glass), and are decomposed on the addition of an acid. Thus, sulphuric acid acts on silicate of soda, forming sulphate of soda and hydrated silicic acid, which under some circumstances, remains dissolved in the water, but readily separates as a jelly. Hydrofluoric acid acts on silica and on the silicates, forming water and gaseous fluoride of silicon (SiF_4). On account of this action, hydrofluoric acid is used for etching glass.

BORON.

103. Boron may be obtained in two forms, corresponding to the diamond and amorphous forms of carbon and silicon. Its oxide is anhydrous boracic acid, B_2O_3. Its most important compound is *Borax*, or borate of soda ($Na_2O,2B_2O_3$).

104. SELENIUM and TELLURIUM are comparatively rare elements, forming compounds corresponding to those of sulphur.

METALS.

105. The general physical and chemical properties of metals have already been described (p. 29). The metals may be divided into several groups, the members of each group having many characters in common. Each group may be named after a metal possessing the common characters in a well-marked degree.

(1.) The *Sodium* group—comprising Sodium, Potassium, Lithium, Rubidium, and Cæsium.

(2.) The *Calcium* group—comprising Calcium, Strontium, and Barium.

(3.) The *Iron* group—comprising Magnesium, Zinc, Cadmium, Iron, Manganese, Chromium, Nickel, Cobalt, Aluminium, and Uranium.

(4.) The *Copper* group—comprising Copper, Mercury, Lead, and Silver.

(5.) The *Platinum* group—comprising Gold, Platinum, Palladium, and the rare metals found along with platinum.

(6.) The *Antimony* group—comprising Arsenic, Antimony, Bismuth, Tin, Titanium, Vanadium, Molybdenum, and Tungsten.

By comparing this list with the table at p. 40, it will be seen that all the known metals are not here enumerated; those omitted are either too imperfectly known to admit of classification, or too rare to be of practical importance.

106.—(1.) The oxides of the metals of the *Sodium group* are powerful bases, and unite with water to form soluble hydrates, which cannot be decomposed by heat (Na_2O,H_2O; K_2O,H_2O; or $NaHO$; KHO). The bases themselves and their hydrates are called "alkalies.". The carbonates and phosphates of the alkalies are soluble in water. The metals themselves can be obtained by electrolysis of their fused chlorides, or by the reduction of their carbonates by means of charcoal: $Na_2CO_3 + 2C = 2Na + 3CO$. They decompose water at the ordinary temperature, hydrogen being given off, and the hydrated base remaining in solution: $2Na + 2H_2O = Na_2O,H_2O + H_2$.

107. *Sodic and Potassic Salts.*—The most important salts of this group of metals are: Chloride of sodium (common salt) (see p. 68); sulphate of soda (Glauber's salt) (see p. 17); carbonate of soda (Na_2O,CO_2 (washing soda). This salt is made from sulphate of soda (which is prepared by acting on common salt with sulphuric acid) by heating it with coal and limestone, dissolving out the carbonate of soda thus formed, by means of water, and evaporating the solution. Bicarbonate of soda, baking-soda (Na_2O,CO_2,H_2O,CO_2 or $NaHCO_3$), is prepared by the action of carbonic acid gas on crystallised carbonate of soda. Nitrate of soda (Chili saltpetre), Na_2O,N_2O_5 or $NaNO_3$, occurs in large quantity in Bolivia, and is used for preparing nitric acid, and also as a manure to supply nitrogen to growing plants. Phosphate of soda (see p. 77); borate of soda (borax) (see p. 23).

108. Chloride of potassium, or muriate of potash (KCl), is found in the salt mines of Stassfurth, near Magdeburg. Carbonate of potash (K_2O,CO_2) is prepared from the ashes of plants. The plants contain various salts of potash, with acids containing carbon, hydrogen, and oxygen (organic acids). These when burnt are converted into water and

carbonic acid, which go off into the air, and carbonate of potash, which remains in the ash. The ash is then treated with water, which dissolves the soluble salts, the solution is evaporated, and the less soluble salts crystallise out (see p. 10), leaving the carbonate of potash in the mother-liquor. This is then evaporated to dryness, and the solid substance remaining forms the "potashes" of commerce, and consists chiefly of carbonate of potash. Nitrate of potash (K_2O,N_2O_5 or KNO_3), known as nitre, or saltpetre (see p. 62), is obtained in Bengal from earth containing it, by treating the earth with water, and evaporating the solution. It is also formed from nitrate of lime by the action of chloride of potassium ($CaO,N_2O_5 + 2KCl = K_2O,N_2O_5 + CaCl_2$). It is used for making gunpowder.

109. Lithium, rubidium, and cæsium are comparatively rare metals, resembling in general properties sodium and potassium.

110.—(2.) *Calcium group* (or metals of the alkaline earths). The oxides of these metals—Lime (CaO) ; Strontia (SrO) ; and Baryta (BaO)—are powerful bases, and unite with water to form hydrates soluble in water. Thus, lime, when treated with water, unites with it, giving out a great deal of heat, and forming "slaked lime." The solution of slaked lime in water is called "lime-water." The *normal* carbonates and phosphates of this group are insoluble in water. If a current of carbonic acid is passed into lime-water, a white precipitate of Carbonate of Lime is formed (CaO,CO_2 or $CaCO_3$). This action enables us to test for carbonic acid in air ; thus, if a jar of air is shaken up with a definite quantity of lime-water, the proportion of carbonic acid present can be approximately estimated by the degree of milkiness produced. If the current of carbonic acid is continued after all the lime has been converted into carbonate, the milkiness gradually disappears, as carbonate of lime is soluble in water containing carbonic acid, probably on account of the formation of a Bicarbonate of Lime (CaO,CO_2,H_2O,CO_2).

111. We cannot obtain this bicarbonate in the solid state, because, when the solution is evaporated or boiled, carbonic acid escapes, and carbonate of lime is precipitated. This

solubility of carbonate of lime in water containing carbonic acid is of great practical importance. Water filtering through the soil takes up carbonic acid from decaying vegetable matters, and if it then comes in contact with carbonate of lime (limestone, or chalk), it dissolves it. Water thus charged with bicarbonate of lime, deposits carbonate of lime when it is exposed to the air: thus, if such water drops from the roof of a cave or from an overhanging rock, each drop before it falls loses some carbonic acid, and deposits some carbonate of lime on the rock. This deposit, increased by every drop which runs over it gradually forms a dependent mass of carbonate of lime, hanging down from the rock; such a mass is called a "stalactite." But the drops do not lose *all* their carbonic acid before falling, and therefore do not deposit *all* their carbonate of lime on the stalactite, so that if they fall upon a rock or upon the floor of the cave, they there, evaporating still more, deposit a further quantity of carbonate of lime; and this second deposit forms a mass, gradually increasing in height, which is called a "stalagmite." As the stalactite grows down, and the stalagmite grows up, they sometimes meet, and form a continuous column, which grows in thickness from the deposits formed by the water, which now runs down the surface of the column.

112. *Hardness in Water.*—Water containing lime salts in solution is "hard;" that is, it requires a greater quantity of soap to form a lather than soft water does. The chief lime salts occurring in hard water are the carbonate and the sulphate. The former can be almost entirely removed by boiling, hence the hardness caused by its presence is called removable hardness; that caused by the sulphate is called permanent hardness. The crust which forms in kettles and boilers in which hard water is boiled, consists usually of both carbonate and sulphate of lime.

113. *Quicklime, Slaked Lime, Mortar.*—When carbonate of lime is heated, it decomposes into lime and carbonic acid. This is the change effected in the lime-kiln. The lime (CaO) thus obtained is called "quicklime," to distinguish it from the hydrate or slaked lime. Common mortar

consists of sand, slaked lime, and water. The sand acts merely mechanically to prevent the mortar shrinking; the hardening of the mortar depends on the slow conversion of the hydrate of lime into carbonate by the action of the carbonic acid of the air ($CaO,H_2O + CO_2 = CaO,CO_2 + H_2O$). Hydraulic mortar, or cement, consists of slaked lime, sand, burnt clay, and water. Here the sand acts also merely mechanically; but the burnt clay (which is frequently introduced by using a limestone containing clay, so that the two are burnt together) contains silica (SiO_2) in a condition such that it can slowly unite with the lime, and form silicate of lime (CaO,SiO_2), and it is upon this union that the hardening or setting of hydraulic mortar or cement depends.

114. *Gypsum.*—Other important salts of lime are: The phosphate (see p. 77); the nitrate (see p. 62). The sulphate ($CaOSO_3$ or $CaSO_4$) occurs *anhydrous* in the mineral anhydrite, also with two molecules of water, as selenite or gypsum. When gypsum is heated to about 500° C. it loses all its water, and is converted into "plaster of Paris." The setting of plaster of Paris, when mixed with water, depends on the sulphate of lime taking up the water to form again the hydrated salt ($CaO,SO_3,2H_2O$). Sulphate of lime is very sparingly soluble in water.

115. The compounds of barium and strontium resemble generally those of calcium. Baryta and strontia are more soluble than lime; their sulphates are nearly insoluble in water. The metals barium, strontium, and calcium can be obtained by the electrolysis of their fused chlorides.

116.—(3.) *Metals of the Iron group.*—Iron forms two basic oxides—namely, protoxide of iron or ferrous oxide (FeO), and sesquioxide, or peroxide, or ferric oxide (Fe_2O_3); each of these forms salts with acids, and these two series of salts are quite different in character from each other. Some metals of the group, like iron, form two basic oxides (manganese, MnO and Mn_2O_3; chromium, CrO and Cr_2O_3; and Uranium, UO and U_2O_3); some have only the oxide corresponding to ferrous oxide (magnesium, MgO; zinc, ZnO; cadmium, CdO); while aluminium has only the oxide corresponding to ferric oxide, Al_2O_3. Nickel and cobalt form both oxides, NiO

and Ni_2O_3; CoO and Co_2O_3; but the peroxide of cobalt has scarcely any basic character, and the peroxide of nickel has none.

117. *Magnesium* occurs in nature in the carbonate of magnesia (MgO,CO_2), the mineral magnesite, and associated with carbonate of lime in magnesian limestone, or dolomite; in the sulphate of magnesia (Epsom salts, $MgO,SO_3,7H_2O$), which is found in many mineral waters. Chloride and bromide of magnesium occur in small quantities in sea-water. Steatite and meerschaum are silicates of magnesia. The soluble salts of magnesia have a peculiar bitter taste. The metal magnesium can be obtained by the electrolysis of fused chloride of magnesium, or by the action of sodium on chloride of magnesium ($MgCl_2 + 2Na = 2NaCl + Mg$). It is a bright white metal, of specific gravity 1.75; when heated to redness in air or oxygen, it takes fire, burning with an intensely bright white light, and producing magnesia.

118. *Zinc* occurs in nature as zincblende (sulphide of zinc, ZnS), carbonate of zinc (ZnO,CO_2), and silicate of zinc. When the carbonate is heated it loses carbonic acid, and oxide of zinc remains. The oxide can also be formed by heating the sulphide in the air, when the sulphur is converted into sulphurous acid, and the zinc into oxide of zinc. The metal is obtained by heating the oxide with coke. Carbonic oxide and metallic zinc are formed thus, $ZnO + C = CO + Zn$. The zinc being volatile distils over, and is condensed in tubes attached to the vessels in which the mixture is heated. Its oxide (ZnO) is formed when the metal is strongly heated in air or oxygen. Sulphate of zinc (white vitriol) is formed when the oxide is dissolved in sulphuric acid, or when sulphuric acid (hydric sulphate) or cupric sulphate acts on metallic zinc: $Zn + H_2SO_4 = H_2 + ZnSO_4$ or $Zn + CuSO_4 = Cu + ZnSO_4$. It crystallises (like Epsom salts) with seven molecules of water, of which one is water of halhydration. Chloride of zinc, $ZnCl_2$, formed by dissolving oxide of zinc or metallic zinc in hydrochloric acid ($ZnO + 2HCl = H_2O + ZnCl_2$ or $Zn + 2HCl = H_2 + ZnCl_2$), is a very soluble salt; it is used in surgery as a caustic, and a strong solution of it is sold under the name " Burnett's Disinfecting Solution."

119. *Cadmium* usually occurs in nature along with zinc, which it greatly resembles. The sulphide of cadmium (CdS) is yellow, and is used as a pigment.

120. *Iron* occurs in nature free as native iron, probably always in the form of meteoric masses which have fallen upon the earth. We know nothing of the origin of these meteoric stones; they appear to have been bodies moving through space, which coming into the earth's atmosphere, have been attracted to the earth, and so have fallen upon its surface. Iron occurs in combination with oxygen as ferric oxide (red hæmatite, specular iron ore, Fe_2O_3); as hydrated ferric oxide (limonite, goethite, brown hæmatite); as magnetic iron ore, or ferroso-ferric oxide (FeO,F_2O_3). Ferrous carbonate (FeO,CO_2) occurs pure in spathic iron ore, mixed with clay in the clay iron ore, and mixed with clay and coal in the black-band ironstone; ferrous silicate occurs in many minerals. The most abundant compound of iron and sulphur is iron pyrites (FeS_2).

Cast-iron, essentially a compound of iron, with about five per cent. of carbon, is obtained from iron ores by a process of which the following is a sketch. The ore is first calcined, that is, heated in the air, and thus, if not already an oxide of iron is converted into one. The calcined ore is placed in alternate layers, with limestone and coal in a blast furnace, of the form shewn in the figure, which represents a vertical section of the furnace. The chemical changes taking place in the blast furnace, may be shortly enumerated thus: Air, which in hot blast furnaces, has been previously heated to a temperature somewhat above that of melting lead, is blown into the furnace by the pipes or "tuyères," near the bottom. The oxygen at once combines with the carbon of the coke to form carbonic acid gas, and this, rising through the strongly heated coke, is converted into carbonic oxide. This gas rising to the upper part of the furnace, where the temperature is lower, acts upon the oxide of iron, removing its oxygen thus: $Fe_2O_3 + 3CO = 2Fe + 3CO_2$, the carbonic acid, thus formed, again acts upon the red-hot fuel, and produces carbonic oxide gas, which in some blast furnaces, is allowed to burn at the top, in others is conducted away by pipes, and used as fuel in heating the air to be blown into the furnace. The iron set free at the upper part of the furnace does not melt there, the temperature not being sufficiently high. It gradually falls

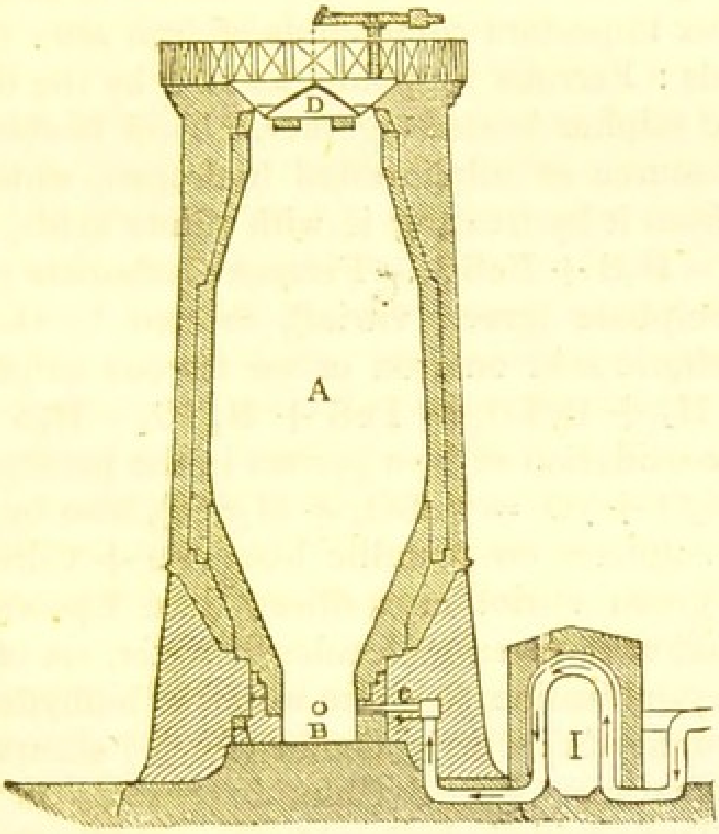

Fig. 8.

A, Body of furnace ; B, hearth; C, tuyère by which hot air enters ; D, belt or cone for closing mouth of furnace ; I, oven for heating blast-pipes.

down in the furnace as the fuel is consumed, and arriving at the hottest zone, unites with carbon to form cast iron, which fuses and runs down into the " crucible," at the bottom of the furnace. The lime unites with the siliceous matters and clay of the ore to form the " slag"—a kind of glass which fuses and runs down into the crucible, where it forms a layer above the cast-iron, and protects the latter from the oxidising action of the blast. Wrought-iron is obtained from cast-iron, by removing the carbon. This is done in the " puddling furnace," in which the cast-iron is melted and exposed to the action of the oxygen of the air. This unites with the carbon, forming carbonic oxide gas which burns on the surface of the metal, and also to some extent with the iron forming magnetic oxide. The puddled iron is then placed under a steam hammer, which squeezes out the melted oxide.

Steel is a compound of iron and carbon, containing a smaller proportion of carbon than is found in cast-iron.

The other important compounds of iron are: (1.) Ferrous Compounds: Ferrous Sulphide, formed by the direct union of iron and sulphur heated together, a black fusible substance, used as a source of sulphuretted hydrogen, which is easily obtained from it by treating it with dilute acids, thus: $FeS + H_2SO_4 = H_2S + FeSO_4$. Ferrous Carbonate; see above. Ferrous Sulphate (green vitriol), formed by the action of dilute sulphuric acid on iron or on ferrous sulphide ($Fe + H_2SO_4 + H_2 + FeSO_4$ or $FeS + H_2SO_4 = H_2S + FeSO_4$), also by the oxidation of iron pyrites in the presence of water ($FeS_2 + H_2O + 7O = FeSO_4 + H_2SO_4$), also by the action of cupric sulphate on metallic iron ($Fe + CuSO_4 = Cu + FeSO_4$); green vitriol crystallises (like Epsom salts and white vitriol) with seven molecules of water, six of which are water of crystallisation, and one water of halhydration. (2.) Ferric Compounds: Ferric Oxide (Fe_2O) occurs in nature as red hæmatite. Ferric Chloride ($FeCl_3$) is formed by dissolving ferric oxide in hydrochloric acid ($Fe_2O_3 + 6HCl = 3H_2O + 2FeCl_3$) or by oxidising ferrous chloride in the presence of hydrochloric acid ($2FeCl_2 + 2HCl + O = 2FeCl_3 + H_2O$). Ferric chloride is the substance often called muriate of iron, and is used in medicine—a solution of it in weak alcohol is sold as "steel drops." The "rust" of iron is a ferric compound, being a hydrate of ferric oxide, and having nearly the same composition as the mineral *limonite*. Ferric oxide is a comparatively weak base, and (see p. 18) acts also as a weak (anhydrous) acid. So we have compounds of ferric oxide with stronger bases—as with magnesia in magnesic ferrite (MgO,Fe_2O_3); with ferrous oxide in magnetic iron ore (FeO,Fe_2O_3); with oxide of zinc in franklinite, etc. (3.) We have a series of salts (of which only a few are known), the Ferrates, as ferrate of potash (K_2O,FeO_3), in which iron appears to play the part of sulphur—K_2O,FeO_3 corresponding to sulphate of potash, K_2O,SO_3.

121. *Manganese.*—The most important compounds of man-

ganese are: (1.) Peroxide of Manganese (MnO_2), which has been already mentioned (p. 69) as used in making chlorine. (2.) The Manganous Salts, corresponding to the ferrous salts, as MnO,SO_3; $MnCl_2$; etc. (3.) Manganic Salts, which easily lose oxygen, and are transformed into manganous salts (as $Mn_2O_3,3SO_3 + H_2O = 2(MnO,SO_3) + H_2O,SO_3 + O$). (4.) Manganates (corresponding to the Ferrates, etc.) as manganate of potash (K_2MnO_4); and (5.) Permanganates, as permanganate of potash ($KMnO_4$), a dark purple salt crystallising in the same form as perchlorate of potash ($KClO_4$). The solutions of the manganates and permanganates readily part with oxygen, especially in the presence of acids—they are therefore used as oxidising and disinfecting agents.

122. *Chromium* occurs in nature chiefly as chrome iron ore (FeO,Cr_2O_3), a compound in which chromic oxide (Cr_2O_3) acts as an acid. Its most important compounds are the *chromates*, corresponding to the ferrates or sulphates, as chromate of potash (K_2O,CrO_3), bichromate of potash ($K_2O,2CrO_3$). Chrome yellow is chromate of lead (PbO,CrO_3). Chromic acid, a red crystalline substance (CrO_3), is a powerful oxidising agent, easily giving up half of its oxygen to form chromic oxide (Cr_2O_3).

123. *Nickel* and *Cobalt* have already been referred to as forming compounds perfectly analogous to the ferrous salts. Silicate of cobalt is remarkable for its intense blue colour; in the state of fine powder it forms the pigment "smalt."

124. *Aluminium.*—The most important compounds of this metal are its oxide alumina (Al_2O_3) and the salts of this oxide. Alumina occurs in nature pure as "corundum;" coloured by small quantities of other oxides, as sapphire, topaz, ruby, and amethyst. Emery is corundum mixed with ferric oxide. Combined with water, it forms the minerals diaspore and gibbsite. Clay is a silicate of alumina, and is formed in nature by the decomposition of felspar. There are three chief species of felspar—potash felspar, soda felspar, and lime felspar—silicates respectively of alumina and potash, alumina and soda, and alumina and lime. Sulphate of alumina (concentrated alum) is formed by the action of sulphuric acid on clay. Common alum is a double sulphate of alumina and potash ($K_2O,SO_3,Al_2O_3,3SO_3,24H_2O$).

125. *Uranium* occurs in the mineral pitchblende, which is essentially an oxide corresponding to magnetic oxide of iron (UO,U_2O_3). This oxide is used for producing an intense and permanent black colour on porcelain. Uranic oxide (U_2O_3) forms a silicate of a yellowish green colour, and is used to give this colour to glass. Uranic oxide is a very feeble base; its salts correspond to basic ferric salts; thus uranic sulphate has the formula U_2O_3,SO_3.

126.—(4.) *Copper group.*—Copper forms two basic oxides —cuprous oxide, red oxide of copper (Cu_2O), and cupric oxide, black oxide of copper (CuO). There are two corresponding oxides of mercury (Hg_2O and HgO), but silver forms only one *basic* oxide (Ag_2O), peroxide of silver (AgO) not being a base. The only *basic* oxide of lead is that corresponding to cupric oxide—namely, plumbic oxide (PbO).

127. *Copper* occurs free, as "native copper," in large quantities in North America, particularly in the neighbourhood of Lake Superior; in combination with oxygen, as, cuprous oxide (red copper ore), in Siberia, in Cornwall, and in Australia; as cupric oxide (CuO), near Lake Superior; as basic carbonate (malachite, lazurite); combined with sulphur as "gray sulphide of copper" (Cu_2S) in Cornwall; along with sulphide of iron as copper pyrites ($CuFeS_2$), the most abundant of all the copper ores, in Cornwall, Devonshire, Sweden, and many parts of the United States; along with sulphide of antimony and sulphide of arsenic as sulphantimonite and sulpharsenite of copper, in the so-called "fahl ore."

Copper is obtained from copper pyrites by a series of processes, the ultimate result of which is the oxidation of the iron and sulphur by the oxygen of the air.

The most important salts of copper are the cupric salts: Cupric sulphate (CuO,SO_3 or $CuSO_4$), formed by the oxidation of sulphide of copper, or by the action of strong sulphuric acid at a high temperature on metallic copper ($Cu + 2H_2SO_4 = CuSO_4 + 2H_2O + SO_2$). It crystallises as blue vitriol or blue stone with five molecules of water, one of which is water of halhydration (p. 43). Cupric nitrate (CuO,N_2O_5 or $Cu(NO_3)_2$), formed by the action of nitric acid on metallic copper (p. 58), or on cupric oxide ($3Cu + 4(H_2O,N_2O_5) = 3(CuO,N_2O_5) + 2NO + 4H_2O$; $CuO + H_2O,N_2O_5 = H_2O + CuO,N_2O_5$), is a blue salt, which, when heated, gives cupric oxide, peroxide of nitrogen, and oxygen ($CuO,N_2O_5 = CuO + 2NO_2 + O$).

128. *Mercury* occurs in nature free as native mercury, but much more frequently as cinnabar, the mercuric sulphide (HgS), from which the metal can be obtained by heating it in the air, when the sulphur is oxidised to sulphurous acid gas, and the mercury distils over. The most important compounds of mercury are: Mercuric sulphate (HgO,SO_3), formed by the action of strong sulphuric acid at a high temperature on metallic mercury ($Hg + 2H_2SO_4 = HgSO_4 + 2H_2O + SO_2$); mercuric chloride (corrosive sublimate, $HgCl_2$), formed by heating common salt with mercuric sulphate ($HgO,SO_3 + 2NaCl = Na_2O,SO_3 + HgCl_2$) ; the corrosive sublimate being volatile, rises in vapour, and is condensed in the cold parts of the apparatus. It is soluble in water, and very poisonous. The mercurous salts are formed by adding metallic mercury to the mercuric salts ; thus, calomel (mercurous chloride, $HgCl$) may be formed by heating 271 parts of corrosive sublimate with 200 of mercury ($HgCl_2 + Hg = 2HgCl$), or by heating mercuric sulphate with metallic mercury and common salt ($HgSO_4 + Hg + 2NaCl = Na_2 SO_4 + 2HgCl$) ; the calomel is volatile, and sublimes, collecting on the cold parts of the apparatus. It is insoluble in water, and can, therefore, be freed from any corrosive sublimate which may be mixed with it by washing with water. Vermilion is mercuric sulphide.

129.—*Lead* occurs chiefly as galena (plumbic sulphide, PbS), from which it is obtained by a series of processes, the final result of which is the removal of the sulphur, in combination with oxygen from the air as sulphurous acid. It forms three oxides : (1.) Plumbic oxide (litharge, massicot, PbO). This is produced when lead is strongly heated in air or oxygen. When fused, it forms brown scales (litharge) : when prepared at a lower temperature, so that it is not fused, it is a yellow powder (massicot). It is the only basic oxide of lead. (2.) Red lead. This oxide is formed when litharge is exposed at a temperature considerably below its fusing-point to the action of air or oxygen; its composition is somewhat variable, but corresponds pretty closely to the formula Pb_3O_4. It may be regarded as a compound of plumbic oxide and the third oxide of lead, peroxide of lead. When treated with nitric acid, it forms plumbic nitrate and peroxide of lead ($2PbO,PbO_2+2(H_2O,N_2O_5)=2(PbO,N_2O_5)+2H_2O+PbO_2$). White-lead is a compound of carbonate of lead, and hydrated oxide of lead. It is formed by exposing metallic lead to air, carbonic acid, water-vapour, and the vapour of vinegar. Sulphate of lead (PbO,SO_3) is insoluble in water; for this reason, persons working in lead are recommended to add a small quantity of sulphuric acid to the water they drink, as the insoluble sulphate is not poisonous. Sulphide of lead is black, and all pigments containing lead are blackened by sulphuretted hydrogen, on account of the formation of the sulphide. Chrome yellow is chromate of lead (PbO,CrO_3).

130. *Silver* occurs in nature free as native silver, as chloride in "horn silver," as sulphide (Ag_2S) both alone and mixed with other sulphides, most specimens of galena (sulphide of lead) containing some silver, also in fahl ore as sulphantimonite of silver. The most important compounds of silver are: Nitrate of silver (Ag_2O,N_2O_5), formed by the action of nitric acid on silver ($6Ag + 4(H_2O,N_2O_5) = 3(Ag_2O, N_2O_5) + 2NO + 4H_2O$). It is soluble in water, and is used in photography, and as a mild caustic (lunar caustic) in surgery. Chloride of silver ($AgCl$) is insoluble in water and acids, soluble in ammonia. British "standard silver," of which our silver coins are made, is an alloy of silver and copper, containing in 100 parts, 92.5 of silver and 7.5 of copper. It is harder than pure silver.

131.—(5.) Of the Platinum group, we need only mention gold and platinum. These metals occur chiefly free, as native gold and native platinum. They are not dissolved by either nitric or hydrochloric acid, but are converted into chlorides ($AuCl_3$ and $PtCl_4$, by the action of chlorine, or of a mixture of nitric and hydrochloric acids (aqua regia). These chlorides unite with the chlorides of the metals of the alkalies, forming double salts, as, aurochloride of potassium (KCl,

$AuCl_3$), aurochloride of sodium ($NaCl,AuCl_3$), platinochloride of potassium ($2KCl,PtCl_4$), platinochloride of sodium ($2NaCl,PtCl_4$). Platinochloride of potassium is sparingly soluble in water, insoluble in a mixture of alcohol and ether; very similar to it is the platinochloride of ammonium ($2NH_4Cl,PtCl_4$). When the latter salt is heated, chloride of ammonium, hydrochloric acid, and nitrogen are given off, and metallic platinum is left as a spongy porous mass (spongy platinum). British standard gold is an alloy of gold and copper, containing in 12 parts, 11 of gold and 1 of copper.

132.—(6.) *The Metals of the Antimony group* resemble in many respects, the non-metallic elements; arsenic, antimony, and bismuth being analogues of phosphorus; while tin has many points of resemblance to silicon. Vanadium, molybdenum, and tungsten are comparatively rare metals.

133. *Arsenic* occurs in nature combined with sulphur in realgar (AsS) and orpiment (As_2S_3); with metals, particularly iron, in mispickel and arsenical pyrites (almost all specimens of iron pyrites contain some arsenic, which thus occurs in sulphuric acid prepared from pyrites). When arsenical ores are heated in a current of air, the arsenic is converted into "white arsenic," or arsenious acid (As_2O_3). Arsenious acid, when heated with nitric acid, is oxidised to form hydrated arsenic acid ($3H_2O,As_2O_5$), an acid very closely resembling phosphoric acid ($3H_2O,P_2O_5$). Arsenious and arsenic acids form arsenites and arseniates with bases. Arsenite of copper is the green pigment known as "Scheele's green." "Schweinfurt green" is a compound of arsenite of copper and acetate of copper. All these compounds of arsenic are highly poisonous.

134. *Antimony* occurs in nature chiefly as sulphide of antimony (Sb_2S_3). Its most important compounds are: Antimonious oxide (Sb_2O_3), a weak base, forming salts with some acids. Tartar emetic is the double tartrate (see p. 106) of potash and antimony ($K_2O,Sb_2O_3,\overline{T}$, where $\overline{T}$ stands for anhydrous tartaric acid). Chloride of antimony ($SbCl_3$) is formed by the action of strong hydrochloric acid on sulphide of antimony; when poured into water, it forms a white precipitate "powder of algaroth," or oxychloride of antimony

($3SbCl_3 + 3H_2O = 6HCl + Sb_2O_3,SbCl_3$ or $SbCl_3 + H_2O = 2HCl + SbOCl$).

135. *Tin* occurs in nature as "tinstone" or stannic oxide (SnO_2), corresponding to silica (SiO_2). The powdered ore is mixed with charcoal and heated in a reverberatory furnace; when the carbon removes the oxygen, and sets free the tin. The most important compounds of tin are: Stannous chloride, "salt of tin," or "pink salt" ($SnCl_2$), formed by the action of hydrochloric acid on tin ($Sn + 2HCl = H_2 + SnCl_2$). It is soluble in water, and is used as a mordant in dyeing. Stannic chloride ($SnCl_4$), formed by the addition of chlorine to stannous chloride. It is a colourless volatile liquid. Stannic oxide acts as an anhydrous acid, and forms salts called stannates.

136. *Alloys.*—Compounds of the metals with one another are called alloys. They resemble metals in their physical characters. We shall mention a few of the most important.

Brass, 64 parts copper and 36 parts zinc; German silver, 51 parts copper, 30.5 parts zinc, and 18.5 parts nickel; bell-metal, 78 parts copper and 22 parts tin; bronze, 80 parts copper, 4 parts zinc, and 16 parts tin; coinage bronze, 95 parts copper, 1 part zinc, and 4 parts tin; aluminium bronze, 90 parts copper and 10 parts aluminum; solder, from 2 parts tin and 1 part lead, to 1 part tin and 2 parts lead; pewter, 4 parts tin and 1 part lead; Britannia metal, pewter with a little copper and antimony; type-metal, 2 parts lead, 1 part tin, and 1 part antimony; standard (or 22 carat) gold contains in 24 parts, 22 of gold and 2 of copper. Alloys containing less gold are used in jewellery—such as 18-carat gold, containing 18 parts gold in 24; 16-carat gold, containing $\frac{16}{24}$ of pure gold; etc.

Standard silver, as already stated, contains 7.5 per cent. of copper.

The alloys of mercury are called amalgams. Tin amalgam is used for silvering looking-glasses. For details respecting the metals, the reader is referred to special treatises on Metallurgy.

ORGANIC CHEMISTRY.

137. The term "Organic Chemistry" was first employed to express that department of chemistry which treats of the substances peculiar to animals and vegetables, and the direct derivatives of these substances. As almost all these substances contain carbon, and as almost all compounds of carbon are practically obtained from animal or vegetable products, it is now found more convenient to group all carbon compounds together, and to define organic chemistry as the "chemistry of the compounds of carbon." These compounds are so numerous, and many of them so complex, that it is impossible in a sketch like this to do more than shortly describe the relations of a few of them, selected on account of their practical importance.

138. *Carbohydrates.*—Some of the simpler carbon compounds—carbonic acid, carbonic oxide, marsh gas, and olefiant gas—have already been described (p. 67), and are therefore omitted here. We shall begin with a large and very important group of compounds known as the "carbohydrates." This name implies, not that they contain carbon and water, but that they contain carbon, hydrogen, and oxygen, and that the hydrogen and oxygen are present in them in the same proportion as in water. The most important members of the group are: (1.) The sugars; (2.) Starch, gum, and inulin; and (3.) Cellulose.

139.—(1.) *Sugars* are substances soluble in water, having a sweet taste, and capable of undergoing the peculiar chemical change called the vinous fermentation, which will be described further on (p. 98). They may be divided into two sets: (1.) Those analogous to grape-sugar; and (2.) Those analogous to cane-sugar. Honey and the juice of sweet fruits contain principally grape-sugars. These can also be prepared from cane-sugar and its analogues, and from starch, inulin, or cellulose. The formula of grape-sugar is $C_6H_{12}O_6$. Cane-sugar and milk-sugar are the most important sugars of the second set. Cane-sugar is obtained from the juice of the sugar-cane, from the juice of the beetroot, from the sugar-maple, and from the sugar-palms. It occurs mixed with sugars of the first set in most sweet fruits. Milk-sugar is contained in the milk of all mammals, and is obtained by evaporating the whey, and allowing the sugar to crystallise out. The formula of cane-sugar and milk-sugar is $C_{12}H_{22}O_{11}$. When cane-sugar is boiled with dilute acids, it takes up water, and is converted into *dextrose* and *levulose*, two sugars of the first, or grape-sugar, set : $C_{12}H_{22}O_{11} + H_2O = C_6H_{12}O_6 + C_6H_{12}O_6$. Milk-sugar undergoes a similar change.

The two sets of sugar are chiefly distinguished from one another by the readiness with which they undergo chemical change, the second set being the more stable. Thus, in fermentation, cane and milk sugars are first changed into sugars of the grape-sugar set, and then these ferment. Cane-sugar can be obtained in crystals, as in loaf-sugar and sugar-candy ; when heated, it fuses, and on cooling, forms a clear, glassy, non-crystalline mass, " barley-sugar," which, if long kept, goes back into the crystalline form. More strongly heated, it loses water, and is converted into a dark-brown substance, called caramel, which is largely used for colouring rum and brandy.

140.—(2.) *Starch* occurs in many parts of plants, as in the seeds of cereal grains, in the tubers of the potato, in the stems of the sago-palm, etc. When starch is examined under the microscope, it is seen to consist of small rounded granules ; these granules vary considerably in size and shape in different plants, so that it is possible by means of the microscope, to discover the source from which a specimen of starch was derived. Starch is insoluble in cold water ; when treated with hot water, the granules swell up, and form a paste, which, when diluted, has all the appearance of a solution. Starch-paste is coloured blue by iodine, and may thus be used as a test for free iodine ; similarly, iodine is used as a test for starch. When starch is heated alone, or with a small quantity of acid, it is converted into *dextrine*, a soluble gummy substance, much used in the arts under the name of British gum. Prolonged boiling with dilute acids, and also contact with some animal liquids, convert starch into *dextrose*, a sugar of the grape-sugar set. The same change takes place in the starch contained in seeds during the process of germination. Thus, malt, which is grain in which the process of germination has been arrested, contains not starch, but dextrine and dextrose derived from starch. Malt also contains a remarkable substance called "diastase," which converts starch into dextrine and dextrose.

Inulin resembles starch very much; it occurs in the Jerusalem artichoke, the roots of the dahlia, chicory, etc. It dissolves in hot water, and does not form a jelly like starch. By boiling with dilute acids it is converted into *levulose*, a sugar of the grape-sugar set. Starch, inulin, and dextrine have all the same composition ($C_6H_{10}O_5$).

Gum-arabic is a compound of a base or bases, generally lime, magnesia, and potash, with Arabic acid ($C_6H_{10}O_5$). Gum-senegal, cherry-tree gum, gum-tragacanth, all of which are exudations from trees, have a similar composition.

141.—(3.) The last carbohydrate of which we shall treat is *Cellulose*. This substance has the same composition as starch, inulin, dextrine, and Arabic acid—namely, $C_6H_{10}O_5$. It occurs in all plants, nearly pure in cotton wool, and young fibrous cells, such as flax, hemp, etc.; and more or less mixed with resinous and other matters in wood. It is quite insoluble in water. When treated with strong sulphuric acid, it is converted into a jelly, which dries up to a horny mass. If unsized paper, which is almost pure cellulose, is dipped for a few minutes in sulphuric acid diluted with about half its volume of water, then washed and dried, a substance called "vegetable parchment" is formed, which consists of the fibres of the paper matted together by means of the above-mentioned horny substance. If the jelly is boiled with dilute acid, it is slowly converted into a sugar of the grape-sugar set. Strong nitric acid converts cellulose into gun-cotton. There are several kinds of gun-cotton, the most explosive having the composition $C_6H_7(NO_2)_3O_5$.

FERMENTATION.

142. If a solution of sugar containing nitrogenous matter is exposed to the air at temperatures between 75° and 95° F.

what is called fermentation takes place. There are several kinds of fermentation to which sugar is liable: we shall here consider only two—namely, the vinous or alcoholic, and the lactic. Each kind of fermentation is produced by the growth in the liquid of a special kind of mould or small fungus, which is called a "ferment;" and fermentation can be prevented by anything which prevents the growth of the fungus: for instance, by keeping away from the liquid the spores or germs from which the fungus springs; by the liquid being either too hot or too cold; by its containing too much sugar; or by the presence of substances which act as poisons to the ferment, and are hence called "antiseptics." The fungus or ferment which produces the alcoholic fermentation is called "yeast," and another quite different fungus or mould produces the lactic fermentation. The vinous fermentation proceeds most favourably between 75° and 85° F.; the lactic, between 85° and 95°. In the vinous fermentation, the sugar is changed into alcohol and carbonic acid gas, the latter escaping in bubbles from the surface, and giving rise to an appearance of frothing, whence the name "fermentation." Some other substances, "secondary products of fermentation," are produced at the same time in small quantity. The chief chemical change may be represented by the equation,

$$\underset{\text{Glucose.}}{C_6H_{12}O_6} = \underset{\text{Alcohol.}}{2C_2H_6O} + \underset{\text{Carbonic Acid.}}{2CO_2}.$$

In the lactic fermentation, the sugar is changed into lactic acid—thus:

$$\underset{\text{Glucose.}}{C_6H_{12}O_6} = \underset{\text{Lactic Acid.}}{2C_3H_6O_3}.$$

The alcoholic fermentation occurs in the making of bread.

143. *Alcohol* is obtained from fermented liquors by distillation (see p. 11). Pure alcohol is a colourless liquid, of specific gravity 0.794, boiling at 173° F. Its composition is indicated by the formula C_2H_6O. It is inflammable, burning with a feebly luminous flame, and producing carbonic acid and water. It is capable of dissolving many substances, and is used as a solvent for resins: an alcoholic solution of shellac is the common "spirit varnish."

144. *Ethers.*—Alcohol acts upon acids in a manner very similar to that of bases. Thus, with hydrochloric acid, alcohol yields water and a volatile substance called hydrochloric ether, or chloride of ethyl; just as caustic soda, with hydrochloric acid, yields water and chloride of sodium, $C_2H_6O + HCl = H_2O + C_2H_5Cl$, corresponding to $NaHO + HCl = H_2O + NaCl$; and as caustic soda is regarded as the oxide of hydrogen and sodium, and represented by the graphic formula, Na—O—H, so we may call alcohol the oxide of hydrogen and ethyl, C_2H_5—O—H. The substances produced by the action of acids upon alcohol (which may be looked upon as the *salts* of ethyl) are called "compound ethers" or "esters," and are named after the acid employed in producing them: thus, nitrous acid acts on alcohol to produce nitrous ether; acetic acid, to produce acetic ether; and so on. The analogy between the compounds of ethyl and those of such a metal as sodium can be carried further; and just as we have anhydrous oxide of sodium, Na_2O or Na—O—Na, so we have anhydrous oxide of ethyl, $(C_2H_5)_2O$ or C_2H_5—O—C_2H_5. This substance is common ether, often, but improperly, called sulphuric ether, because sulphuric acid is used in making it. When alcohol is mixed with sulphuric acid, the first change which takes place is the formation of water and "sulphovinic acid," which is the acid sulphate of ethyl, $C_2H_5OH + H_2SO_4 = HOH + C_2H_5HSO_4$. This sulphovinic acid is obviously the analogue of bisulphate of soda, $NaHSO_4$. When sulphovinic acid is heated along with alcohol, ether and sulphuric acid are formed—thus, $C_2H_5OH + C_2H_5HSO_4 = C_2H_5\text{—O—}C_2H_5 + H_2SO_4$. In the ordinary process for making ether, these two actions go on together, so that the sulphovinic acid is decomposed as fast as it is formed, and ether and water distil over together, leaving sulphuric acid behind. A comparatively small quantity of sulphuric acid is thus able to convert a large quantity of alcohol into ether and water.

Common ether is a colourless liquid, of specific gravity 0.723, boiling at 96° F. It is therefore a very volatile substance; and as it evaporates rapidly below its boiling-point, it can be used to produce intense cold. It is also used as a solvent for fats and oils, and as an anæsthetic in surgery.

145. *Acetous Fermentation, Acetic Acid.*—If fermented liquors—that is, solutions containing alcohol and nitrogenous substances—are exposed to the air, they gradually become sour, and what is called "vinegar" is produced. This change is known as the "acetous fermentation," and, like other fermentations, depends on the growth of a fungus, *Mycoderma aceti*, the vinegar-plant, or "mother of vinegar." The acetous fermentation not only requires the presence and growth of a ferment, but also the presence of air or oxygen, and in this differs essentially from the other two kinds of fermentation which we have been considering. It is, in fact, a process of oxidation taking place under the influence of the ferment. In the "quick process" for making vinegar, weak alcohol is made to trickle through casks containing wood-shavings, and pierced with holes for the admission of air. The shavings become coated with *mycoderma*, and the oxidation of the alcohol proceeds very rapidly. Alcohol can also be oxidised by various oxidising agents, and we can thus trace the process more minutely than is possible in the case of the acetous fermentation. When alcohol is heated with a mixture of sulphuric acid and solution of bichromate of potash (or what comes to the same thing, sulphuric acid and chromic acid), the alcohol loses hydrogen, and the chromic acid loses oxygen; these combine to form water, and the chromic acid is reduced to chromic oxide, which, with the sulphuric acid, forms chromic sulphate. The alcohol, by the loss of hydrogen, is converted into a very volatile liquid, called aldehyd (*al*cohol *dehyd*rogenatum—that is, alcohol from which hydrogen has been removed), having the composition indicated by the formula C_2H_4O—that is, $C_2H_6O - H_2$. Aldehyd is very easily oxidised, readily taking up another atom of oxygen, and forming acetic acid, $C_2H_4O_2$.

146. *Distillation of Wood.*—Besides the oxidation of alcohol, there are various ways in which acetic acid can be produced; of these, the most practically important is the distillation of wood. As has been already stated (p. 97), wood consists principally of cellulose. When it is heated to redness in a retort, closed so as to exclude air, and provided

with a tube, by which the gaseous and volatile products can be led to a cooling and condensing apparatus, a great many different substances are formed. They may be grouped thus: (1.) The charcoal which remains in the retort; (2.) Uncondensable gases which pass through the condenser; and (3.) Volatile substances, which flow as liquids from the condenser. Of these we may again distinguish the *tar*, which contains the substances insoluble, or sparingly soluble in water, and a watery liquid floating upon the tar, and consisting chiefly of water, acetic acid, and a light inflammable liquid called pyroxylic spirit. These may be separated from one another by converting the acetic acid into an acetate by the addition of a base (soda, lime, or oxide of lead) distilling off the pyroxylic spirit; and, if the acetic acid is required as such, decomposing the acetate by means of sulphuric acid, and distilling.

147. Pure acetic acid is a colourless liquid, with a pure sour taste and pungent odour; at 32° F. it freezes, and forms a colourless crystalline mass, which does not fuse till the temperature is raised to about 60° F. The specific gravity of the liquid is 1.063. It boils at 246° F. Its composition is represented by the formula $C_2H_4O_2$. The strongest vinegar of commerce contains about 5 per cent. of pure acetic acid. The most important acetates are: Acetate of soda, acetate of lead (sugar of lead), basic acetate of lead (Goulard's solution), acetate of copper, basic acetate of copper (verdigris), acetate of alumina, and ferric acetate; the last two are used as mordants in dyeing and calico-printing.

ALCOHOLS AND THEIR DERIVATIVES.

148. Many substances have a chemical character similar to that of common alcohol—that is to say, they form compound ethers when treated with acids, lose two atoms of hydrogen to form bodies analogous to aldehyd, which, again, easily take up oxygen, and are converted into acids corresponding to acetic acid. Thus, there is a substance contained in pyroxylic spirit called "methylic alcohol," which has the formula CH_4O (or $CH_3—O—H$). With hydrochloric acid,

it forms water and CH_3Cl, chloride of methyl; when oxidised, it is converted into CH_2O, its aldehyd; and this, again, into CH_2O_2, formic acid. Formic acid is interesting as the acid contained in the bodies of red ants, and in the stinging fluid of the common nettle. To take another example, common fousel oil (see p. 12) consists mainly of an oily liquid, to which the name "amylic alcohol" has been given. This substance has the composition $C_5H_{12}O$ (or $C_5H_{11}—O—H$); it yields water and a compound ether when treated with an acid, for instance:

$$\underset{\text{Amylic Alcohol.}}{C_5H_{11}—O—H} + \underset{\text{Hydrochloric Acid.}}{HCl} = \underset{\text{Water.}}{H—O—H} + \underset{\text{Chloride of Amyl.}}{C_5H_{11}Cl.}$$

When oxidised by means of a mixture of sulphuric acid and bichromate of potash, it is converted by the loss of two atoms of hydrogen into $C_5H_{10}O$, which is easily oxidised to valerianic acid, $C_5H_{10}O_2$, an acid also obtained from the plant "valerian," whence its name.

149. *Polyatomic Alcohols and their Derivatives.*—Chloride of methyl, which is the hydrochloric ether of methylic alcohol, can also be obtained by the action of chlorine upon marsh gas ($CH_4 + Cl_2 = CH_3Cl + HCl$); and similarly, the chloride of ethyl, the chloride of amyl, etc., can be obtained by the action of chlorine upon the corresponding hydrocarbons, C_2H_6; C_5H_{12}; etc. We have thus a relation between the class of alcohols which we have just been considering, and compounds of carbon, hydrogen, and *one* atom of chlorine. Now there are other classes of alcohols which stand in a similar relation to certain compounds of carbon and hydrogen with *two or more* atoms of chlorine. It will be sufficient for our present purpose to give a few examples of such alcohols. Olefiant gas (see p. 68) unites with its own volume of chlorine gas to form a colourless volatile liquid, sparingly soluble in water, called chloride of ethylene, or "oil of Dutch chemists," because it was discovered by four Dutch chemists. This substance has the formula $C_2H_4Cl_2$, and is formed by the union of C_2H_4 and Cl_2. It has many points of analogy with such a metallic chloride as chloride of lead, $PbCl_2$, just as chloride of ethyl resembles in many respects chloride of

sodium, $NaCl$. Thus, if chloride of lead is treated with acetate of silver, we get chloride of silver and acetate of lead; and similarly, chloride of ethylene with acetate of silver gives us chloride of silver and acetate of ethylene; and by acting on acetate of ethylene with caustic potash, we obtain acetate of potash and hydrated oxide of ethylene; just as acetate of lead and caustic potash yield acetate of potash and hydrated oxide of lead. Hydrated oxide of lead is $H—O—Pb—O—H$, and hydrated oxide of ethylene is $H—O—C_2H_4—O—H$. Here ethylene (C_2H_4) is a dyad radical, and its hydrated oxide (which, from its sweet taste, has been called glycol) is a diatomic alcohol. Glycol forms compound ethers with acids, and just as in the case of lead we have normal and basic salts, so from glycol we can obtain normal and basic ethers; $C_2H_4Cl_2$ or $Cl—C_2H_4—Cl$, and $H—O—C_2H_4—Cl$ may be given as examples.

150. *Oxalic Acid.*—When oxidised, glycol yields, among other products, its aldehyd, "glyoxal" ($C_2H_2O_2{=}C_2H_6O_2-2H_2$), which is easily oxidised to form oxalic acid, $C_2H_2O_4$. Oxalic acid is a white crystalline solid, readily soluble in water. As crystallised from its aqueous solution, it contains two molecules of water of crystallisation. It has an intensely sour taste, and is very poisonous. It is produced in the oxidation of very many organic substances; thus, when sugar is boiled with nitric acid, much oxalic acid is formed. It is now usually prepared by heating sawdust (impure cellulose) with caustic potash—hydrogen is given off, and oxalate of potash ($C_2K_2O_4$) formed; from this, oxalic acid can be obtained. Oxalic acid is a dibasic acid (see p. 46). Its most important salts are: Acid oxalate (binoxalate) of potash, or "salt of sorrel," C_2HKO_4, which occurs in the juice of various kinds of sorrel; oxalate of lime (C_2CaO_4).

151. *Glycerine*, a substance of great importance, the preparation of which will be described presently, is an example of a triatomic alcohol. Its formula is

$$C_3H_8O_3 \text{ or } C_3H_5\begin{cases}—O—H\\—O—H\\—O—H\end{cases}$$

Here the radical C_3H_5 is triad, like bismuth in $Bi(OH)_3$.

Accordingly, glycerine forms with acids compound ethers, of which there are three series, which we may represent by the examples $C_3H_5Cl_3$, $C_3H_5Cl_2(OH)$, and $C_3H_5Cl(OH)_2$. Erythromannite, a sweet substance obtained from certain lichens, is an example of a tetratomic alcohol ($C_4H_{10}O_4$ or $C_4H_6(OH)_4$); and mannite, a sweet crystalline substance found along with sugar in the manna, or sweet exudation from the ash-tree, is an example of a hexatomic alcohol. The formula of mannite is $C_6H_{14}O_6$ (or $C_6H_8(OH)_6$), and differs from that of grape-sugar by containing two atoms of hydrogen more; and dextrose (p. 96), a sugar of the grape-sugar set, can be converted into mannite by treating it with nascent hydrogen.

FATS AND OILS.

152. *Glycerides.*—If pure acetic acid and glycerine be mixed together and heated, the product will be found to be different according to the temperature and the proportion in which the two substances are mixed. If the temperature does not rise above 212° F., the reaction takes place in accordance with the equation:

$$\underset{\text{Glycerine.}}{C_3H_5\left\{\begin{array}{l}OH\\OH\\OH\end{array}\right.} + \underset{\text{Acetic Acid.}}{H{-}C_2H_3O_2} = \underset{\text{Water.}}{H{-}O{-}H} + \underset{\text{Monoacetine.}}{C_3H_5\left\{\begin{array}{l}C_2H_3O_2.\\OH.\\OH.\end{array}\right.}$$

If sufficient acetic acid is present, and the temperature is raised to 480° F., a more complete action of exactly the same kind takes place, thus:

$$\underset{\text{Glycerine.}}{C_3H_5\left\{\begin{array}{l}OH\\OH\\OH\end{array}\right.} + \underset{\text{Acetic Acid.}}{\begin{array}{l}H{-}C_2H_3O_2\\H{-}C_2H_3O_2\\H{-}C_2H_3O_2\end{array}} = \underset{\text{Water.}}{\begin{array}{l}H{-}O{-}H\\H{-}O{-}H\\H{-}O{-}H\end{array}} + \underset{\text{Tricetine.}}{C_3H_5\left\{\begin{array}{l}C_2H_3O_2.\\C_2H_3O_2.\\C_2H_3O_2.\end{array}\right.}$$

When the conditions are intermediate, diacetine

$$\left(C_3H_5\left\{\begin{array}{l}C_2H_3O_2\\C_2H_3O_2\\OH\end{array}\right.\right) \text{ is formed.}$$

Monoacetine and diacetine are *basic* compound ethers of glycerine; while triacetine is a *normal* compound ether. Now, the fats and fixed or greasy oils, which are found in such abundance in many seeds, and in the cellular tissue of animals, are all *normal compound ethers of glycerine*, constituted like triacetine; such compounds are called "glycerides." As triacetine is formed by the union of glycerine and acetic acid and the simultaneous separation of water, so we can reverse the process, and by heating triacetine with a large quantity of superheated steam, add water to it, and obtain glycerine and acetic acid. The fats and oils treated in the same way yield glycerine and one or more "fatty or oily acids."

153. *Soap.*—A similar decomposition takes place, but much more readily, when the fat or oil is treated with caustic potash or caustic soda. In this case, of course, we obtain, not the acid, but its potash or soda salt, and as the potash and soda salts of the fatty and oily acids are *soaps*, this process is called "saponification," or soap-making; and a fat or oil is said to be "saponified" when it is treated with a caustic alkali. In order to separate the soap thus produced from the glycerine formed at the same time, common salt is added to the liquid, when the soap, being insoluble in brine, separates as a curdy solid, leaving the glycerine dissolved. "Hard soap" has soda, "soft soap" potash, as base.

154. The most important "glycerides" are stearine, palmitine, oleine, and linoleine, which are normal compound ethers of glycerine and stearic, palmitic, oleic, and linoleic acids, respectively. Stearine and palmitine are white solids, melting at 160° F. and 142° F. respectively. Oleine and linoleine are liquids. The ordinary fats, such as suet, lard, tallow, etc., are mixtures of stearine, palmitine, and oleine in various proportions; the harder and less fusible containing most stearine; the softer and more fusible containing most oleine. Olive-oil contains palmitine and oleine; almond-oil, oleine with a small quantity of palmitine. Linoleine occurs in linseed oil, poppy-oil, hemp-seed oil, and other "drying oils;" when exposed to the air, it absorbs oxygen, and is converted into a solid varnish. Castor-oil consists almost entirely of ricinoleine, the glyceride of ricinoleic acid. The composition of these fatty and oily acids is given in the following table:

Palmitic Acid	$C_{16}H_{32}O_2$.
Stearic Acid	$C_{18}H_{36}O_2$.
Oleic Acid	$C_{18}H_{34}O_2$.
Linoleic Acid	$C_{16}H_{28}O_2$.
Ricinoleic Acid	$C_{18}H_{34}O_3$.

ORGANIC ACIDS.

155. We have already mentioned a considerable number of organic acids—namely, acetic, lactic, formic, valerianic, oxalic, stearic, palmitic, oleic, linoleic, and ricinoleic. We shall here name, and very shortly describe a few more.

Succinic Acid, $C_4H_6O_4$, a dibasic acid, obtained by the distillation of amber, by the oxidation of fatty acids, and by the reduction of malic and tartaric acids.

Malic Acid, $C_4H_6O_5$, a dibasic acid, obtained from the juice of sour apples, currants, rowan-berries, rhubarb, etc.

Tartaric Acid, $C_4H_6O_6$, a dibasic acid. Acid tartrate of potash, $C_4H_5KO_6$, occurs in the juice of the grape. This salt is somewhat sparingly soluble in water, and still less soluble in dilute alcohol; it is therefore deposited as a crystalline crust when the grape-juice is fermented. This crust, which contains, besides bitartrate of potash, tartrate of lime, and colouring-matter, is called tartar or argol. Purified by recrystallisation, it is known as cream of tartar. Tartaric acid is obtained from it by first converting it into tartrate of lime, and decomposing this by sulphuric acid Tartar emetic is prepared by dissolving antimonious oxide (Sb_2O_3) in a solution of cream of tartar.

Citric Acid, $C_6H_8O_7$, a tribasic acid, occurs in the juice of the orange, lemon, citron, and along with malic acid, in the currant, gooseberry, raspberry, and many other fruits. It is prepared by neutralising the acid juice with lime, and decomposing the citrate of lime by means of sulphuric acid.

When citric acid is heated, it loses water, and is converted into *aconitic acid*, $C_6H_6O_6$, a tribasic acid, also obtained from the aconite plant, whence its name.

Benzoic Acid, $C_7H_6O_2$, a monobasic acid, is obtained in gum-benzoin, and is obtained from it by sublimation. Oil of bitter almonds is a mixture of prussic acid and benzoic aldehyd (C_7H_6O). Benzoic acid when distilled with lime yields *benzol*, C_6H_6; thus, $C_7H_6O_2 + CaO,H_2O = C_6H_6 + CaO,CO_2 + H_2O$.

Gallic Acid, $C_7H_6O_5$, a monobasic acid obtained by the fermentation of the tannin of nut-galls. It produces, when mixed with solutions of ferric salts, a deep blue-black precipitate, which is the basis of ordinary writing ink. With ferrous salts, it produces a white precipitate, which becomes black, owing to oxidation, when exposed to the air.

Tannin or *Tannic Acid.*—This name is applied to a number of substances occurring in nut-galls, oak-bark, catechu, kino, cinchona bark, etc., and having the property of forming an insoluble compound with gelatine.

Uric Acid, $C_5H_4N_4O_3$, a dibasic acid, occurs as urate of soda, and urate of ammonia in the excrements of birds and reptiles, in small quantity in the urine of other animals, in some urinary calculi, and in the "chalk-stones" which form in the joints of gouty persons. Urate of ammonia forms a large part of guano.

156. *Prussic Acid* or *Hydrocyanic Acid.*—If nitrogen gas is passed through a heated mixture of charcoal and caustic potash, carbonic oxide, hydrogen, and a substance having the composition KCN, are formed, thus:

$$2KHO + 4C + N_2 = 2KCN + 2CO + H_2.$$

The potassium in this compound may be replaced by other metals, thus: $KCN + AgNO_3 = AgCN + KNO_3$, and $KCN + HCl = HCN + KCl$. There is thus a series of compounds in which the group CN acts as a monad salt-radical—plays, in fact, the part of Cl. This radical is called "cyanogen," and its compounds, cyanides. HCN is hydrocyanic (or prussic) acid; KCN, cyanide of potassium; and so on. Almost all cyanogen compounds are prepared from the substance known as "yellow prussiate of potash," or "ferrocyanide of potassium." This salt has the composition $4KCN, Fe(CN)_2$, and may be regarded as a compound of cyanide of potassium and ferrous cyanide. It is formed by fusing animal refuse containing nitrogen (such as dried blood, parings of horn, hide, etc.) along with caustic potash and iron, exhausting the mass with water in the presence of air, and concentrating the clear solution, when the salt crystallises out in large tabular crystals containing two molecules of water of crystallisation. In the fusion, cyanide of potassium is formed by the union of the nitrogen and carbon of the animal matter with the potassium of the potash; and the cyanide of potassium, by the action of water, oxygen, and iron, is converted into the ferrocyanide, thus: $6KCN + Fe + H_2O + O = 2KHO + 4KCN,Fe(CN)_2$. Ferrocyanide of potassium, when treated with dilute sulphuric acid, yields hydrocyanic acid, which, being volatile, can be distilled off from the residue, consisting of sulphate of potash and a substance called "Everitt's salt."

157. Prussic acid is an extremely poisonous substance, and this character belongs also to most of the cyanides. The ferrocyanides are, however, exceptions. By the action of chlorine, ferrocyanide of potassium is converted into ferricyanide of potassium or red prussiate of potash, $4KCN,Fe(CN)_2 + Cl = 3KCN,Fe(CN)_3 + KCl$. The most important cyanides are: Cyanide of potassium, KCN; cyanide of silver, $AgCN$; mercuric cyanide, $Hg(CN)_2$, formed by dissolving mercuric oxide in aqueous hydrocyanic acid, and crystallising; ferrocyanide and ferricyanide of potassium; ferric ferrocyanide (Prussian blue), and ferrous ferricyanide (Turnbull's blue). Mercuric cyanide, when heated, decomposes into metallic mercury and cyanogen. Part of the cyanogen passes off as cyanogen gas, $(CN)_2$ or C_2N_2, part remains as a brown solid of the same composition, known as paracyanogen. Just as chlorine, when passed into a cold solution of caustic potash, gives chloride of potassium, and hypochlorite of potash, KCl and $KClO$, so cyanogen, under the same conditions, gives cyanide of potassium, KCN, and cyanate of potash, $KCNO$. Cyanate of potash can also be formed by the oxidation of cyanide of potassium by means of red oxide of lead or black oxide of manganese.

ORGANIC BASES.

158. It has already been pointed out that the alcohols have a great resemblance in their mode of action upon acids to

hydrated bases (p. 99); but there are other organic compounds which are much more completely analogous to the bases of inorganic chemistry, forming, with acids, salts, which are usually crystalline, and which undergo double decomposition exactly as the salts of metallic oxides do. Many of these organic bases, or alkaloids, as they are called, are soluble in water, and have an alkaline reaction. Some of them can be formed artificially, and some occur as salts in the juices of various plants. Thus, in opium, the dried juice of the unripe heads of the white poppy (*Papaver somniferum*), there occur salts of morphia, codeia, narcotine, thebaine, papaverine, narceine, and some other less completely investigated alkaloids. The juice of the deadly nightshade (*Atropa belladonna*) contains a salt of the alkaloid atropia. Nux-vomica contains salts of strychnia and brucia; cinchona bark, salts of quina and cinchona; henbane (*Hyoscyamus niger*) contains a salt of hyoscyamine; tobacco (*Nicotiana tabacum*) contains a salt of nicotine; hemlock (*Conium maculatum*), a salt of conia; and so on. In most cases, the plant owes its special action on the animal system, as a poison or drug, to the alkaloid or alkaloids contained in it, so that it is possible to substitute a salt of the alkaloid as a medicine for the extract or tincture of the plant, with the advantage of having a substance of constant composition and action, instead of a mixture which sometimes contains more, sometimes less, of the alkaloid which is its really active ingredient.

For detailed accounts of these organic alkaloids, we must refer the reader to the larger handbooks of chemistry. They all contain nitrogen, and may be regarded as ammonia in which the hydrogen has been partially or completely replaced by organic radicals; thus, trimethylamine, a base which occurs in herring-brine, is $N(CH_3)_3$, corresponding to ammonia, NH_3. The bases obtained from plants have a similar, though, in most cases, a much more complicated constitution.

VOLATILE OR ESSENTIAL OILS

159. Are obtained from many plants by distillation with water, the oil coming over with the water, and collecting in the receiver, partly dissolved in the water, partly floating upon its surface. The watery solution has the odour of the oil. In this way, oil (or *attar*) of roses and rose-water, oil of lavender and lavender water, etc., are prepared. Many of these oils, so different in odour, have the same composition as oil of turpentine—namely, $C_{10}H_{16}$. Of these we may name—oil of lemons, of bergamot, of juniper, of thyme, of parsley. Others contain various volatile substances. Thus, oil of bitter almonds is a mixture of benzoic aldehyd (C_7H_6O) and prussic acid; oil of meadow-sweet is salicylic aldehyd ($C_7H_6O_2$); oil of mustard, C_4H_5NS.

ALBUMINOUS OR PROTEIN COMPOUNDS.

160. The white of egg consists chiefly of a watery solution of a substance called *albumin;* a similar substance occurs in the serum of blood and in dropsical fluids. *Fibrin* occurs in the clot of blood; *casein* is that constituent of milk which is curdled by rennet or by the addition of an acid to the milk. These substances have many properties in common, and have nearly the same composition. We now know a considerable number of such bodies. They form essential constituents of animal organisms, and also occur in plants. They are *produced* in the plant from simpler substances. In the animal system they are never formed, but only undergo transformation. They are thus necessary ingredients in the food of animals. They exist both in the soluble and in the insoluble condition, and are easily changed from the one to the other. Thus, albumin occurs in solution in white of egg, but when the egg is boiled, the albumin becomes insoluble. Casein is in solution in milk, but when the milk is curdled, the casein is rendered insoluble. By the process of digestion in the stomach, insoluble albuminous

substances are rendered soluble, and capable of being absorbed. These albuminous substances have an extremely complex composition, and chemists are not yet able to give *formulæ* for them. Analysis gives the following results :

Carbon	52.7	to	54.5	per cent.
Hydrogen	6.9	,,	7.3	,,
Nitrogen	15.4	,,	16.5	,,
Oxygen	20.9	,,	23.5	,,
Sulphur	0.8	,,	1.6	,,

APPENDIX.

Data and Rules for the calculation of Numerical Examples.

I. FRENCH WEIGHTS AND MEASURES.

The *Mètre*, or French unit of length, is divided into 10 decimètres, 100 centimètres, or 1000 millimètres (1000 mm.) —10 mètres = 1 decamètre, 100 mètres = 1 hectamètre, 1000 mètres = 1 kilomètre.

1 mètre = 39.37079 inches.
1 inch = 25.39954 millimètres.

The *litre*, or French unit of volume, is defined as a decimètre cube, and is divided into 1000 centimètres cube (1000 c.c.)

1 litre = 0.035317 foot cube.
1 foot cube = 28.315312 litres.
1 inch cube = 16.38618 centimètres cube.
1 gallon = 4.54346 litres.

The *gramme*, or French unit of mass, is divided into 10 decigrammes, or 100 centigrammes, or 1000 milligrammes—10 grammes = 1 decagramme, 100 grammes = 1 hectagramme, 1000 grammes = 1 kilogramme.

1 gramme = 15.43235 grains.
1 grain = 64.79896 milligrammes.
1 kilogramme = 2.20462 lbs.
1 pound = 435.5927 grammes.

The volume of 1 kilogramme of pure water at the temperature of 4° C., or 39°.2 F. is 1 litre.

II. FAHRENHEIT AND CENTIGRADE THERMOMETRIC SCALES.

The interval of temperature between the freezing point of water, and the point at which water boils when the barometer stands at 760 millimetres (nearly 30 inches), is divided in Fahrenheit's scale into 180 degrees, in the Centigrade scale into 100 degrees. 9 degrees of Fahrenheit's scale are therefore equal to 5 degrees of the Centigrade. The zero, or point from which the numbering starts, is, in the Centigrade scale, the freezing-point of water; in the Fahrenheit scale, it is 32° F. below the freezing-point. The freezing-point is therefore represented on the two scales thus—0° C., 32° F. By the following rules we can convert the expression for any temperature on one scale into that on the other.

To convert from F. to C., subtract 32, multiply the remainder by 5, and divide by 9.

To convert from C. to F., multiply by 9, divide by 5, and add 32.

Thus 60° F. = 15°.5 C. For $60-32 = 28$, and $28 \times 5 \div 9 = 15°.5$.

Again, 36° C. = 96°.8 F. For $36 \times 9 \div 5 + 32 = 96.8$.

III. RELATIONS OF THE MASS, THE VOLUME, THE TEMPERATURE, THE PRESSURE, AND THE MOLECULAR WEIGHT IN GASES.

These relations depend upon the three following laws:

1. BOYLE'S LAW.—If the temperature be kept constant, the volume occupied by a given quantity of any gas varies inversely as the pressure to which it is subjected. Thus, if we double the pressure, the gas is squeezed into half the space; if we take off half of the pressure, the gas expands and fills twice as much space as it did before.

2. CHARLES' LAW.—If the pressure be kept constant, the volume occupied by a given quantity of any gas varies directly as the *absolute temperature*, that is, the temperature counted from a point 273° C. below 0° C. Thus a quantity of gas which at 0° C. occupies 273 c.c., expands to 274 c.c. if it be warmed to 1° C., to 275 c.c. at 2° C., to 283 c.c. at 10° C., and so on.

3. AVOGADRO'S LAW.—The density of any gas is directly proportioned to its molecular weight (p. 48), the temperature and pressure being constant.

From these laws we can deduce the following rules:

1. To find the volume occupied by a given quantity of a gas when the molecular weight, the temperature, and the pressure are given.

The volume of one gramme of hydrogen at 0° C., and under a pressure of 760 millimètres of mercury, is 11.16 litres. From this we can of course at once find by multiplication the volume of any given quantity of hydrogen under the above-mentioned conditions of temperature and pressure. To obtain the volume at any other temperature and pressure, we multiply by the number representing the absolute temperature, and divide by 273 to correct for the temperature, and multiply by 760 and divide by the number representing the pressure to correct for the pressure.

For example, to find the volume occupied by 23.8 grammes of hydrogen at 15° C. and a pressure of 748 millimètres.

At 0° C. and 760 mm., 23.8 grammes of hydrogen occupy 23.8×11.16 litres, *i.e.*, 265.608 litres. To obtain the volume at 15° C. and 748 mm., we multiply by $273 + 15$, *i.e.*, 288, and divide by 273 for the temperature; and multiply by 760, and divide by 748 for the pressure. Thus $265.608 \times \frac{288}{273} \times \frac{760}{748} = 284.691$, the volume in litres of 23.8 grammes of hydrogen at 15° C. and 748 mm. pressure. To obtain the volume of a given quantity of any other gas, from the volume of the same quantity of hydrogen, we, in accordance with Avogadro's law, divide by half the molecular weight of the given gas.* For example—to find the volume of 23.8 grammes of car-

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* Because the molecular weight of hydrogen (H_2) is 2.

bonic acid gas at 15° C. and 748 mm. pressure, divide the volume, as above obtained, of the given mass of hydrogen under the given conditions, by 22 which is the half of 44, the molecular weight of carbonic acid ($12 + 2 \times 16$), thus $284.691 \div 22 = 12.940$, the volume in litres of 23.8 grammes of carbonic acid gas at 15° C. and 748 mm. pressure.

2. To find the mass of a given volume of a gas when the molecular weight, the temperature, and the pressure are given—

We first find what the given volume of hydrogen will become if the temperature and pressure are changed to 0° C. and 760. For this purpose we multiply by 273 and divide by the number representing the absolute temperature; multiply by the number representing the pressure, and divide by 760. If we now divide the result by 11.16 (or what is the same thing, multiply it by 0.0896), we obtain the mass in grammes of the given volume of hydrogen. To obtain the mass of a given volume of any other gas, we multiply the mass of the same volume of hydrogen, by half the molecular weight of the given gas.

For example, to find the mass of 45 litres of steam at 180° C. and 800 mm. pressure.

45 litres of hydrogen at 180° C. and 800 mm. become at 0° C. and 760 mm. $45 \times \frac{273}{273 + 180} \times \frac{800}{760} = 45 \times \frac{273}{453} \times \frac{800}{760} =$ 31.45 litres, and the mass of this volume of hydrogen is $31.45 \times 0.0896 = 2.8179$ grammes. Therefore the mass of 45 litres of hydrogen at 180° C. and 800 mm. is 2.8179 grammes. To obtain the mass of the same volume of steam under the same conditions, we multiply by 9, the half of the molecular weight of water ($2 + 16$), and find $2.8179 \times 9 = 25.3611$ grammes, the mass of the given volume of steam under the given conditions.

QUESTIONS.

Section 3. What is meant by a pure substance? Give examples of pure substances and of mixtures.

4-10. Describe ways by which the following mixtures could be separated into their ingredients : sawdust and sand—clay and sand —common salt and butter—gunpowder—sand and sugar—common salt and sulphate of lime—gum and sugar—salt and water—alcohol and ether.

11, 12. What is meant by "diffusion of gases?" State the relation between the rate of diffusion and the density of a gas. How can atmospheric air be proved to be a mixture? Explain what is meant by the terms "simple" and "compound." Give examples of simple and of compound substances. What is the difference in meaning between "compound" and "mixed?"

13, 14. By what means can the compound character of a substance be proved?

15. Explain the meaning of the terms "binary compound," "ternary compound," "quaternary compound." State the general characters of acids. What is meant by the "acid reaction?"

17. What is an alkali? what is the alkaline reaction?

18. When is a solution said to be neutral? When is an acid (or an alkali) said to be neutralised? What is formed when an acid (or an alkali) is neutralised? Explain and illustrate the nomenclature of salts founded on the names of the acid and base from which each is formed. What is the difference between a nitrate and a nitrite, between a sulphate and a sulphite, between a phosphate and a phosphite, etc.?

19. Give instances of substances capable of acting either as acids or as bases, and explain the circumstances under which they play the one or other part.

20. State the law of "equivalence" of acids and bases.

21-24. Define the terms "normal salt," "acid salt," "basic salt," "double salt," and give examples.

25-27. Describe fully the various ways in which acids act upon salts, bases upon salts, and salts upon salts. Give examples of complete and of partial double decomposition. Explain the effect which the insolubility and the volatility of the products have upon the actions in each of the above cases.

28-30. State the different ways in which water unites with acids, bases, and salts. Define the terms "anhydrous acid," "anhydrous base," "anhydride," "hydrate," "hydric salt," and give examples. What is the composition of water? How is it proved?

32, 33. State the physical and chemical characters of a metal.

34. Explain the action of acids and of salts upon metals. What is meant by the terms "positive" and "negative," as applied to metals?

35, 36. Explain the terms "salt-radical" and "halogen."

37. Compare the three systems of nomenclature of salts, and translate the name of a salt from any one system into any other.

38. Explain the terms "oxidation" and "reduction," and give examples.

39. What is combustion? What is stability, and how may the stability of compounds be approximately measured?

40. Give examples of oxidising and of reducing agents.

41. Explain the term "equivalent" as applied to acids, bases, oxygen, and metals respectively. Explain the term "replacement," and give examples.

42. What is electrolysis? Give the products of electrolysis of as many salts as you can.

45. What relation is there between the atomic weight and the equivalent of a metal?

46. Explain the meaning of the following formulæ: KCl; KNO_3; K_2O,N_2O_5; $Na_2CO_3,10H_2O$; $K_2O,SO_3,Al_2O_3,3SO_3,24H_2O$; $K_2Al_2(SO_4)_4,24H_2O$; MgO,Al_2O_3; KH_2PO_4; KH_2PO_4. (See 95.)

48. What is meant by the "molecular weight" of a substance?

50. Explain the meaning of the following equations: $CaO + CO_2 = CaCO_3$; $CaCO_3 = CaO + CO_2$; $2NaHCO_3 = Na_2CO_3 +$

$H_2O + CO_2$; $CaCO_3 + 2HCl = CaCl_2 + H_2O + CO_2$; $ZnO + 2HCl = ZnCl_2 + H_2O$; $2H_2SO_4 + C = 2H_2O + 2SO_2 + CO_2$; $H_2S + Fe_2O_3,3SO_3 = H_2O,SO_3 + 2(FeO,SO_3) + S$; $2(FeO,SO_3) + H_2O,SO_3 + Cl_2 = Fe_2O_3,3SO_3 + 2HCl$; and translate them from the metal-radical system to the acid-base system, and *vice versâ*. Calculate what weight of carbonic acid gas can be obtained from one pound (or any other given quantity) of (*a*) marble, (*b*) bicarbonate of soda—how much chloride of calcium from one pound of marble, how much chloride of zinc from one pound of oxide of zinc, etc.

51. Give a sketch of the atomic theory.

52. What is a molecule?

53, 54. State Avogadro's law. Calculate from the formulæ the weight of one litre (see Appendix) of each of the following gases and vapours: Hydrogen (H_2) at 500 millimètres pressure and -20° C. temperature; Ammonia (NH_3) at 1000 millimètres pressure and 15° C. temperature; Marsh gas (CH_4) at 750 millimètres pressure and 10° C.; Nitric oxide (NO) at 900 millimètres and 15° C.; Nitrous oxide (N_2O) 815 millimètres and 23° C.; Alcohol (C_2H_6O) at 700 millimètres and 100° C.; Methylamine (CH_5N) at 450 millimètres and 35° C.; Steam (H_2O) at 760 millimètres and 200° C.; Mercury (Hg) at 10 millimètres and 250° C.; Benzol (C_6H_6) at 740 millimètres and 100° C.

50, 54. What weight of zinc must be taken in order to obtain one mètre cube of hydrogen gas, at 700 millimètres and 15° C.? ($Zn + 2HCl = H_2 + ZnCl_2$.) What volume of nitrous oxide gas at 40° C. and 730 millimètres can be obtained from one kilogramme of nitrate of ammonia? ($NH_4NO_3 = N_2O + 2H_2O$.) [Such questions can of course be indefinitely multiplied by the reader or teacher.]

55. What is meant by the "atomicity" of an element? Give instances of different degrees of atomicity. Write out the graphic formulæ of as many substances as you can.

56. State Dulong and Petit's law. How does it assist in the determination of the atomic weight of the elements?

57. State the physical characters of oxygen. **58.** How does it occur in nature? How can it be obtained pure? How many litres of oxygen gas at 10° C. and 700 millimètres can be obtained by heating (*a*) one kilogramme of pure peroxide of manganese; (*b*) one kilogramme of pure chlorate of potash? In what way do plants produce free oxygen?

59. What function does oxygen perform in combustion? What is the relation of oxygen to the process of respiration in air-breathing and in water-breathing animals?

60. What is ozone? How can it be produced from ordinary oxygen, and changed into common oxygen?

61. State the physical characters of hydrogen.

62. How does it occur in nature? How can it be obtained pure? How many litres of hydrogen gas at 15° C. and 750 millimètres can be obtained from one kilogramme of sodium by the action of water?

63. What takes place when a red-hot body is placed in a mixture of oxygen and hydrogen? In what other way can the same effect be produced? In what proportions (*a*) by volume, and (*b*) by weight, must these gases be mixed, so that complete combination may take place?

64. What is peroxide of hydrogen? How is it produced? Describe its chemical characters.

65. State the physical characters of nitrogen. How does it occur in nature? How can it be obtained pure? What is the function of nitrogen in the atmosphere?

66. Enumerate the compounds of nitrogen and oxygen, giving the formula and percentage composition of each. How is hydrated nitric acid prepared? Describe the physical characters of peroxide of nitrogen, and the modes by which it can be prepared.

67. How is nitrous acid prepared? How is nitrite of potash prepared?

68. Describe the physical characters of nitric oxide. What is its action on oxygen? How many litres of nitric oxide at 20° C. and 800 millimètres can be obtained, by acting with a sufficient quantity of nitric acid on one kilogramme of metallic mercury?

69. State the physical, chemical, and physiological character of nitrous oxide.

70. Give the formula of ammonia, its physical and chemical characters.

71, 72. Explain the constitution of the ammonia salts. What is ammonium? Explain the analogy between the salts of ammonia and those of potash. How is pure ammonia gas prepared? 73. State the sources of ammonia. 74. What are the products of its oxidation in the presence of bases? Under what circumstances does such oxidation occur.

75. How does carbon occur in nature? **76.** What is charcoal? **77.** And lampblack?

78, 79, 80. Give the formula and percentage composition of the two compounds of carbon and oxygen. State their action on animals. Mention some carbonates which occur in nature.

81. What are hydrocarbons? Give some examples. State their general characters. **82.** Describe the physical character of marsh gas. In what proportions must marsh gas and oxygen be mixed in order to produce an explosive mixture, containing no excess of either gas. Explain the Davy lamp. **83.** Give the mode of preparation and properties of olefiant gas. (See also 149.)

84. How does chlorine occur in nature? How is common salt obtained? How is hydrochloric acid prepared from it? How many litres of hydrochloric acid gas at 17° C. and 1000 millimètres can be obtained from 1250 grammes of common salt? The specific gravity of a solution of hydrochloric acid in water containing 40.8 per cent. of hydrochloric acid is 1.2—how much common salt must be taken in order to prepare a litre of such a solution? How is chlorine gas prepared? **85.** Give the physical and chemical characters of chlorine. Explain the bleaching action of chlorine and water.

86, 87. Describe the compounds of chlorine and oxygen, and of their compounds with bases. What is bleaching-powder?

88. How do bromine and iodine occur in nature? State the analogies of these elements and of their compounds to chlorine and its compounds.

89. How does sulphur occur in nature? How is it obtained pure? State the action of heat upon sulphur.

90, 91. Give the formulæ, the character, the percentage composition, and the modes of preparation of the oxides of sulphur. Mention the most important sulphates and sulphites.

92. What is sulphuretted hydrogen? how is it prepared? What are the products of its combustion? Explain its action on metallic salts. **93.** Give the formula, mode of preparation, properties, and percentage composition of bisulphide of carbon?

94. How does phosphorus occur in nature? Explain its relation to places and animals. **95.** Give the formulæ of its oxides and state fully their action on water and on bases. **96.** How is phosphorus obtained from bone ash. **98, 99.** Mention the compounds of phosphorus with hydrogen, chlorine, and bromine, giving their chief properties. **100.** How does fluorine occur in nature? Describe the preparation and properties of hydrofluoric acid. **101.** Compare the characters of silicon with those of carbon. What is the chemical character of glass?

105. Give a classification of the metals. **106-136.** Mention the most important salts of the metals treated of in the text. Describe the ways in which zinc, iron, copper, mercury, and lead, are obtained from their ores. **112.** What is meant by hard water? **113, 114.** Explain the "setting," or hardening, of common mortar, of hydraulic mortar, and of plaster of Paris.

137. What is organic chemistry? **138.** Explain the term "carbohydrate," and mention the most important carbohydrates. **139.** Define sugar. Mention the most important kinds of sugar. **140, 141.** What is the action of acids upon starch, inulin, and cellulose? **142.** What is the alcoholic fermentation? Under what conditions does it occur? **143.** How can pure alcohol be obtained? **144.** Explain the action of various acids upon common alcohol.

145. What are the products of the oxidation of alcohol?

146. Describe the products of the distillation of wood, and the mode of separating them from each other.

148. Give the general characters of the genus alcohol.

149, 151. Give examples of polyatomic alcohols and shew how they resemble common alcohol.

152, 154. State the chemical constitution of fats and fatty oils. **153.** What is the chemical constitution of soap? How is it formed. **147, 150, 154, 155, 156, 157.** Name the more important organic acids, giving their source, mode of preparation, and chief salts.

158. What is meant by the term "organic base," or "alkaloid?" Give examples. How are these bases related to ammonia? **159.** How are volatile oils obtained from plants? Give some examples of volatile oils.

160. Give the general composition of albuminous substances. How are they produced? What is their relation to animals and vegetables?

THE END.

Edinburgh: Printed by W. & R. Chambers.

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