The first step in chemistry : a new method for teaching the elements of the science / by Robert Galloway.

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THE

FIRST STEP IN CHEMISTRY.

A NEW METHOD

FOR

TEACHING THE ELEMENTS OF THE SCIENCE.

THE FIRST STEP IN CHEMISTRY.

A NEW METHOD
FOR
Teaching the Elements of the Science.

BY

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'A MANUAL OF QUALITATIVE ANALYSIS,' ETC.

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PREFACE TO THE THIRD EDITION.

In this edition I have given a condensed account of the chemical and physical properties of the Metalloids and of their more important compounds, and an outline of the general properties of the Metals; this part of the work will, therefore, be found useful as a note-book for the lecture student. I have also given an increased number of Exercises, and made some other alterations which have been suggested to me by my further experience as a teacher; but the general plan of the work remains unchanged.

I trust these alterations and additions will give increased value to the book as an educational work.

R. GALLOWAY.

Dublin, *August*, 1860.

PREFACE

TO THE SECOND EDITION.

FOUR years ago I published, under the title of a "First Step in Chemistry," a plan for teaching the language of the science. It was the first, and continues to be the only work published in this or any other country, so far as I am aware, with this object in view. All that has been attempted in other works, in the way of teaching the subject, has been confined to a few general rules on the nomenclature and notation of the science; the construction of chemical formulæ, the mode of expressing chemical changes, &c., being passed over with little or no notice.

Few persons could learn arithmetic by simply attending *lectures*, or by *reading;* these important means of deriving instruction require to be followed up by the practice of exercises on the part of the student. Fewer still could become proficient in this branch of useful knowledge, if not only should the use of exercises be denied, but the various operations of addition, subtraction, multiplication, and division be presented indiscriminately to the mind; and not, as is the invariable practice, treated separately. Strange, however, as it may appear, the method of teaching the language of Chemistry, which is certainly not less difficult to acquire, has been hitherto characterised by the defects just enumerated. Yet, without a knowledge of this important part of Chemistry, no real progress can be made in the science, for chemical symbols are to the chemist what figures are to the arithmetician; "a student pound, just as words like *to*, *be*, &c., are converted into new words by having one of the letters doubled, as *too*, *bee*, &c. 3rd. That two compound substances can combine together, a more complex compound being formed. 4th. That the constituents of any compound are separated, if a substance, having a greater affinity for one of them, be brought in contact with the compound, by reason of the added substance combining with that one, and forming a new compound, whilst the other constituent of the original compound is set free—in such cases combination accompanies decomposition. Afterwards heat, cohesion, elasticity, light, and electricity, as promoters of decomposition, are separately considered and illustrated; and as all the experiments on combination were effected at the ordinary temperature, or by means of heat, the influence of cohesion, elasticity, light, and electricity in producing or opposing combination, is likewise considered.

In order to render the book as suitable as possible for the general teacher, a few pages have been devoted to the fitting up of apparatus, and a list of the apparatus and chemicals required is likewise given. It may be as well to observe, that the lessons do not follow in consecutive order; but this will occasion no perplexity either to the teacher or learner, as ample directions on this point are given in foot-notes at the proper places. A series of four large tables have been published as a companion to the book when used in schools.

R. GALLOWAY.

DALSTON, *Nov.* 1855.

CONTENTS.

CHAPTER I.

ELEMENTS AND COMPOUNDS.

Imponderable bodies. Ponderable bodies. The different states in which matter can exist. Exercises on the weight of gases. Some substances can exist in each of these states. Exercises. All substances either simple or compound. Distinction between simple and compound substances. One of the objects of chemistry. Into how many classes the elements are divided. Tables of the elements. Other facts respecting them. The elements capable of uniting together. Experimental exercises on the combination of two elementary bodies. Directions to teachers and the self-instructed .... Page 1

CHAPTER II.

THE CONDITIONS NECESSARY FOR COMBINATION. EXERCISES ON THE COMBINATION OF A COMPOUND WITH AN ADDITIONAL AMOUNT OF ONE OF ITS ELEMENTS. EXERCISES ON THE COMBINATION OF TWO COMPOUND SUBSTANCES. IN WHAT WAY COMBINATION REACHES ITS LIMIT.

All chemical experiments either synthetical or analytical, or a combination of the two. The force which causes substances to unite contrasted with the other natural forces. Difference between a mere mixture of substances and a chemical compound. Chemical combination attended with an evolution of heat, and frequently of light, attended sometimes with changes in colour and form. All the elements do not unite with equal facility. The temperature at which combination takes place varies with the different substances. Beautiful application, by Sir H. Davy, of the fact, that substances require a certain temperature for their combination. Evolution of heat and light regarded as a sign of destruction by the generality of persons; the reason of this erroneous idea. All solid substances emit light when heated beyond a certain degree. Principle upon which all practical methods of illumination are founded. Combustible and incombustible inappropriate terms 10

Exercises on the Combination of a Compound with an Additional Quantity of one of its Elements. These exercises show also the cause of the blue flame which appears on the surface of fires, and that the atmosphere is a mere mixture of gases, and not a chemical compound 35

Different Kinds of Compound Substances. Exercises on the Combination of Two Compound Substances. How combination reaches its limit 38

CHAPTER III.

PROPERTIES OF MATTER.

Force and matter. Imponderable matter. Ponderable matter. Physical properties of matter. Extension, impenetrability, divisibility, porosity, indestructibility, mobility, cohesion, gravitation. Absolute, specific, and atomic weight. Exercises 41

CHAPTER IV.

LAWS OF COMBINATION.

Affinity causes unlike substances to unite together. Exercises. Chemical force exerted only at insensible distances. Exercises. Formation of compounds by substitution. Exercise. Constancy of composition in chemical compounds. Exercises. Equivalent proportions. Atomic theory. Exercises. A difference in the properties of compounds does not always arise from a difference in their elementary constitution. Multiple proportions. Exercises 57

CHAPTER V.

CHEMICAL NOTATION AND NOMENCLATURE.

Advantages which signs possess over words. The signs used in chemistry. Rules for naming chemical compounds 73

CHAPTER VI.

ON THE DECOMPOSITION OF SUBSTANCES. SINGLE ELECTIVE AFFINITY. EXERCISES. DOUBLE ELECTIVE AFFINITY. EXERCISES.

Single Elective Affinity. Substances exercise a choice in combining. Decomposition of binary compounds. Exercises. Heat evolved varies with the combining substances. On the decomposition of ternary compounds. Exercises. Diffusion of gases and vapours. Important part played by this property in the great economy of nature. Double elective affinity. Peculiarity of double decomposition. Exercises. Formation of compounds by substitution. Order of affinity 79

CHAPTER VII.

INFLUENCE WHICH HEAT EXERCISES OVER AFFINITY.

The decomposition of chemical compounds impossible if affinity were the sole producing cause of chemical changes. The other forces which act on matter assist in these changes. The influence which heat exerts. Exercises 98

CHAPTER VIII.

INFLUENCE WHICH COHESION AND ELASTICITY EXERCISE OVER AFFINITY.

Cohesion opposes combination. Exercises. With affinity it plays a most important part as a decomposing agent. Exercises. Influence of elasticity in promoting combination. Nascent state of substances. Exercises. The surface action of platinum, charcoal, &c. This action applied. Exercises. Influence of elasticity in promoting decomposition. Substances unite in different proportions at different temperatures. In many cases no chemical action will ensue between a solid and a liquid unless a third substance is present. Laws of Berthollet. Exercises 103

CHAPTER IX.

PRACTICAL APPLICATION OF THE PRINCIPLES CONTAINED IN THE PRECEDING CHAPTERS.

Table showing the solubility of the basic oxides. Exercises. Table showing the solubility of salts. Exercises 125

CHAPTER X.

INFLUENCE WHICH LIGHT EXERCISES OVER AFFINITY.

Analysis of the sunbeam. An association of three different principles. The influence which heat, light, and actinism exercise over affinity. Production of photographic pictures. Action of light in producing mechanical changes. Lake-maker's partiality for a fine bright day when he makes his colours. The different colours substances assume under different rays. Influence of light in the germination of seeds, and the growth and flowering of plants. The proportion of the three principles in the sunbeam varies with the seasons. Exercises 140

CHAPTER XI.

INFLUENCE WHICH ELECTRICITY EXERCISES OVER AFFINITY.

Excitation by friction. Electric spark. Conductors and non-conductors. Attraction and repulsion. Theories with regard to the nature of electricity. Excitation by chemical action. Voltaic circle. The different action acids have upon two metals separately and conjoined. Application of this principle. The essential elements for the formation of a voltaic circle. Upon what the direction of the current depends. Disadvantages of the ordinary acid battery. Smee's and Daniell's batteries. The electricity developed by friction and chemical action essentially the same. Quantity and intensity. Influence which electricity exercises over affinity. Exercises. Arrangements of the elements in the decomposing cell. Attractive power supposed to reside in the wires. This supposition shown to be erroneous. The wires only paths for the ingress and egress of the fluid. Explanation of terms. Summary of the more important principles. Definite nature of electro-chemical decomposition. Electrotype and electroplating 155

Influence of mass in the formation of chemical compounds. Exercises........ 180

CHAPTER XII.

THE INDUCING ACTION WHICH SOME SUBSTANCES POSSESS AT THE MOMENT OF CHEMICAL CHANGE.

Friction as an inducer of chemical action. Exercises. Some substances undergoing combination induce others to do the same. A slightly different class—two compounds, which separately are stable, when brought together are both decomposed. Exercises. Some substances, in the act of decomposing, induce others to do the same. Putrefaction, fermentation, and decay. Distinction between putrescible and fermentescible bodies. Relation as to quantity between the ferment and the fermentescible body. A certain temperature required in fermentation. At different temperatures different substances are formed. Preservation of food. Bread-making. Manufacture of beer and wine. Germination. Malting. Does the vital influence prevent putrefaction? &c. Necessary conditions for the decay of organic substances 184

CHAPTER XIII.

ISOMERIC COMPOUNDS.

The same chemical compound always contains the same elements in the same proportions; but the same elements in the same proportions do not of necessity generate the same substances. Examples. Explanation of terms. Isomeric substances converted and reconverted into each other. Doctrine of substitution. Important applications. Bleaching. Chloroform. Artificial oil of almonds. One of the colouring matters in madder from a substance in coal tar. Guncotton. Exercises 199

CHAPTER XIV.

BASIC OXIDES.

All the metals unite directly or indirectly with oxygen. Metals combine with oxygen in more than one proportion. List of the more important basic oxides. This class divided into four groups. Exercises 206

CHAPTER XV.

ACID SUBSTANCES.

Characteristics of an acid. This class of substances divided into two groups. Acids either monobasic or polybasic. A list of acid bodies. Their nomenclature 212

CHAPTER XVI.

SALTS.

Divided into two groups. General formulæ for neutral salts. Nomenclature of salts. Exercises. Salts either neutral, acid, or basic. Exercises. Characteristics of an acid salt. Exercises. Characteristics of a basic salt. Exercises. Polybasic salts. Double salts. Exercises 215

CHAPTER XVII.

CONSTRUCTION OF CHEMICAL FORMULÆ.

Use of the comma, and plus sign. Bracketting. Exercises. 225

CHAPTER XVIII.

ON THE MODE OF EXPRESSING CHEMICAL CHANGES. EXERCISES. 228

CHAPTER XIX.

THE METHOD FOR DETERMINING THE AMOUNT OF THE SEVERAL CONSTITUENTS CONTAINED IN A GIVEN QUANTITY OF ANY COMPOUND. EXERCISES.......... 236

CHAPTER XX.

THE MODE OF DETERMINING THE RELATIVE PROPORTION OF THE ELEMENTARY ATOMS IN A CHEMICAL COMPOUND. EXERCISES. THE METHOD FOR DEDUCING NOT ONLY THEIR RELATIVE, BUT LIKEWISE THEIR ABSOLUTE NUMBERS. EXERCISES 239

CHAPTER XXI.

CONSTRUCTION OF APPARATUS. CHEMICAL OPERATIONS. APPARATUS AND CHEMICALS REQUIRED.

Corks, their preparation. Glass tubing, its preparation. Indian-rubber tubing. Apparatus used for the disengagement of gases, heat not being required. Heat being required. Apparatus for collecting gases. Solution. Exercises. Evaporation. Exercises. Precipitation. Filtration and decantation. Apparatus and chemicals required.......... 243

CHAPTER XXII.

SPECIAL PROPERTIES OF THE METALLOIDS, AND OF THEIR MOST IMPORTANT COMPOUNDS 264

CHAPTER XXIII.

GENERAL PROPERTIES OF THE METALS.......... 290

FIRST STEP IN CHEMISTRY.

CHAPTER I.

ELEMENTS AND COMPOUNDS.

Imponderable bodies. Ponderable bodies. The different states in which matter can exist. Exercises on the weight of gases. Some substances can exist in each of these states. Exercises. All substances either simple or compound. Distinction between simple and compound substances. One of the objects of chemistry. Into how many classes the elements are divided. Tables of the elements. Other facts respecting them. The elements capable of uniting together. Experimental exercises on the combination of two elementary substances. Directions to teachers and the self-instructed.

1. HEAT, LIGHT, and ELECTRICITY cannot be exhibited in a mass like wood, metal, water, air, &c., they can be collected only through the intervention of other substances. They are likewise destitute of weight, hence they are called immaterial or imponderable bodies. They are considered to be produced by the vibrations of unknown and highly elastic fluids called ethers, which are supposed to fill the whole universe, and penetrate the pores of all solid and fluid bodies.

2. All other known bodies or substances have *weight*, and they occupy a certain space; and the space which any one of them occupies cannot be occupied by another body at the same time, hence two bodies cannot occupy the same space at the same time; this property has received the name of *impenetrability*. All known bodies then, with the exception of heat, light, and electricity, possess *weight* and *impenetrability*, hence they are called, in contra-distinction to the three immaterial bodies, material or ponderable bodies or substances, or simply *matter*.

3. All ponderable substances exist in one or other of

three states; the three states are, the solid, the liquid, and the gaseous or aëriform. Every one is aware that solid and liquid bodies possess weight, but the fact that gaseous bodies possess weight is not so generally known; the following experiments are therefore given to teach the learner this fact, and also that all gases have not the same weight, but that some are heavier, some are lighter, than others; in other words, gases differ in weight like solids and liquids.

EXPERIMENTAL EXERCISES ON THE WEIGHT OF GASES.

1. Fill a small balloon of goldbeater's skin with hydrogen gas (as directed in Expt. 52, p. 27), the balloon, after it is filled with the gas, will rise, if allowed, to the ceiling of the class-room, because hydrogen gas is much lighter (fourteen and a half times) than atmospheric air; in fact, hydrogen is the lightest body in nature.

2. Prepare some carbonic acid gas as directed in Expt. 78; let the exit tube of the apparatus in the present experiment dip into a dry glass vessel (the tube ought to reach to the bottom of the vessel); the precipitating vessels (Fig. 32), described in the chapter on the construction of apparatus, &c., are very suitable for the experiment. As soon as the vessel is filled with the gas, which is ascertained by a candle being extinguished when introduced just below the edge of the vessel, pour the gas as you would a liquid into another vessel of similar size and shape. Prove that the gas has been really transferred from the one vessel to the other by introducing a lighted candle (Fig. 8) first into the vessel originally containing it (in which the candle ought now to burn), and then into the one which ought now, if the experiment has been properly performed, to contain it, and in which the candle ought not now to burn. If great care be observed in the experiment, it may be transferred from one vessel to the other three or four times. This experiment shows the great density of the gas; it also shows the incapability of the gas to support the combustion of a candle.

3. Fill a wide and deep glass jar* half full of carbonic

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* The jar ought to be about twelve or fourteen inches wide, and about two feet in depth.

acid gas, the upper half being filled with atmospheric air; fill a collodion balloon with hydrogen and air in such proportions that the balloon will just sink in air; when so prepared, let the balloon sink into the jar; as soon as it reaches the uppermost layer of carbonic acid it will rebound as if it had touched a solid body; it will finally float quietly upon the carbonic acid, and it is curious to see the balloon suspended midway in the jar, apparently resting upon *nothing*. This experiment, which I devised a short time ago, is an exceedingly interesting and instructive one if well performed.

4. Some substances can exist in each of the three states; in ice, water, and steam we have a familiar example of the same substance in all the three forms. A substance which can assume more than one state, can be made to pass from one state to another any number of times. The following experiments are given to impress on the learner the fact that substances can be made to change their state.

EXPERIMENTS.

4. Place a few fragments of sulphur in a Florence flask, and then heat the flask by means of a gas or spirit lamp; the sulphur will become liquid, and if the heat be long continued, it will finally become converted into vapour; if the vapour be received into another flask which is kept cool, the vapour will be reconverted into the solid state.

5. Place a few fragments of iodine in a large glass flask, and then heat the flask by means of a lamp; the iodine will be converted into vapour, which will fill the flask; the vapour is of a beautiful violet colour.

6. Fill very nearly a small glass retort with water, then introduce into the retort a little ether; the latter liquid will swim above the water in the upper part of the retort; invert the beak of the retort in a vessel of water. Then apply a gentle heat to that part of the retort containing the ether; the heat will convert the liquid ether into vapour which will, from its occupying more space than the ether did when in the liquid state, expel the water from the retort. On removing the heat and suffering the glass to cool, the ether will return to the liquid state, and the water will then flow back into the retort.

7. Half fill a retort with water, place the retort upon a

retort stand, and insert the beak of the retort in a flask; keep the flask cool by means of a wet cloth or ice, heat that part of the retort containing the water by means of a lamp. The water will be converted by the heat into vapour, which will pass into the flask, and be then condensed (converted back into the liquid state).

5. The student will have seen by the experiments that the addition or abstraction of heat is the cause of substances changing their state.

6. The external world, as every one is aware, is not composed entirely of any one uniform substance—such as iron or sulphur—but is made up of a variety of materials, and the science of chemistry owes its origin to the fact that all these different substances—whether *animal, vegetable*, or *mineral*—are either *simple* or *compound.*

7. Simple and compound substances may be compared to letters and words. Letters do not admit of being separated into more primary signs, as they are the simplest employed in language; but words, being a combination of two or more letters, can be resolved into their elements (letters). In the same way, all substances which do not admit of being separated into simpler forms of matter, because they consist of one material only, are called *simple substances* or *elements;* whilst such as admit of being so separated are called compound substances. Sulphur, for example, can be resolved into no other substance: it consists of only one material, and is consequently an element or chemical letter; whilst common kitchen salt, which can be separated into two others, chlorine and sodium, is a compound substance.

8. As one of the principal objects of chemistry is to discover the elementary bodies from which all the various compounds are formed, the student's first lesson must be, to learn how many elements have, as yet, been discovered, their names, into how many classes they are divided, and other facts respecting them.

9. They are divided into two classes — metals, and metalloids. The metals are good conductors of heat and electricity, and reflect light powerfully, which gives them that peculiar appearance termed "metallic lustre." These three properties are never found associated in the non-metallic bodies, which are not distinguished, as a class, from the metals, by any positive properties, with, perhaps,

this one exception, that their oxygen compounds never possess basic properties. This division is, however, more convenient than strictly correct, as the members of the one class gradually merge into those of the other.

10. About sixty-two elementary substances have been discovered; the majority of them are never met with in their uncombined state, and many of them have hitherto been found in such minute quantities that they have no practical value.

11. The names of the elements are seldom written at full length, but are generally indicated by the first letter of their Latin names, a second being employed when more than one element begins with the same letter. When a single letter is employed as the symbol of an element, it is always printed as a capital; but when two are employed, the initial letter *only* is a capital. These symbols or abbreviations are taken from the Latin names of the elements, that they may be universally understood. The student must commit to memory the names and symbols of the elements in the following table of the more commonly occurring elements. The figure, under the head "atomic weights," in the complete list of elements, will be explained in another chapter.

TABLE OF THE MORE COMMONLY OCCURRING ELEMENTS, WITH THEIR SYMBOLS.

Names of the Elements.		Symbols.	Names of the Elements.	Symbols.
METALLOIDS.			METALS—(*continued.*)	
Hydrogen	Gaseous at the common temperature.	H.	Cadmium	Cd.
Oxygen		O.	Calcium	Ca.
Nitrogen		N.	Chromium	Cr.
Fluorine		F.	Cobalt	Co.
Chlorine		Cl.	Copper (Cuprum)	Cu.
Bromine fluid		Br.	Gold (Aurum)	Au.
Iodine	Solid at the common temperature.	I.	Iron (Ferrum)	Fe.
Carbon		C.	Lead (Plumbum)	Pb.
Boron		B.	Magnesium	Mg.
Silicon		Si.	Manganese	Mn.
Phosphorus		P.	Mercury (Hydrargyrum)	Hg.
Sulphur		S.	Nickel	Ni.
			Platinum	Pt.
METALS.			Potassium (Kalium)	K.
Aluminum		Al.	Silver (Argentum)	Ag.
Antimony (Stibium)		Sb.	Sodium (Natrium)	Na.
Arsenic		As.	Strontium	Sr.
Barium		Ba.	Tin (Stannum)	Sn.
Bismuth		Bi.	Zinc	Zn.

12. A few of the elements have a popular as well as a scientific name. Brimstone, for example, is the common or popular name for sulphur; quicksilver for mercury; whilst for carbon there are several,—these varying according to the state and preparation of this element: it is met with in nature both crystallized and uncrystallized. In its crystallized state it constitutes the diamond; uncrystallized, the black lead used in the manufacture of pencils. It is obtained artificially from several of its compounds, and according to its source and mode of preparation, passes under the name of lampblack, bone or ivory black, soot, charcoal, &c.

TABLE OF THE ELEMENTS, WITH THEIR SYMBOLS, AND ATOMIC WEIGHTS OR EQUIVALENTS.

Names of the Elements.	Symbols.	Atomic Weights.	Names of the Elements.	Symbols.	Atomic Weights.
Aluminum	Al.	13·7	Nickel	Ni.	29·6
Antimony	Sb.	120·3	Niobium	Nb.	
Arsenic	As.	75·	Nitrogen	N.	14·
Barium	Ba.	68·5	Norium	No.	
Bismuth	Bi.	213·	Osmium	Os.	99·6
Boron	B.	10·9	Oxygen	O.	8·
Bromine	Br.	80·	Palladium	Pd.	53·3
Cadmium	Cd.	56·	Pelopium	Pe.	
Calcium	Ca.	20·	Phosphorus	P.	31·
Carbon	C.	6·	Platinum	Pt.	98·7
Cerium	Ce.	47·	Potassium	K.	39·
Chlorine	Cl.	35·5	Rhodium	R.	52·2
Chromium	Cr.	26·7	Ruthenium	Ru.	52·2
Cobalt	Co.	29·5	Selenium	Se.	39·5
Copper	Cu.	31·7	Silicon	Si.	21·3
Didymium	D.	48·	Silver	Ag.	108·
Erbium	E.		Sodium	Na.	23·
Fluorine	F.	19·	Strontium	Sr.	43·8
Glucinum	G.	7·	Sulphur	S.	16·
Gold	Au.	197·	Tantalum	Ta.	184·
Hydrogen	H.	1·	Tellurium	Te.	64·2
Iodine	I.	127·	Terbium	Tb.	
Iridium	Ir.	99·	Thorium	Th.	59·6
Iron	Fe.	28·	Tin	Sn.	58·
Lanthanum	La.	47·	Titanium	Ti.	25·
Lead	Pb.	103·7	Tungsten (Wolfram)	W.	92·
Lithium	L.	6·95	Uranium	U.	60·
Magnesium	Mg.	12·	Vanadium	V.	68·5
Manganese	Mn.	27·6	Yttrium	Y.	
Mercury	Hg.	100·0	Zinc	Zn.	32·6
Molybdenum	Mo.	46·	Zirconium	Z.	33·6

13. The names of the metals discovered within the present century terminate in *um*, as platinum, potassium, &c. The Latin names of all the metals terminate thus,—as cuprum, stannum, &c. The names of none of the metalloids have this termination, with the exception of selenium. Five of the elements are gaseous in their free or uncombined state, viz., hydrogen, oxygen, nitrogen, fluorine, and chlorine. Two are fluid substances, bromine and mercury, the rest are solid bodies. All the metals are solid bodies at ordinary temperatures, except mercury.

14. Compound substances are made up of two or more elements; the elements must therefore be capable of combining or uniting together. That two elements are capable of uniting together and forming a compound substance the following experiments are given as proofs:—

EXPERIMENTAL EXERCISES ON THE COMBINATION OF TWO ELEMENTS.

8. Place a bit of phosphorus, about half the size of a pea, in the deflagrating spoon (having previously dried it by pressing it gently between folds of blotting paper),* (Fig. 30); hold the spoon in the flame of a lamp until the phosphorus takes fire, and then introduce it into a jar filled with oxygen gas. The light produced by the combination of these two elements is so intense that the eye can scarcely bear it. The acid compound produced, appears at first under the form of white smoke, which gradually collects into flakes, falls to the bottom of the vessel, and is dissolved in the water. This compound is called phosphoric acid.

9. Dry a piece similar in size and in the same way as directed in Expt. 8. Cut it into small fragments, and introduce them unignited, by means of the spoon, into a bottle filled with chlorine. The phosphorus will instantly take fire, burning with a yellowish green flame. A compound called chloride of phosphorus is produced.

10. Place a few fragments of phosphorus (dried) upon a plate, and throw upon them a small quantity of iodine; the two elements will instantly combine, and form a red solid

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* The experimenter must dry the phosphorus as expeditiously as possible, and avoid friction, as the phosphorus takes fire readily and causes very severe burns; he must also obey the instructions as to the size of the pieces of phosphorus to be used in the experiments.

called iodide of phosphorus. The combination is attended with evolution of heat and light.

11. Place a piece of roll sulphur about the size of a pea in the cup of the spoon, hold the cup in the flame of a lamp or candle until the sulphur takes fire, and then introduce it into a wide-mouthed bottle or jar (Fig. 31), filled with oxygen gas. The sulphur will instantly burst into a brilliant purple flame and rapidly disappear. The two elements form by their union a gaseous acid compound called sulphurous acid, which is very soluble in water, and has an intensely suffocating odour.

12. Introduce, by means of the spoon, a piece of red hot charcoal into a jar filled with oxygen gas ; the charcoal enters into a vivid state of combustion. The compound produced by the union of these two metalloids is a gaseous acid called carbonic acid.

13. Coil a thin iron wire round a stick so as to bring it into a cork-screw shape, and then draw it off. Tip one end of the wire with sulphur, by immersing it in melted brimstone, the other end being fixed into a cork which fits the mouth of the gas jar. The sulphur having been ignited, the spiral wire must be immediately inserted into a jar filled with oxygen gas, and the cork is in this case closely pressed into the mouth of the jar. The sulphur will burst into full flame ; the iron, thus becoming heated strongly, is capable of entering into combination with the oxygen ; a brilliant light accompanies the union, and the compound produced, an oxide of iron, falls down in brilliant sparks.

14. Put a little powered antimony into a small muslin bag, and shake the bag over a bottle filled with chlorine, in such a manner that the small particles of metal coming through the muslin may fall into the bottle ; they will take fire and burn brilliantly, a chloride of antimony being produced. The experiment may be varied by substituting powdered metallic arsenic for the antimony. In both cases the experimenter must be very careful not to inhale any of the vapour, and the apparatus, as soon as the experiment is completed, ought to be removed from the class-room. If copper or gold leaf be introduced into chlorine, the metalloid and metal combine, and the combination is attended, as in the two preceding cases, with evolution of heat and light.

15. *Directions to teachers and the self-instructed.*—The methods for preparing the elementary gases required in the above experiments are described under the head of the special properties of the elements in chapter xxii. It is not intended that the teacher should explain how the different elements employed in the preceding lesson are obtained from their compounds; to do so would be to derange entirely the plan of the work. The object of the lesson is not to teach the learner how the different elements are obtained from their compounds (this forms one of the subjects in the more advanced lessons), but what is much simpler, viz., that two elements can combine together. The self-instructed student is requested to prepare the different gases without attempting to understand the mode by which they are obtained from their different compounds.

16. The collection and transference of the gases, as well as the vessels in which the gases are collected, are described in chapter xxi., which ought to be read by the experimenter who is unaccustomed to chemical manipulation.

CHAPTER II.

THE CONDITIONS NECESSARY FOR COMBINATION. EXERCISES ON THE COMBINATION OF A COMPOUND WITH AN ADDITIONAL AMOUNT OF ONE OF ITS ELEMENTS. EXERCISES ON THE COMBINATION OF TWO COMPOUND SUBSTANCES. IN WHAT WAY COMBINATION REACHES ITS LIMIT.

All chemical experiments either synthetical or analytical, or a combination of the two. The force which causes substances to unite contrasted with the other natural forces. Difference between a mere mixture of substances and a chemical compound. Chemical combination attended with an evolution of heat, and frequently of light, attended, sometimes, with changes in colour and form. All the elements do not unite with equal facility. The temperature at which combination takes place varies with the different substances. Beautiful application, by Sir H. Davy, of the fact, that substances require a certain temperature for their combination. Evolution of heat and light regarded as a sign of destruction by the generality of persons; the reason of this erroneous idea. All solid substances emit light when heated beyond a certain degree. Principle upon which all practical methods of illumination are founded. Combustible and incombustible inappropriate terms.

17. All chemical experiments are either experiments of *combination* or experiments of *decomposition*, or they are a combination of the two; the student ought therefore to remember that however complex any chemical experiment he witnesses may appear, it must either be an experiment of combination, which is termed a *synthetical* experiment, or an experiment of decomposition, which is termed an *analytical* experiment, or it must be both a synthetical and analytical experiment. *No chemical compound* is composed of all or a majority of the elements; a large proportion are only made up of some two, three, or four. The elementary substances composing a compound are called its *constituents* or *components.*

18. The last course of experiments was given to teach the learner the important fact that two elements can

combine together, and that a compound substance is produced by their union. One of the experiments must be repeated before we attempt to extract any further information from them; suppose we repeat the eighth, which was the most brilliant.

15. Burn a piece of phosphorus in a jar of oxygen, in the way described in Expt. 8.

19. The first question any student would ask, after witnessing an experiment of this kind, and after he knows that it is two elements combining together, would be this,—What is it which causes these two and any two or more elements to unite? A *force* called CHEMICAL ATTRACTION or AFFINITY is considered to be the cause of substances entering into combination. We must first explain what is meant by force. *Force is that which puts matter in motion, or which stops or changes a motion once commenced, or which exercises pressure.* We will now name some of the other natural forces and contrast their effects.

20. The force called the ATTRACTION OF GRAVITATION affects every variety of matter in each of the three states in which matter can exist, and each particle of the entire mass. It is the force by which matter attracts matter; "it is exerted at all, even the greatest conceivable, distances; and is the invisible yet insuperable tie which, connecting together the satellites and planets of our system with the central sun, assigns to each of the tenants of our boundless skies its place and motions." All bodies within the earth's sphere fall to the earth (if not prevented) by reason of this force, because the earth within its sphere is the largest mass of matter, and has therefore the greatest number of particles, and consequently possesses the greatest attractive force. The *downward pressure* occasioned by this attractive force, which matter of every kind exerts on whatever supports or prevents it from falling to the earth, is termed THE WEIGHT of the body.

21. The force called the ATTRACTION OF COHESION binds particles of the same nature together: a lump of sugar, for instance, is made up of a number of smaller particles of sugar; the particles are united together by means of the cohesive force. Sometimes the particles of matter are, as it were, indiscriminately collected; in other cases they are beautifully arranged in a regular crystalline

form. The cohesive force acts only at *insensible distances*, particles of the same nature must therefore be brought immeasurably near together for this force to act upon them. Heat, we have already seen, tends to separate particles of matter from one another; it is therefore the antagonist of cohesion, and upon the relative intensity of the two depends the solid, fluid, or gaseous condition of matter. When the cohesive force prevails, a solid is the consequence; when the repulsive power is in the ascendant, matter, as we have seen, assumes the gaseous form; and when the two forces are balanced, the liquid state results.

22. Scientific men are still undecided whether to regard the adhesion of dissimilar substances as the effect of a force distinct from that of cohesion, called the Attraction of *Adhesion*, or to consider it as due to the cohesive force. The sticking of dust to the walls of buildings and articles of dress, the writing with chalk, charcoal, plumbago, &c., are examples of the adhesion of dissimilar substances.

23. The attraction of gravitation operates at the *greatest distances;* chemical attraction, and the attractions of cohesion and adhesion, operate only at *insensible distances.*

24. CHEMICAL ATTRACTION differs from the attractions of cohesion and adhesion in a great many important particulars. When substances combine by means of chemical attraction, they *lose their individual properties* as long as they remain *united*,—the compound produced by the union possessing properties altogether different from those of its constituents. If we contrast the properties of the compounds we have just formed by the combination of phosphorus and oxygen, with the properties of its constituents, we shall see that this is the case. First of all, the compound, we have just formed, is a solid body, and therefore oxygen, which, in its uncombined state, is a gas, has become transformed into a solid, by its union with phosphorus. Then, again, the compound is very soluble in water, and therefore differs from phosphorus, which is entirely insoluble in that liquid, and from its other constituent, oxygen, which is only very slightly soluble. The compound possesses *acid** properties, which neither of its constituents possesses.

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* Acids turn vegetable *blue* colours *red*.

25. Although, in all the experimental exercises, the student's attention will be drawn to the fact that substances lose their individual properties when they combine together, and that the compound formed assumes properties peculiar to itself, yet it may be as well, whilst we are alluding solely to this particular effect of chemical combination, to adduce a few more examples. Let us take, as our first example, the compound body water. "One would not suppose, from its appearance, that it is a compound body; much less that it is composed of two gases, oxygen and hydrogen, neither of which, when uncombined, has ever been compressed into a liquid. Hydrogen is one of the most inflammable substances in nature, and yet water cannot be set on fire; oxygen, on the other hand, enables bodies to burn with great brilliancy, whilst water extinguishes combustion."—(*Turner's Chemistry.*) The pungent substance, ammonia, is composed of the two gases, hydrogen and nitrogen, both destitute of odour. The constituents of sugar are carbon, hydrogen, and oxygen. The first of these bodies is a solid, which has never in its elementary state been dissolved in any liquid; the other two components of sugar are colourless gases, which have never yet been liquefied, —yet the compound produced by their union is a white, solid substance, which is very soluble in water, and has a sweet taste. The compound resulting from the union of the two solid substances, carbon and sulphur, is a volatile, colourless liquid, so volatile, that it even evaporates in stoppered bottles, unless covered with a layer of water.* Hydrochloric acid (spirit of salts) reddens vegetable blue colours, whilst ammonia restores the red thus produced to its original colour. On bringing together these two substances, so opposite in properties, they unite and form a neutral salt called chloride of ammonium (sal ammoniac), in which neither the distinguishing properties of the acid nor the base are retained, as the salt has no action upon vegetable colours. As the properties of the acid and the base have been both destroyed (so long as the two substances remained united) by the union, they are said to have neutralized each other. The leading circumstance

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* **Bisulphide of carbon being heavier, and not miscible with water, this latter liquid floats upon its surface.**

which characterizes chemical combination is, as these examples sufficiently illustrate, the loss of properties experienced by the combining substances, the compounds produced being endowed with entirely new ones.

26. But chemical affinity differs from the attractions of cohesion and adhesion in another respect; affinity causes substances to unite in certain definite proportions by weight, whereas substances cohere or adhere in any proportions; the full consideration of this peculiarity of chemical affinity forms the subject of a future lesson.

27. From what has already been stated, the learner will be able to understand the difference between a mere *mixture of substances* and a *chemical compound;* in a *mere mixture of substances* the different ingredients composing the mixture do not lose their individual properties, but retain them unaltered and unimpaired, and they can be mixed together in any proportions by weight. Sugar, for example, when mixed with sand, retains its sweetness and all its other properties, and the sand likewise retains its properties unaltered.

28. We have inquired as to the cause of substances chemically uniting; we have now to inquire whether any outward manifestations or phenomena *attend* chemical combination. This has already been partly answered in the affirmative, when we stated, and proved by example, that substances, when they chemically combine, lose their individual properties, the compound produced being endowed with entirely new ones. And did we not observe that the combination of phosphorus and oxygen was attended with very marked phenomena? We all saw that it was attended with an intense development of light, and we also discovered that it was attended with a great development of heat. Chemical combination is *generally* attended with the liberation of *heat,* and frequently with the evolution of *light.* Chemical combination is also frequently attended with change of *colour.*

29. A change of colour frequently attends chemical combination. Thus, when mercury and sulphur combine, the beautiful scarlet-coloured substance called vermilion is produced. Silver and sulphur form by their union a black-coloured substance. The beautiful blue-coloured pigment called ultramarine is composed of three colourless bodies,—silica (sand), alumina, and soda,—besides which

it contains small traces of iron and sulphur, neither of which is blue. This is one of the many natural compounds which the chemist has prepared artificially, and it furnishes a striking proof of the advantages which have resulted to commerce and the arts from the study of chemistry; "for the artificial ultramarine is even more beautiful than the natural, whilst for the price of a single ounce of the latter we may obtain many pounds of the former."—(*Liebig.*) In addition to these examples that chemical combination is frequently attended with change of colour, we will add the following experimental illustrations.

EXERCISES.

16. Dissolve some nitrate of lead in water, and also some iodide of potassium in water; add some of the iodide of potassium solution to the lead solution; when the two solutions are mixed together, the iodine and lead will unite, and form a solid compound (iodide of lead), which is insoluble in water, and of a brilliant *yellow colour.*

17. Dissolve some corrosive sublimate (chloride of mercury) in water; add to this solution the remainder of the iodine solution; when the two solutions are mixed together, the iodine and mercury will unite and form a solid compound (iodide of mercury), which is insoluble in water, and of a most *brilliant scarlet colour.*

18. Dissolve some sulphate of iron in water, and add to the solution some sulphide of ammonium; the sulphur and iron will unite and form a solid compound (sulphide of iron), which is insoluble in water, and of a *black colour.*

19. Dissolve some sulphate of zinc in water, and add to the solution some sulphide of ammonium; the sulphur and zinc will unite and form a solid compound (sulphide of zinc), which is insoluble in water, and of a *white colour.*

30. The preceding experiments are likewise examples of precipitation, which is a *change of form;* the compounds that were formed, as the learner saw, were insoluble in the liquid in which their constituents were dissolved; they therefore fell or were precipitated to the bottom of the vessel. Chemical combination is, therefore, sometimes attended with a change of form; the last experiments were

examples of this in one direction; the following experiments are examples of it in other forms.

EXERCISES.

20. Place some fragments of marble or chalk in a deep glass vessel, add some water, and finally some hydrochloric acid; effervescence will be produced on the addition of the acid; effervescence is caused by a gas in its passage through a liquid; the gas (carbonic acid) in this instance is liberated from the marble by the hydrochloric acid.

When the evolution of gas is instantaneous and for a moment, we call it not effervescence but an explosion; as, for instance, when we apply a light to gunpowder, and convert it into gaseous substances.

21. Take two precipitating vessels of equal size, moisten the sides of one with a few drops of ammonia, the sides of the other with a few drops of hydrochloric acid; ammonia and hydrochloric acid are gaseous bodies, and they escape from their aqueous solutions when exposed to the air; the atmosphere of the jars becomes therefore filled with these gaseous bodies. The mouths or openings of the two vessels are then to be brought together, and the two gaseous bodies will combine, and the compound produced by their union will be a white solid body, which will appear like smoke, owing to its finely divided state. By this experiment we learn that gases may produce by their union *solids*.

31. It has already been stated, and it will be proved experimentally hereafter, that the elements of water are two gases, consequently gases sometimes produce by their union *liquids*.

32. Therefore the changes of form or state that attend chemical combination are exceedingly various; the combination of gases may give rise to liquids or solids; solids sometimes become liquids, and liquids solids. And we have seen by the experiments, that several familiar chemical phenomena, such as detonation, effervescence, and precipitation, are owing to these changes.

33. The next question, I think, any learner would ask about chemical combination would be this, — Can every element unite with every other element? Every

element has been made to unite with the greater number of the elements, but never with all; but the student is not to conclude from this that every element cannot unite with every other element. All we are entitled to say is, that it has not as yet been accomplished. Oxygen, for example, has been united with every element but fluorine, and we conclude from analogy that it would unite with this element if they were brought together under the proper conditions.

34. But although every element may be capable of uniting with every other element, they do not all unite with equal facility, nor do they all unite by direct methods, as the student will learn from the two following experiments.

EXERCISES.

22. Introduce into a jar filled with nitrogen gas* a small piece of ignited phosphorus, by means of the deflagrating spoon; the phosphorus will cease to burn in the nitrogen; it will on its introduction into the gas be immediately extinguished, because a union of the two elements cannot be effected under these conditions.

23. Introduce into a jar filled with nitrogen a fragment of ignited sulphur, by means of the deflagrating spoon; the sulphur, like the phosphorus, will cease to burn in the nitrogen, because the union of the two elements, sulphur and nitrogen, cannot be effected under these conditions.

35. The student must not conclude from these experiments that the elements which were brought together will not unite; they were only given to teach him that all the elements do not unite with the same facility, and that they cannot all be made to unite directly. Nitrogen, for instance, cannot be made to unite directly with any of the other elements, it can only be made to combine with them by indirect means. As combination by indirect means involves decomposition as well as combination, this mode of uniting substances cannot be explained until we study decompositions.

36. The combination of phosphorus with oxygen, and

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* The method for preparing nitrogen is described under the head of that substance in the chapter on the special properties of the elements.

phosphorus with chlorine, will now be contrasted, and the student must observe the different circumstances which mark the combination of phosphorus with these two elements.

EXERCISES.

24. Introduce a piece of *ignited* phosphorus into a jar of oxygen, in the way directed in Expt. 8.

25. Introduce a piece of *unignited* phosphorus into a jar of chlorine, in the way directed in Expt. 9.

37. These two experiments have been contrasted for the sake of teaching the student the important fact *that the temperature at which combination takes place varies with the different substances.** In order to effect the combination of the oxygen with the phosphorus, the phosphorus had to be introduced into the oxygen in an ignited state; whereas the chlorine and phosphorus combined at the ordinary temperature of the air. The student may ask, Would not the phosphorus combine with oxygen, without the aid of heat? Not to form the compound produced when the phosphorus burns in oxygen gas, unless it be kept in contact with the air for some time. The reason of this is fully explained in paragraph 68; but in order to give the learner a convincing proof that a certain temperature is requisite for the combination of substances, and that the temperature varies with the different substances, the following experiment must be made.

EXERCISE.

26. Place, in a beaker, or other convenient glass vessel, a piece of phosphorus, and half fill the vessel with water. Fill a bladder, which is fitted with a stop-cock and bent tube (Fig. 29), with oxygen, and direct a stream of gas upon the phosphorus. When the two elements come in contact, the phosphorus will not burst into flame; increase the temperature of the water ten degrees, and then direct the stream of oxygen upon the phosphorus. Continue to

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* The temperatures at which bodies enter into rapid combustion are very various; thus, phosphorus inflames at a temperature of 120° Fah., and sulphur at 300° Fah. Phosphuretted hydrogen gas inflames at all ordinary temperatures, whilst hydrogen requires a dull red, and carburetted hydrogen a bright red heat, before they will take fire.—*Kane's Elements of Chemistry.*

increase the temperature of the water ten degrees, after each occasion that the oxygen has been directed upon the phosphorus, *until* the phosphorus bursts into flame when the two elements are brought into contact. When this takes place, the temperature of the water will be about 145° Fah.

38. A certain temperature, then, is requisite for the combination of substances; and after combination has commenced, *the heat necessary for its continuance is produced by the combination;* for we have already seen that heat is evolved when two substances combine together.

39. As a certain temperature is necessary for the combination of substances, it follows *that if the heat evolved by substances in the act of combining, be conducted away, the combination must cease, for want of the necessary amount of heat.* The following experiments are given to teach the student this fact. He must remember what was stated in the first chapter,—that metals are good conductors of heat.

EXERCISE.

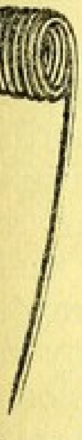
Fig. 1.

27. Form a small metallic spiral (Fig. 1), by twisting a piece of copper wire around a pencil; if it be placed cold over the flame of a wax candle, the flame is extinguished, because the heat evolved by the combining substances is conducted away by the metal, and therefore the combination ceases for want of the necessary amount of heat. The experiment must be repeated, first heating the spiral to redness in the flame of a spirit lamp, and then placing it over the flame. When the wire is heated the flame is not extinguished by it.

40. Inflammable vapour cannot, for the same reason, pass through wire gauze in an ignited state, because the metal conducts away a large portion of heat, and thus reduces the temperature below the point at which combination can take place between the elements of the vapour and the oxygen of the air; the flame is therefore arrested at the under surface of the wire gauze, whilst the vapour passes through the orifices, and can be lighted at the upper surface.

28. Lay a piece of camphor on some iron wire gauze, and

kindle it. The camphor will burn on the surface with a smoky flame, whilst a portion of the melted mass will pass through the gauze. The melted camphor, in its passage from the upper to the under surface of the gauze, will be deprived by the metal of so much heat, that when it comes in contact with the air at the under surface, they will be unable, from the low temperature of the vapour, to enter into a state of combination.

29. Place a piece of wire gauze over a jet from which coal gas is issuing; apply a light to the upper surface of the wire, when the gas will instantly take fire. The metallic gauze may be raised an inch or two above the jet from which the gas is issuing; the gas above the gauze will continue to burn, whilst that below will remain unignited.

41. Sir H. Davy beautifully applied this impenetrability of metallic gauze to ignited vapour, in the construction of a lamp for coal mines, which invention may be truly regarded as "one of the happiest efforts of his genius." A gas composed of carbon and hydrogen, called by chemists light carburetted hydrogen, and by miners fire-damp, often issues in considerable quantities from the fissures in the coal beds, and gradually mingles with the atmosphere of the mine. This gas is not only combustible in air, but they likewise form, when mingled together in certain proportions, a most explosive mixture, which, on ignition, detonates with terrific violence. Davy attempted the task of finding some plan whereby the miner could carry a light into the explosive atmosphere, without causing it to ignite, and thus prevent those terrible explosions which were the dread and destruction of the miner. Davy accomplished this apparently impossible task by simply screwing on to the top of a common oil lamp a cylinder of wire gauze (Fig. 2), of about 1,500 orifices in the square inch. The lamp, with this addition, can be carried safely into the most explosive atmospheres; for although the cylinder becomes filled with flame, from the ignition of the explosive

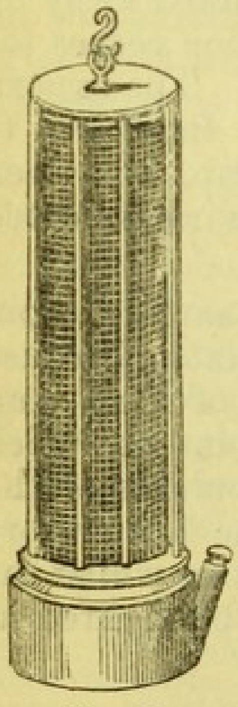
Fig. 2.

atmosphere within the cage, yet the explosive atmosphere without cannot become ignited, by reason of the heat-conducting power of the metallic gauze. The fire-damp may even burn within the cage with such energy as to heat the wire to dull redness, yet, even then, the flame is not communicated to the external atmosphere, as carburetted hydrogen requires a high temperature before its elements can separate and enter into combination with the oxygen of the air; "and hence, most fortunately for humanity, it is one to which the cooling orifices may be most successfully applied."—*Kane.*

42. Before we make any further observation upon the combination of substances, we must give the student a few questions to answer upon the subjects of the previous lessons.

EXERCISES.

30. What elements do the following symbols stand for:—Fe, Au, Br, Mn, Cd?

31. Give the symbols for the following elements:—Magnesium, Chlorine, Lead, Copper, Platinum, Potassium, Sodium.

32. How are the metals distinguished from the metalloids?

33. Name the elements which are gaseous, and the elements which are fluid, at the common temperature.

34. Of what elements are the following compounds composed:—HO, PbS, $NaCl$, CaF, FeO, KBr, CaO, ZnI, CoO?

35. What is weight?

36. In what respect does the attraction of gravitation differ from the attraction of cohesion and chemical attraction?

37. What is the difference between a mere mixture of substances and a chemical compound?

38. What is the burning of phosphorus, of carbon, of sulphur, of hydrogen in the air due to? Air is a mixture of oxygen and nitrogen.*

43. We will resume the experiments and remarks on the combination of substances by burning some iron wire

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* It contains small quantities of other gaseous substances, which need not be regarded in the question.

in oxygen gas; the wire must be tipped with sulphur. Before the experiment is made, we must inform the student why the iron has to be tipped with sulphur, as several facts will claim his attention after the experiment. We proved in our last lesson, as the student will remember, that substances require a certain temperature for their combination, and that the degree of heat varies with the substances. That iron must require a high temperature for its combination with oxygen, the student must be aware, from his own experience: he will have seen carbon burn in the atmosphere, he will have seen sulphur burn in the atmosphere, and he will have seen phosphorus burn in the atmosphere, when lighted; but he will not have seen iron burn in the atmosphere, with the exception of the sparks at a smith's forge. It is evident, then, that iron must require to be heated intensely, in order to make it unite with oxygen; the heat required is so great, that although a gas or spirit lamp might give the necessary degree of heat, yet by the time the iron had been removed from the flame and placed in the oxygen gas it would have become too cold; we therefore tip it with a substance which combines with oxygen at a much lower temperature. The substance we have selected for this purpose as the most convenient in every respect is sulphur. We ignite the sulphur, and then plunge it into the oxygen gas; the sulphur and the oxygen combine, and the heat liberated by their combination is sufficient to cause the iron and oxygen to combine. A similar plan is adopted for kindling coal fires; for coals, like all other substances, require to be heated to a certain degree before they will burn. This is accomplished, as all know, by the use of the more readily combustible paper and wood.

EXERCISES.

39. Coil a thin iron wire round a stick so as to bring it into a cork-screw shape, and then draw it off. Tip one end of the wire with sulphur, by immersing it in melted brimstone, the other end being fixed into a cork which fits the mouth of the gas jar. The sulphur having been ignited, the spiral wire must be immediately inserted into a jar filled with oxygen gas, and the cork is, in this case, closely pressed into the mouth of the jar. The sulphur will burst into full flame; the iron thus becoming heated

strongly is capable of entering into combination with the oxygen; a brilliant light accompanies the union, and the compound produced, an oxide of iron, falls down in brilliant sparks. This experiment is an illustration of the statement made in a preceding page, that the combination of iron with oxygen is sometimes attended with an evolution of both light and heat.

40. We will now make the same experiment, with the exception that instead of plunging the wire into oxygen gas, after the sulphur is ignited, we will allow it to remain in the air, to see if the iron wire will burn in the air: you see that after all the sulphur has entered into combination with the oxygen of the air the combustion ceases, no union taking place between the iron and the oxygen of the air.

44. Atmospheric air is merely a mixture of the gas oxygen, in which the iron burned in Expt. 39, and nitrogen; then why will not the iron burn as well in air as in oxygen gas? Because the nitrogen, which does not enter into combination with the iron (35), or contribute in any way to the combination, *absorbs* some of the heat evolved by the combination of the sulphur and oxygen, and thus reduces the temperature below the point at which combination will take place between the iron and oxygen. This gaseous body nitrogen acts with respect to the burning of iron in the air in the same way that the metallic spiral acted in Expt. 27, and the wire gauze in Expts. 28 and 29. An example of the same kind the student will frequently have seen; he will have seen, for instance, that when glowing coals were placed on considerable masses of metal the combustion was extinguished, simply because the metal conducted away the necessary degree of heat which was required for their combustion.

45. By the non-combustion of iron in atmospheric air, and its combustion in pure oxygen, we learn why substances that will burn in air as well as oxygen, burn more vividly in oxygen than in air. The indentation made in the plate by the oxide of iron, produced in Expt. 39, shows that great heat is generated by the combination of iron and oxygen.

46. By the generality of persons, an evolution of heat and light is regarded as a sign of destruction; they suppose, that as matter disappears by burning, it is therefore destroyed. This prevailing opinion is owing to the

substances, which are produced by the combustions ordinarily witnessed, being gaseous and invisible. Had charcoal, like zinc, phosphorus, and iron, produced a solid substance in burning, this erroneous idea could never have arisen. Instead of these agents, heat and light, being indicative of destruction, they are, as we saw by the experiments, signs that two or more substances are in the act of combining. But the learner may say, Are not coal, tallow, and similar combustible substances destroyed by burning? The reply to this question will be conveyed most intelligibly by first selecting some one substance. For example, the elements of tallow—carbon and hydrogen—separate from each other at high temperatures when in contact with air; they each unite with the oxygen of the atmosphere, the carbon forming with that element carbonic acid, and the hydrogen forming with it water. The particular combination, therefore, of the carbon and hydrogen which formed the tallow, is destroyed by the burning, but not the elements themselves, for matter is indestructible. Coal, peat, tallow, wax, gas, and all kinds of combustibles (coke and charcoal excepted), whether for heat or illumination, consist essentially of carbon and hydrogen; the two latter kinds of fuel consisting of carbon only. Atmospheric air is a mere mixture of oxygen and nitrogen. When, therefore, a compound of carbon and hydrogen is burnt in the atmosphere, the burning is due to the decomposition of the compound into its elements, and the combination of each of the elements with oxygen. The decomposition is caused by the oxygen having a greater affinity for the hydrogen than this latter element has for carbon at a high temperature; the two former, consequently, unite and form water, whilst another portion of oxygen unites with the liberated carbon and forms with it carbonic acid. The nitrogen, having no affinity under the circumstances for either the carbon or the hydrogen, plays no part in the chemical action, its only office being to dilute the oxygen and thus to moderate the combustion, rendering it slower and less brilliant than it would be if the air were composed of oxygen only; for the phenomena and the results are the same whether a substance be burnt in air or pure oxygen, the only difference being in the intensity of the combustion.

47. We employ in ordinary language several terms to express the combination of substances. If it be attended with evolution of heat and light, we call it burning or combustion; for example, when a piece of sulphur, or of carbon, is set on fire, we say it *burns*, because heat and light are evolved; we likewise say it *consumes*, because it gradually decreases in bulk, and at last disappears entirely. When it is a combination of a metal with the oxygen of the air, and the combination is not attended with evolution of light, we say the metal *rusts*, or we say it *corrodes*.

48. A few experiments must now be made, and the student must regard these experiments as illustrations of the facts and principles which have been explained.

EXERCISES.

41. Introduce a piece of ignited phosphorus into a jar of oxygen in the way described in Expt. 8.

42. Introduce a piece of unignited phosphorus into a jar of chlorine in the way described in Expt. 9.

43. Add some phosphorus and iodine together in the way described in Expt. 10.

44. Introduce a piece of ignited phosphorus into a jar of nitrogen in the way described in Expt. 22.

45. Introduce some burning sulphur into a jar of oxygen in the way described in Expt. 11.

46. Take a fragment of sulphur and melt it in the cup of the spoon; as soon as it is liquid, and *before it takes fire*, introduce it into a bottle filled with chlorine gas. It will immediately take fire, and burn rapidly, a compound called chloride of sulphur being formed.

47. Introduce some burning sulphur into a jar of nitrogen in the way described in Expt. 23.

48. Burn some iron wire in a jar of oxygen in the way described in Expt. 39.

49. Make a small ball of turnings of zinc, and enclose in it a small fragment of phosphorus. Place the ball in the cup of the spoon, and set fire to the phosphorus by means of a lamp, and then introduce the spoon as quickly as possible into a jar of oxygen. The zinc will enter into combustion and burn with a beautiful white light.

50. Place a few small fragments of antimony in the

cup of the spoon, and then heat them in the flame of a lamp until they take fire; introduce the burning metal immediately into a jar of oxygen, the two elements will immediately combine, a compound called antimonious acid being formed.

51. Introduce some powdered antimony into a jar of chlorine in the way described in Expt. 14.

52. Introduce some ignited charcoal into a jar of oxygen in the way described in Expt. 12.

49. A question which any one would naturally ask after witnessing these or any similar experiments would be this: How are heat and light produced in chemical combination? As to the cause of the evolution of heat, we are as yet entirely ignorant; we shall allude to the evolution of light in the next paragraph. "The element which most frequently develops heat and light, in combining with others, is oxygen; and the act of its combination with other bodies is pre-eminently denominated *combustion*. The body which, next to oxygen, most commonly produces light and heat in combining with others, is chlorine; next follow bromine and iodine, then sulphur and phosphorus." The student could not fail to notice, during the course of the experiments, the great disparity between the oxygen and chlorine combinations in the development of light and heat.

50. It is a well-known fact, that *solid* substances emit light when heated beyond a certain degree, the intensity of the light depending upon the degree of heat to which the substances are exposed. A lump of iron or lime, for instance, becomes red-hot when heated to a certain temperature, and the higher the temperature the whiter or more intense the light becomes. Substances are said to be *incandescent*, or *ignited*,* when they are heated to such a degree that they emit light.

51. All substances which do not undergo any chemical change when ignited—lime and porcelain are examples of such substances—do not themselves supply the heat necessary for their incandescence, but require to be supplied with it; the incandescence of such substances con-

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* The fire which accompanies the process of combustion appears either as *glow* or *incandescence* (white heat), when the burning body does not, before combustion, pass into the gaseous state—or as *flame*, when the burning body is previously converted into gas or vapour.—*Gmelin's Chemistry*.

sequently ceases when they are removed from the source of heat. But there are other substances—carbon, for example—which, after they have been once ignited, continue incandescent after they are removed from the source of heat which first caused their ignition; because the ignition enabled them to enter into chemical combination with some other substance—oxygen of the air, for instance—and the union furnished sufficient heat to *render the solid*, whether it be the compound formed as in the case of phosphorus and oxygen, or the uncombined portion, as in the case of carbon, incandescent.

52. Gases develop little light, even on intense ignition. It is a well-known fact, that common air may be heated to such an extent, that it will inflame pieces of wood, and yet itself remain invisible. A good illustration of this is afforded by the air which issues from the chimney-glass of an Argand burner, which is sufficiently hot to ignite pieces of paper, and even to make a thin piece of wire red-hot. Upon the fact, that all bodies evolve light when heated to a high degree, depends the possibility of obtaining artificial illumination. And as gaseous bodies evolve in burning so small an amount of light as scarcely to be visible, it is evident that a solid body must be present in all materials used for illumination; therefore, when the substances which combine, and the substance which is formed, are gases, little or no light is evolved; for light to be produced, either one of the combining substances, or the compound formed, must be solid at the temperature at which the combination takes place.

53. The light and heat emitted by burning bodies bear no proportion to each other; for the heat is due solely to the energy of the chemical action, without respect to the state of the combining matter.

EXERCISES.

53. Generate some hydrogen gas in a common round bottle, by the method given under the special properties of this gas. Fit a narrow glass tube into a perforated cork, the latter fitting air-tight into the neck of the bottle; the tube should be made of hard infusible glass, and the end, which is not fixed into the cork, should be drawn out into a fine open point (Fig. 19). A light must

be applied to the orifice as soon as the operator considers that all the common air has been expelled from the bottle, *but not before*, on account of the violent explosion which ensues, when hydrogen, mixed with oxygen or common air, is inflamed; the utmost care and precaution are always necessary in inflaming this gas. To prevent any accident arising from the bursting of the vessel, it is advisable to wrap the vessel in a towel before applying the light. When a light is applied to the orifice, the hydrogen takes fire, and burns with a pale bluish-coloured flame, which is scarcely visible in the daytime, but is intensely hot. The burning of the hydrogen is caused by its combining with the oxygen of the atmosphere, forming with it water: this is readily proved, for if a dry glass vessel be held over the burning gas, it becomes covered with drops of water. If a glass tube, about three feet long, an inch and a half wide, and open at both ends, be held over the flame, strange musical sounds will be produced, the sharpness varying with the depression or elevation of the tube. This phenomenon is produced by a series of small explosions, which succeed each other so rapidly that they produce a continuous sound. The explosive nature of a mixture of hydrogen and oxygen is better exhibited by filling a *soda water bottle* two-thirds full of hydrogen and one-third full of oxygen, and then inflaming the gases by applying a light to the mouth of the bottle; the explosion is less violent if atmospheric air be used instead of pure oxygen.* If air be employed, five-sixths of it are required for one-sixth of hydrogen; but whether atmospheric air or oxygen be used, it is requisite, before exploding the mixture, to wrap the bottle in a towel.

Hydrogen is the lightest body in nature, being fourteen and a half times lighter than air, and sixteen times lighter than oxygen. This property is pleasingly demonstrated by filling a small balloon of gold-beaters' skin with the gas, and allowing it to ascend in the lecture-room. The hydrogen ought not to pass direct from the generating vessel into the balloon; before entering the balloon it

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* The student will see that the difference between combustion and explosion consists simply in the difference in the rapidity of the combination; in combustion the two substances combine together by degrees, but in explosions they are both intimately intermingled, and therefore can be made to combine instantaneously.

ought to be made to traverse a tube filled loosely with fragments of quicklime, which will absorb any sulphuric acid that may have been carried up by the gas, as well as arrest the moisture which accompanies the gas.

54. Fill a soda water bottle with equal volumes of chlorine and hydrogen, and inflame the mixture by applying a light to the mouth of the bottle,—the explosion is more feeble than with oxygen and hydrogen, and the light is faint. The compound produced is hydrochloric acid; the acid nature of the compound may be demonstrated by applying a piece of blue litmus paper to the bottle.

54. The hydrogen flame, the student will observe, develops little light, although there is a great evolution of heat; indeed, the flame of a mixture of oxygen and hydrogen produces the most intense heat that can be obtained by artificial means.

55. That a solid is necessary for the evolution of light, is beautifully exemplified in the following way:—The combustion of a mixture of oxygen and hydrogen produces the most intense heat that can be obtained by artificial means, yet the light produced by the combination of the two gases is so small, as scarcely to be visible. If we place in this *almost* invisible flame a substance like lime, which will not melt, or undergo any chemical change, a light so brightly luminous will be produced, as to rival in intensity the noon-day sun. This light is caused by the solid becoming luminous from being intensely heated.

EXERCISE.

55. Exhibit the oxyhydrogen lime light,* so as to prove to the student that a solid is necessary for the evolution of light.

56. This method of introducing the solid matter which is to evolve the light, into the burning matter from which

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* The burning of a mixture of oxygen and hydrogen requires great care. The gases ought to be contained in separate holders, and mixed only at the jet; or if they are contained in the same vessel, the tube which conveys them to the jet must be filled with small iron rods, so that in case the flame were to recede, it would be cooled by the rods below the point at which combination takes place between the two gases, so that by no possibility could the flame reach the gaseous mixture in the gas holder; for a mixture of the two gases, when ignited, explodes with terrific violence.

the heat proceeds, is one which is never employed for ordinary illumination. The principle upon which all practical methods of illumination are founded is, that the heat-producing material and the incandescent solid, both exist in the substances employed for illumination, and that the burning of the former sets free the latter, yielding it at the same time by combustion, the necessary degree of heat to render it luminous.

57. All substances employed as illuminating materials are compounds of carbon and hydrogen, and the flame produced by their combustion contains solid particles of carbon, which can be proved by a very simple experiment.

EXERCISE.

56. Introduce a cold body, such as a plate of metal, or a piece of glass, or even a piece of card, into a luminous flame; it speedily becomes blackened from the deposition of carbon. Intercept the flame, by means of the card, far down near the wick; then higher up, about the middle of the flame, and then at the top. The deposit of carbon near the wick will be very slight; the deposit will be considerable in the middle of the flame, and only very slight at the top.

58. We learn, by this simple experiment, not only that carbon is present in the flame, but that it is not present in equal amount in different parts of the flame; the quantity is small in the area of the faintly illuminated halo just around the wick; it is also small towards the summit of the flame; it is present in the largest quantity about the middle of the flame, in that portion from which the maximum of light is given forth. We have now to explain how the free carbon comes to be present in the flame. Tallow, oil, gas, and all other substances employed as illuminating materials, consist essentially of carbon and hydrogen, as previously stated. During the burning, both the elementary bodies combine with the oxygen of the air, *but not at the same time;* the hydrogen, having a greater affinity for the oxygen than it has for the carbon, instantly combines with the former element. The carbon is consequently liberated in the form of minute solid particles (soot), which become incandescent, from the intense heat evolved by the combustion of the hydrogen:

the incandescent carbon, when it reaches the edge of the flame, likewise combines with oxygen, its place being immediately occupied by another particle of liberated carbon.

59. The flame of a candle is a good illustration of the principles just stated. The heat generated by the flame melts the tallow, which is conveyed by the capillarity of the wick to the sphere of combustion. The flame itself consists of three parts; the first, or outer part of the flame, is of a pale blue colour, so faint as scarcely to be visible, because no separation of carbon occurs, the hydrogen and carbon *burning simultaneously*, as the air is in excess; it is the hottest though the least luminous part of the flame. The air has not free access to the next or luminous part of the flame; the consequence is, that the oxygen is almost entirely consumed in combining with the hydrogen, whilst almost the whole of the carbon is liberated in minute solid particles, which become intensely heated, and give out a bright light. The interior part surrounding the wick consists of black, inflammable vapour, which, from having no access to the external air, is incapable of entering into combination. The presence of this inflammable vapour may be easily shown by holding obliquely in the flame a glass tube, open at both ends, the lower end of the tube being placed in the centre of the flame, and the upper end reaching beyond its edge. A large quantity of the inflammable vapour will pass up the tube, and may be ignited at the upper end.

60. In describing the different parts of the flame of a candle, we have drawn attention to the fact, that if the illuminating material be burned in such a manner that its carbon and hydrogen are consumed at the same moment, the largest possible amount of heat is procured, but the amount of light evolved is not greater than that obtained from the burning of pure hydrogen; this is due to the immediate combustion of the carbon, and therefore the absence of any solid matter in the flame, which is necessary, as we have previously stated, for the evolution of light. That illuminating materials derive their light from the separation of their carbon, and that if they be so burnt that this separation does not take place, owing to the carbon being burnt simultaneously with the hydrogen with which it was united, little or no light will be pro-

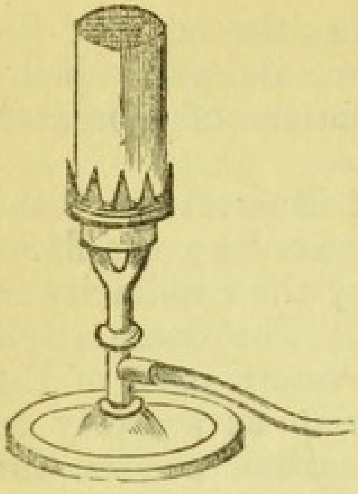

Fig. 3.

duced, is very simply and very conclusively demonstrated in the following way:—Place over a gas jet a chimney, or hollow cylinder, covered over at the top with wire gauze, as shown in Fig. 3; when the gas, *i. e.*, coal gas, is turned on, it ascends within the chimney, and mixes with atmospheric air before passing through the gauze. On lighting it above the wire gauze, if the air and gas have been so proportioned that its carbon and hydrogen are consumed at the same time, it will burn with a pale blue flame of no more illuminating power than that of pure hydrogen.

61. When the burning body does not exist as a gas naturally, or does not pass into the state of gas at the temperature at which it combines with the other body, oxygen in the air, for instance, the fire which accompanies the combustion appears as glow, for it is necessary for the production of flame that the burning body should exist naturally in the state of gas, or be converted into gas at or below the temperature at which combination takes place, otherwise no flame results. Well-burned charcoal, and also iron, burns with a steady glow, unattended with flame; as these two elements do not volatilize at the temperature at which their combination takes place. Sulphur, phosphorus, and zinc, &c., burn with flame, because they either exist naturally in the form of gas, or they pass into the gaseous state at the temperature at which they enter into combination. Flame is in fact produced whenever, by a sufficiently elevated temperature, a continuous supply of vapour or gas is made to combine with oxygen or some other gaseous substance with which it comes in contact. Flame, then, is produced when two vapourous or gaseous substances enter into combination, and the combination is attended with evolution of light and heat; and as combination can only take place at the point of contact, it is the boundary line of the two gases.

EXERCISE.

57. Place a piece of sulphur in a long test tube or flask of hard glass; heat the vessel by means of a lamp until

the sulphur melts, and the vessel has become filled with its vapour. Introduce a narrow strip of tinfoil into the sulphur atmosphere, the metal will instantly inflame, a compound called sulphide of tin being formed. The experiment may be varied by employing, instead of the tinfoil, a narrow strip of sheet lead, the combination being attended with evolution of heat and light. If very thin iron and copper wires be twisted into a coil and introduced into an atmosphere of sulphur, they will likewise combine with that metalloid, the combination being attended with evolution of heat and light.

62. The burning of sulphur in oxygen gas, or of tinfoil in sulphur vapour, proves the incorrectness of calling some substances *combustible*, and others *supporters of combustion;* for in the first of these experiments we should have to call the sulphur the combustible substance, whilst in the latter it would be the supporter of combustion. The fact is, that in all cases of combustion (all combinations attended with evolution of heat and light), each of the combining substances is combustible, and each is also a supporter of combustion, and the heat and light are derived from the combination. Oxygen is as capable, for instance, of being burnt in an atmosphere of hydrogen as the latter is in one of, or containing, oxygen. But the learner will find it stated in many chemical works that this or that substance is not a supporter of combustion. He will find it stated in such works that hydrogen is a combustible substance, but not a supporter of combustion; and, in proof of the last assertion, the fact that a lighted taper is extinguished when immersed in an atmosphere of hydrogen is adduced. Now, it would be quite as correct to say that oxygen is not a supporter of combustion, because carbonic acid cannot be made to burn in an atmosphere of that gas. If one element, B, has already combined with another element, A, in the largest possible proportion, the resulting compound cannot unite with a still further quantity of the element A. Hence tallow cannot burn in hydrogen, or carbonic acid in oxygen; the first (tallow), being a compound of carbon and hydrogen, cannot unite with a *further quantity* of the latter element; in the same way, carbonic acid, being a compound of carbon and oxygen, cannot unite with a *further quantity* of the latter metalloid. To

say that an element is not a supporter of combustion, is to say that it cannot enter into chemical combination with any other substance, which is incorrect, as every element can combine, either directly or indirectly, with some of the other elements, if not with all.

63. The following exercises upon the subjects of the previous lessons must be answered by the student, either *vivâ voce* or in writing.

EXERCISES.

58. What elements do the following symbols stand for :—Zn, Ni, Na, Ca, Ba, Sb, Hg, Sn?

59. Give the symbols for the following elements :—Cadmium, Chlorine, Calcium, Carbon, Chromium, Copper, Cobalt.

60. Of what elements are the following compounds composed :—$\mathrm{Ag\,Cl}$, $\mathrm{Ca\,F}$, $\mathrm{Pb\,Br}$, $\mathrm{Hg\,O}$, $\mathrm{B\,N}$, $\mathrm{Cu\,Cl}$?

61. Name some of the terms employed in ordinary language to express the combination of substances.

62. What conditions are necessary for light to be produced in chemical combination?

63. Name some of the conditions necessary for the combination of phosphorus and oxygen, of phosphorus and chlorine, and the phenomena which accompany the combinations, and the properties of the compounds produced.

64. State the effects which intense heat has upon solid and gaseous bodies, and give examples.

65. Do the light and heat emitted by burning bodies bear any proportion to each other? Confirm the opinion expressed by examples.

66. Why do substances burn more vividly in pure oxygen than they do in atmospheric air?

67. Upon what facts depends the possibility of artificial illumination?

68. What is necessary for the production of flame?

69. Name some of the conditions necessary for the combination of antimony and chlorine, and of sulphur and oxygen, and the phenomena which accompany the combinations, and the properties of the compounds produced.

70. Of what elements are all materials employed for illumination composed, and what changes do they undergo when burned in the air?

71. Explain the flame of a candle.

EXERCISES ON THE COMBINATION OF A COMPOUND WITH AN ADDITIONAL QUANTITY OF ONE OF ITS ELEMENTS.

These exercises show also the cause of the blue flame which appears on the surface of fires, and that the atmosphere is a mere mixture of gases, and not a chemical compound.

64. This course of experimental exercises is designed to show that even after combination has been effected between two elements, the chemical force of one of the elements may not be wholly quiescent in the compound produced; this element may still be capable, under certain circumstances, of taking up another portion of the one with which it is united, and forming, by this further combination, a new and more complex compound. This can be rendered intelligible to every one, if we make use of our former comparison,—such words as To, Be, &c., are converted into new and perfectly different words, if one of their letters be twice repeated, as Too, Bee, &c. In the same way the compound carbonic oxide, which is made up of the two elements carbon and oxygen, and the symbol for which is CO, is capable of uniting with an additional quantity of oxygen; this addition converts it into another compound, called carbonic acid, which we will represent for the present by the symbol COO.

EXERCISES.

72. Place at the bottom of a long test tube some crystals of oxalic acid, add to them some strong oil of vitriol, and then warm the tube in the flame of a lamp. As soon as effervescence commences, apply a piece of lighted paper, or a splinter of wood, to the mouth of the tube, until the evolved gas takes fire: it burns with a blue flame. The gas is the compound carbonic oxide we have already alluded to; the heat and light are occasioned by its combining with some of the oxygen of the air, and forming with it carbonic acid.

73. Put into the Woolfe's bottle (Fig. 20) a few small pieces of metallic copper (copper turnings), and add to the metal, by means of the funnel tube, equal parts of nitric acid and water; effervescence, without the application of heat, will instantly ensue. On the first evolution of the gas the bottle will be filled with reddish fumes; when they have nearly passed away, the gas may be collected by

dipping the exit tube under the mouth of a gas jar or wide mouthed bottle, which is filled with water, and standing inverted on the shelf of the pneumatic trough. This gas is a compound of nitrogen and oxygen, and is called nitric oxide.

74. Pass rapidly into a jar half full of this nitric oxide (the vessel containing it being inverted on the shelf of the pneumatic trough) a quantity of oxygen; as soon as the two gases are brought together, the jar will be instantly filled with an orange-red gas, which is very soluble in water; this liquid will therefore rapidly ascend in the vessel by dissolving the new formed gas. The oxygen and nitric oxide unite together, and the compound produced is this orange-coloured substance named nitrous acid. This experiment furnishes a striking example of the difference between a mere mixture of substances and a chemical combination. If the oxygen and nitric oxide had merely mixed, and not chemically united, these two colourless gases, in whatever proportions they were mixed, would never have become coloured; neither would the mere mixture of two gases insoluble in water render both of them soluble in that liquid.

The experiment may be made in the following manner:—Fill a large jar with nitric oxide, remove it from the pneumatic trough, and expose it with its mouth upwards to the air; the nitric oxide will instantly abstract oxygen from the air, and become converted into nitrous acid; before the acid gets diffused place the jar, with its mouth downwards, in water; the water will ascend.

65. These experiments prove that some compounds have the power of uniting with another portion of one of their constituents; thus, carbonic oxide, the elements of which are carbon and oxygen, can combine with another portion of oxygen, and by so doing become converted into a new and different compound, called carbonic acid; in like manner, carbonic acid can unite with another quantity of carbon, and thereby become converted into carbonic oxide. This interesting chemical action is daily witnessed. The blue flame which frequently appears on the surface of our fires, or which is seen issuing from limekilns or iron furnaces, is caused by the combustion of carbonic oxide. This gas is produced in our fires in the following way:—

The air, having free access at the bottom of the grate, converts the carbon it comes in contact with into carbonic acid; this acid, as it traverses the red-hot fuel, parts with one proportion of its oxygen to the carbon of the fuel, and thus becomes reduced to the state of carbonic oxide, the liberated oxygen and the carbon of the fuel likewise forming carbonic oxide; when the carbonic oxide comes in contact with the air at the surface of the fire, it combines with some of the oxygen, and becomes converted into carbonic acid, and the blue flame is the effect of the combination.

66. Nitric oxide cannot combine with oxygen if this element be already in a state of chemical combination; it can only appropriate it when it is uncombined; in other words, when it is in a pure state, or is one of a mere mixture of gases. As it can abstract oxygen from the atmosphere, we conclude from this and other facts, that the atmosphere is not a *chemical compound,* but a mere mixture of oxygen and nitrogen.

67. But some compounds can either combine with another proportion of one of their constituents, or with some other element. Ex.—Carbonic oxide can take up an additional quantity of oxygen, which converts it into carbonic acid; likewise, if carbonic oxide and chlorine be mixed together, they combine, a compound called chlorocarbonic acid being formed. Sulphurous acid (the compound produced by burning sulphur in oxygen) can combine, under certain circumstances, with another proportion of oxygen, which converts it into another compound, named sulphuric acid; sulphurous acid can also take, in the place of this additional proportion of oxygen, a quantity of chlorine, a new compound called chlorosulphuric acid being formed.

68. There are some elements which can combine both at ordinary and higher temperatures; different compounds being produced at the different temperatures: when this is the case, the lower combination is attended with little or no evolution of light, and the amount of heat developed is less than that produced by the higher combination. Ex.—Potassium combines at common temperatures with oxygen, forming potash; but when heated it burns with flame, and combines with three times as much oxygen. When phosphorus is exposed to the air, it always appears to emit a whitish

smoke, which in the dark is luminous. This effect is due to a slow combination of the phosphorus with the oxygen of the air, forming with it phosphorus acid; if phosphorus be heated, it bursts, as we have seen, into a brilliant flame, phosphoric acid being produced, which contains two-thirds more oxygen than phosphorus acid.

DIFFERENT KINDS OF COMPOUND SUBSTANCES. EXERCISES. EXERCISES ON THE COMBINATION OF TWO COMPOUND SUBSTANCES. HOW COMBINATION REACHES ITS LIMIT.

69. In the first lesson we compared simple substances to letters, and compound substances to words; this comparison may be carried still further. Letters are divided into vowels and consonants; elements are divided into metals and metalloids. Two letters can be made to produce two or more words; two elements may unite in two or more proportions, giving rise to as many different compound substances. There are also different kinds of words, as noun, verb, &c.; and there are likewise different kinds of chemical words—or, as these words are usually called, compound substances.

70. There are *four* different kinds of compound substances, viz., *acids*, *bases*, *salts*, and *indifferent bodies.* Whether a compound can or cannot unite with another quantity of one of its elements, it will nevertheless belong to one of these four classes; in fact, every compound substance must either be an acid, a base, a salt, or an indifferent body.

71. The term ACID is applied to all substances which possess a *sour taste*, and turn vegetable *blue* colours *red.* A familiar illustration of this latter property is the change effected on the colour of the common blue cabbage by vinegar (acetic acid). BASIC BODIES have an *acrid taste:* they restore the *blue colour* to vegetable bodies which have been reddened by an acid; they change the colour of yellow turmeric to *brown;* acids do not alter the colour of yellow turmeric, but they restore the yellow colour when it has been rendered brown by a basic body. The term SALT is applied to all substances which are composed of an acid and a base. INDIFFERENT BODIES have no action upon vegetable colours, and they do not form

salts either with acids or bases; water is the best known member of this class.

EXERCISE.

75. The teacher must fill three test glasses, or other convenient vessels, with water, — to one he must add a few drops of any acid, as hydrochloric; to the second he must add a few drops of any base, as soda or ammonia; the water in the third represents indifferent bodies. He must then pass the liquids round to the students, along with blue and red litmus papers and turmeric papers, and they must state which liquid is the base, which the acid, and which the indifferent body, by the action of the liquids on the test papers.

72. The object of the present lesson is to show that *compound substances*, whether they can or cannot unite with another quantity of one of their constituents, or with some other element, can nevertheless *combine* with the members of an *opposite* class of compounds, and, in *particular instances*, with some members in their own class. Ex.—Acids unite with bases to form salts. Some of the bases, likewise, combine with each other. Salts unite with salts to form double salts. As indifferent bodies (water excepted) are comparatively unimportant, they will be disregarded with this one exception. The student will learn, by the following experiments, that light is seldom developed when two compound substances combine together.

EXERCISES.

76. Add a little water to some caustic (quick) lime, the two substances will combine together, and form a solid compound called hydrate (slacked) of lime. The heat evolved by the combination causes some of the water added in excess to pass off in the form of steam.

77. Procure two Florence flasks, place in one of them one ounce of a solution of ammonia, and in the other an equal quantity of hydrochloric acid (spirit of salts); fit a narrow straight tube to each of the flasks, by means of a perforated cork; place them upon retort stands, and adjust two bottles or flasks in such a way that the tubes may

ascend into them, then boil the liquid in both vessels for a few minutes. Ammonia and muriatic acid are gaseous bodies, and lighter than atmospheric air, consequently, when the solutions are boiled they escape and collect in the bottles; if the mouths of the two vessels be brought together after they are filled with the gaseous compounds, the gases will combine and form a solid substance, called chloride of ammonium.

78. Place in the apparatus (Fig. 21) some fragments of marble, adjust the tubes, and then pour into the bottle, by means of the funnel tube, equal parts of hydrochloric acid and water; effervescence will instantly ensue, the carbonic acid contained in the marble being expelled by the hydrochloric acid. Prepare a solution of lime (lime water), by adding water to slacked lime, and allowing them to remain in contact for some time; pour off the solution when clear, and conduct the carbonic acid into this clear solution by dipping the exit tube into it. The acid and basic body (lime) will combine together; the compound produced by the union is a salt, called carbonate of lime, which, being insoluble in water, will be precipitated.

73. Carbonate of lime, according to its density and degree of hardness, is known under the name of chalk, limestone, marble, &c.

74. Salts are capable of uniting with each other, thus forming more complex compounds. But as the constitution of a substance increases in complication, the combining tendency of its elements becomes more satisfied, "the less therefore will be the inclination of those elements to enter into further combinations. In this manner chemistry reaches its limit."—*Gmelin.*

75. The following exercises must now be answered by the student:—

EXERCISES.

79. Can more compounds than one be formed out of the same elements?

80. Give some proof that the air is a mixture, and not a chemical compound.

81. Describe the properties of an acid.

82. What produces the blue flame which is frequently seen on the surface of coal fires?

83. Describe the properties of a base.
84. Why will not carbonic acid burn in air?
85. Why will not water burn in air?

CHAPTER III.

PROPERTIES OF MATTER.

Force and matter. Imponderable matter. Ponderable matter. Physical properties of matter. Extension, impenetrability, divisibility, porosity, indestructibility, mobility, cohesion, gravitation. Absolute, specific, and atomic weight. Exercises.

76. As it is impossible to describe the chemical without alluding to the physical properties of matter, we shall very briefly describe the properties of matter in general.

77. The essential nature, both of matter and force, is unknown. "We have an intuitive conviction of their existence; we know a great deal about them—every fresh accession to our knowledge increases our power over them; the steam engine and the electric telegraph are results which have sprung from our acquaintance with their laws; but the more profoundly we investigate their relations, the more we become convinced of our ignorance, and the wide field of discovery which still lies before us. We see a loadstone attract a piece of iron, and we find it attract one end of a magnetic needle and repel the other, and we attribute this attraction and repulsion to the existence of a force in the loadstone, which we call the magnetic force; we see also a stone let fall from the hand descend to the ground, and we ascribe its descent to the attraction of the earth: we call the force which produces this effect gravity. Now, we can investigate the laws of the magnetic force as well as those of gravitation, and estimate their effects on material bodies; yet, after all, we shall be obliged, with Dr. Young, 'to acknowledge our total ignorance of the intimate nature of forces of every description!'"

78. "Whenever we see a body in motion, we attribute its motion to the existence of a force. A ship sails by the force of the wind and tide, a boat is propelled by the

muscular force of the rower, and a locomotive by the expansion of the steam generated in the boiler; in addition to this, we find that two or more forces, which, acting separately on a body, would cause the body to move, may be so applied as to counteract each other's effects, and keep it at rest. *We may, therefore, define force to be that which either produces, or tends to produce, motion.*"

79. "Having thus arrived at a definition of force, we may be able to obtain one for matter, as *matter is that which is either moved or can be moved by force.*"

80. "Force and matter may thus be considered correlative terms, and we should be unable to arrive at a knowledge of the existence of the one, without the aid of the other. Every particle of matter in the universe is endowed with distinct properties of force, which fit it in many marvellous ways to act on other particles of matter. How many of these are still hidden from the researches of the human mind, we know not; but this we do know, that all the phenomena of the external world which we can explain, can be traced to these properties of force, to which we can ascribe no other origin, when we contemplate the wisdom of their application, than the will of an almighty and all-wise Creator, unless we would be guilty of the folly of believing that the print which now meets the eye of the reader, owed its existence to no other cause than the attraction of the ink for the paper, occurring by chance, without the intervention of an intelligent agent."

81. "Matter which can be acted on by the force of gravitation is called ponderable, while that which is unaffected by it is termed imponderable. The particles of light, caloric or the principle of heat, the electric fluids, and ether, are the only known imponderable bodies. The prevailing opinion at present is, that heat, light, and electricity are not themselves composed of material particles, but are produced by vibrations of unknown and highly elastic fluids called ethers, which are supposed to fill the whole universe, and penetrate the pores of all solid and fluid bodies. Whether the ether, which is supposed to produce light by its vibrations, be the same as the ether, to which the effects of heat and electricity are attributed, can only at present be matter of conjecture, though the

advance of natural science every day leads us to new facts, which seem to refer heat, light, and electricity to the modifications of some common cause."

82. "All ponderable matter is found in one or other of three states—the solid, liquid, or aëriform (gaseous). A solid body is composed of particles of matter united together by forces which cause the body to retain its shape unaltered, except the particles are forced asunder or displaced by some degree of violence; a solid body is considered hard or soft, according as it requires a greater or less degree of force to alter its form or displace its particles. The particles which form a liquid body are united together in such a manner as to allow them to move about one another with great freedom and with but little friction; a liquid consequently yields so readily to external force or pressure, that it retains no form of its own, but readily assumes that of any vessel in which it may be placed, without altering its volume. A gas or aëriform fluid is one whose particles mutually repel each other in such a manner that a gas has neither definite form nor volume; its form and volume being only limited by the vessel in which it is inclosed, or by the pressure exerted on it. A quantity of gas, however small, may be made to fill a vessel of any size or shape.

83. "Heat and pressure seem to be chief causes of bodies existing in each of these three states, and it is probable that there is a particular temperature and pressure for every solid body at which it would assume any one of these three states. There is no solid substance known which may not be rendered liquid, and finally converted into vapour, by the application of a heat sufficiently intense; and we may reasonably conclude that all bodies which are liquid would become solid, or freeze, if we could sufficiently reduce their temperature, although some liquids have hitherto resisted the greatest amount of cold we have been able to procure by artificial means. Some vapours or aëriform fluids are readily condensed by cold into the liquid state; others require great intensity of cold, or great pressure, or both combined, to render them liquid; and we may infer, from the gases already condensed by cold and pressure, that all might be, could we only procure the necessary degree of cold and pressure. Water is known in three states—the solid, the liquid, and

the aëriform; and the amount of heat by which it is influenced at the moment determines its existence in one or other of these three conditions."*

84. Matter, in whichever of these three states it exists, is always either elementary or compound.

85. The properties of matter are of two kinds, *physical* and *chemical;* the former class is a part of natural philosophy, or physics, as it is sometimes called; the latter of chemistry.

86. "The physical properties of an object are those which refer to its condition, whether solid, liquid, or gaseous. Crystalline form, specific gravity, hardness, colour, transparency, or opacity, and the relations of the object to heat and electricity, are physical properties. Physical properties are independent of the action which the body exerts upon other bodies, whilst the chemical properties of the body relate essentially to its action upon other bodies, and to the permanent changes which it either experiences in itself or which it effects upon them. For example, in indicating the physical properties of such a substance as sulphur, we should refer to its brittleness, its faint peculiar smell, yellow colour, crystalline structure, its semi-transparency, the facility with which, if rubbed, it exhibits electrical attraction, and so on: but if we would take note of the chemical properties, it would be necessary to refer to those operations by which the body usually becomes changed, and loses its distinctive physical characters, such as the ease with which it takes fire; the rapidity with which it unites with silver or copper, especially if heated; its insolubility in water and spirit, and its solubility in turpentine or in alkaline liquids.

87. "It is not, however, always possible to draw the line between physics and chemistry; this is of the less importance, since the chemical nature of any substance could be but imperfectly studied without a tolerably complete knowledge of its leading physical characters, which are those by which it is most readily defined."—*Miller.*

88. The physical properties of matter may be divided into essential or principal, and non-essential or secondary. The former are common to all substances; the latter belong only to certain substances. Among the general

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* Mitchell's "Natural Philosophy;" in Orr's "Circle of the Sciences."

properties of matter may be enumerated extension, impenetrability, divisibility, porosity, indestructibility, mobility, and gravitation.

89. Extension is that property in consequence of which every substance occupies a certain limited space; a substance is said to be extended when it possesses length, breadth, and thickness. Impenetrability is that property of matter which prevents two substances from occupying the same space at the same time; we cannot, for instance, cause one portion of matter to occupy the place of another portion without moving or displacing it, and the opposition met with in moving it is called its *resistance.*

90. The divisibility of matter can be carried to an extreme degree of minuteness, and in some cases to an almost incredible extent. "In gilding silver wire, a grain of gold is spread over a surface of 1,400 square inches; and as, when examined in a microscope, the gold upon a millionth of a square inch is distinctly visible: it is proved that gold may be divided into particles of at least $\frac{1}{1{\cdot}400{\cdot}000{\cdot}000}$th of a square inch in size, and yet possess the colour and all the other characters of the largest mass." "Dr. Thomson has shown that a portion of lead may be rendered *visible,* the bulk of which cannot exceed the 888,492,000,000,000th of a cubic inch. He dissolved one grain of nitrate of lead in 500,000 grains of water, and after having agitated the solution, passed through it a current of hydrosulphuric acid gas. The whole liquid became sensibly discoloured. Now we may consider a drop of water to weigh about a grain, and a drop may be easily spread out so as to cover a square inch of surface. Under an ordinary microscope the millionth part of a square inch may be distinguished by the eye. The water, therefore, could be divided into 500,000,000,000 parts, every one of which would contain some lead united to sulphur. But the lead in a grain of nitrate of lead weighs only 0·62 of a grain. It is obvious, therefore, that an atom of lead cannot weigh more than $\frac{1}{310{\cdot}000{\cdot}000{\cdot}000}$th of a grain, while the atom of sulphur (for the lead was in combination with sulphur, which rendered it visible) cannot weigh more than $\frac{1}{2{\cdot}015{\cdot}000{\cdot}000{\cdot}000}$th of a grain. According to Biot, the thread by which a spider lets itself down is composed of more than 6,000 single threads.

91. All substances admit of expansion and compression;

there must therefore be spaces or pores between the molecules (minute particles) of matter; this property is termed porosity. These spaces (or pores) are in some cases so large as to be seen by the naked eye; in others by the aid of the magnifying glass; and even when they cannot be rendered visible, it is nevertheless certain that they do exist!

92. It has already been stated that not a particle of matter can be destroyed, and that its apparent destruction is owing to a mere change of form or composition; this property is called indestructibility.

93. Matter cannot, when at rest, be set in motion, or when in motion be brought to rest, without the application of a force. Bodies in motion gradually decrease their speed, and at last stop, unless the force which set them in motion be continued; they stop, not because matter has a greater tendency to the state of rest than it has to that of motion, but because they are under the influence of what are termed the *passive forces*, such as friction, the resistance of the air, &c., which are continually acting against the movement, and are therefore constantly diminishing the motive force.

94. The term gravitation will be explained presently.

95. The secondary properties of matter are opacity, transparency, softness, hardness, elasticity, colour, density, solidity, and fluidity.

96. Particles of matter are subject to the action of two opposing forces—cohesion and repulsion: upon the relative intensity of these two opposing forces depend several of the secondary properties, especially the two last mentioned. The attraction of cohesion binds particles of the same nature together. Sometimes the molecules are, as it were, indiscriminately collected, at other times they are arranged in a regular crystalline form; this force operates only at insensible distances. The repulsive force, which is considered to be due to the agency of heat, separates the molecules from one another. Upon the relative intensity of these two forces depends the solid, fluid, or gaseous condition of matter; when the cohesive force prevails, a solid is the consequence; when the repulsive power is in the ascendant, matter assumes the gaseous form, and when the two forces are balanced, the liquid state is the result.

97. Sometimes particles of a dissimilar nature adhere together. The sticking of dust to the walls of buildings and articles of dress, the writing with chalk, charcoal, plumbago, &c., are examples of the mutual adhesion of dissimilar substances. Scientific men are still undecided, whether to regard the mutual adhesion of dissimilar substances as the effect of a force distinct from that of cohesion, called the attraction of *adhesion*, or to consider them as due to the cohesive force. If this latter opinion be adopted, the union of all substances, whether similar or dissimilar, if they possess the same properties after the union as before, and unite in no definite proportion by weight, must be regarded as due to the attraction of cohesion.

98. Matter is subject to the action of another force, called the attraction of *gravitation.* This force operates at the greatest conceivable distances, and is common to all forms of matter; and as each particle is affected by it, the mass containing the greatest number of particles must consequently exert the greatest force: hence it is that all bodies, when unsupported, and at a distance from the earth's surface, descend in straight lines towards its centre.* The simplest effect of gravity, and that which is immediately evident to the senses, is the downward pressure which bodies exert on whatever supports or prevents them from falling to the earth; this pressure is termed their weight.

99. There are three kinds or relations of weight, viz., ABSOLUTE WEIGHT, SPECIFIC WEIGHT, and ATOMIC WEIGHT. By *absolute weight* is meant, the measure of the weight of a body, estimated by that of some other, which serves as a unit: thus, to ascertain the absolute weight of any substance, we place it upon one of the pans of the scale, and upon the other as many grains, ounces, or pounds as will restore the equilibrium of the balance. *Absolute weight signifies, then, the whole quantity of ponderable matter in any substance, irrespective of its volume or bulk.*

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* "An earth greater or smaller, denser or rarer than the one on which we live, would require a change in the structure and strength of the footstalks of all the little flowers that hang their heads under our hedges. There is something curious in this, considering the whole mass of the earth, from pole to pole, and from circumference to centre, as employed in keeping a snowdrop in the position most suited to the promotion of its vegetable health."—*Whewell's Bridgewater Treatise.*

100. By *specific weight*, or, as it is frequently called, *specific gravity*, is meant the comparative or relative weights of equal bulks of different substances; thus, when we speak of one substance being lighter than another, we do not mean that one ounce, or one pound, of the one substance weighs less than an ounce or a pound of the other; but we mean that in a given volume or bulk, the one contains less ponderable matter than the other. One cubic inch of cork, for example, weighs less than a cubic inch of iron; this difference in weight between equal bulks of different substances, expressed in numbers, is termed their specific gravity or weight.

101. To arrive at the relative weights of equal volumes of different substances, it is necessary to fix upon one as the standard of comparison; pure water has been selected as the standard for solid and liquid bodies, its density being reckoned as 1000 or 1. The sp. gr. of substances heavier than water is consequently represented by a higher number, and those which are lighter by a lower number than 1000 or 1.

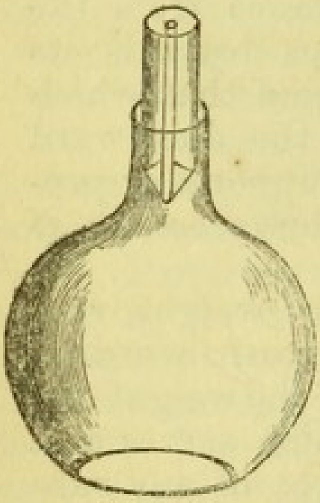
Fig. 4.

102. Bottles (Fig. 4) are made for the express purpose of determining the sp. gr. of liquids; they are made to hold a given quantity of distilled water, as 1,000, 500, 250 grains, &c. A weight is usually sold with them, which counterpoises the bottle full of distilled water, and upon which is marked the quantity of distilled water the bottle holds. All that is required in estimating the sp. gr. of any other fluid is to fill the bottle with it completely; to close the bottle with the stopper in such a way that no bubbles of air are left in it; then, after wiping it perfectly dry, to ascertain its weight, by observing how much heavier or lighter it is than the weight of water the bottle is capable of holding, and adding or subtracting accordingly; and the result, divided by the weight of water the bottle is capable of holding, will be the sp. gr.

103. A bottle capable of holding 500 grains of distilled water will hold 922·5 grains of sulphuric acid; the latter weight divided by the former will give the sp. gr. of the

acid, water being taken as 1; thus, $\frac{922{\cdot}5}{500} = 1{\cdot}845$ sp. gr. of the acid: again, the same bottle, or one of like size, will hold only 396 grains of turpentine, therefore $\frac{396}{500} = 0{\cdot}792$ sp. gr. of the turpentine.

104. As the volume of liquids expands with increase of temperature, the quantity of ponderable matter in a given volume becomes thereby proportionably diminished; it is therefore requisite, in determining the sp. gr. of substances, to conduct all the experiments at one uniform temperature; the standard generally adopted is 60° Fahrenheit. For the same reason, the bottle should never come in contact with the naked hand during the experiment; it should be protected by a cloth during the wiping and drying of it and its transfer to the balance.

EXERCISES.

86. If a bottle, capable of holding 300 grains of distilled water, holds 260 of some other liquid, what is the sp. gr. of that liquid?

87. If a bottle, capable of holding 360 grains of distilled water, holds 320 grains of some other liquid, what is the sp. gr. of that liquid?

88. If a bottle, capable of holding 400 grains of distilled water, holds 470 grains of some other liquid, what is the sp. gr. of that liquid?

89. If a bottle, capable of holding 700 grains of distilled water, holds 600 grains of some other liquid, what is the sp. gr. of that liquid?

105. If the sp. gr. of a fluid be known, the absolute weight of a given volume of the same fluid can be determined. To resolve this problem, we have simply to multiply the weight of an equal volume of water by the sp. gr. of the fluid; the result, divided by the sp. gr. of the water, will be the weight of the volume of the fluid we wish to determine. If we wished to know, for instance, the absolute weight of a gallon of sulphuric acid, the sp. gr. of which is 1·85, we should multiply the weight of a gallon of water, which is 70,000 grains, or 10 lbs. avoirdupois, by 1·85, and the product, divided by the sp. gr. of water, will be the weight of a gallon of the acid;

thus, $10 \times 1{\cdot}85 = 18{\cdot}50$, then $\frac{18{\cdot}50}{1} = 18{\cdot}5$ lbs., the weight of a gallon of the acid.

EXERCISES.

90. Required the weight in pounds of a gallon of linseed oil, its sp. gr. being 0·953.

91. Required the weight in pounds of a gallon of turpentine, its sp. gr. being 0·792.

92. Required the weight of a gallon of the water of the Dead Sea, its sp. gr. being 1·172.

93. Required the weight of a gallon of vinegar, its sp. gr. being 1·063.

94. Required the weight of a cubic inch of mercury, the sp. gr. of which is 13·59; a cubic inch of water weighing 252·458 grains.

106. When a solid is immersed in water or any other liquid, it displaces a quantity of the fluid equal to its own bulk (as no two bodies can occupy the same space at the same time), the *absolute weight* of which being determined, as well as that of the solid, the sp. gr. of the solid is the quotient obtained by dividing the latter weight by the former.

107. The specific gravity of solids in the form of powder or small fragments is determined by weighing them in air and then introducing the weighed particles into a sp. gr. bottle filled with water; a quantity of water overflows, equal in bulk to the solid particles introduced; the bottle containing the substance weighs, therefore, less than the bottle filled with water and the substance when they are weighed separately, the difference being the weight of the volume of water expelled by the solid. Thus, if we weigh 200 grains of sand and then introduce it into a sp. gr. bottle holding 500 grains of water, if no water were expelled, the water and sand together would weigh 700 grains; but instead of that it only weighs 624 grains, the difference, 76, being the weight of the water expelled, therefore $\frac{200}{76} = 2{\cdot}63$ the sp. gr. of the sand.

EXERCISES.

95. If 100 grains of a solid be introduced into a bottle holding 500 grains of water, and if after the introduction

of the solid the bottle weighs 560 grains, what is the sp. gr. of the solid?

96. If 160 grains of a solid be introduced into a bottle holding 400 grains of water, and if after the introduction the bottle weighs 500 grains, what is the sp. gr. of the solid?

97. If 300 grains of a solid be introduced into a bottle holding 700 grains of water, and if after the introduction the bottle weighs 850 grains, what is the sp. gr. of the solid?

108. When the substance whose sp. gr. has to be determined is soluble in water, it is necessary to employ some other liquid in which it is insoluble; alcohol, naphtha, turpentine, oil, &c., are the liquids generally employed when water cannot be used. The sp. gr. of the fluid to be employed is first determined, then the sp. gr. of the solid in that fluid; the two numbers thus obtained, multiplied together, give the sp. gr. of the solid in water. Thus, suppose that the sp. gr. of a solid was found to be in turpentine 3·6, the sp. gr. of the turpentine being 0·792, sp. gr. of the body will be, taking water as the standard, $3·6 \times 0·792 = 2·85$. Great care must be taken to prevent air being admitted when the solid is added to the water in the bottle; and if any should be introduced, every bubble must be expelled before weighing, if we would obtain accurate results. As an illustration, take 100 grains of carbonate of soda, and introduce it into a sp. gr. bottle which is capable of holding 1,000 grains of water, but which is filled with alcohol, the sp. gr. of which is known; weigh the bottle after the introduction, and then calculate the sp. gr. of the carbonate of soda.

EXERCISES.

98. If 200 grains of a solid be introduced into a bottle holding 400 grains of alcohol, the sp. gr. of which is 0·870, and the bottle weighs, after the solid is introduced, 570 grains, what is the sp. gr. of the solid, taking water as the standard of comparison?

99. If 300 grains of a solid be introduced into a bottle holding 700 grains of turpentine, the sp. gr. of which is 0·790, and the bottle weighs, after the introduction of the solid, 870 grains, what is the sp. gr. of the solid, taking water as the standard of comparison?

109. We have noticed *one* of the effects of the immersion of solids in liquids, viz., the displacement of so much of the liquid as is equal in volume to the solid immersed; and if we can collect and weigh the volume of the liquid displaced, and we have weighed the solid previous to its immersion, their weights are of course the *relative* weights of equal volumes of the solid and liquid. We have now to consider another of the effects attending the immersion of solids in liquids. It is this:—

110. *The solid will be pressed upwards with a force equal to the weight of the liquid it displaces.* For when a solid is wholly immersed in a liquid, the *lateral* pressures are equal, and contrary to each other, and therefore *neutralize* each other; but the vertical pressures are unequal, the *upward* pressure being greater than the *downward;* therefore the solid, as a consequence, has a tendency to move upwards. Thus, suppose that a cube is immersed in a vessel of water (Fig. 5), and that four of its sides are arranged vertically. These four sides, presenting the same surface to the liquid, and being immersed to the same depth, experience *equal* pressures, and as the sides are opposite to each other, two and two, the lateral pressures must be *contrary* as well as *equal;* hence they are neutralized, or in equilibrium. With regard, however, to the pressures which act vertically on the horizontal sides A and B, it is evident that the downward pressure on A is equal to that of the weight of a column of water having the side A for its base and A D for its height: and that the upward pressure on B is equal to that of the weight of a column of water having the side B for its base and B D for its height. The cube, therefore, tends to rise under the pressure of a force equal to the difference of these pressures, which is equal, evidently, to the weight of a column of water having the same base and the same height as the cube; consequently, this pressure is equivalent to the weight of water displaced by the body immersed.

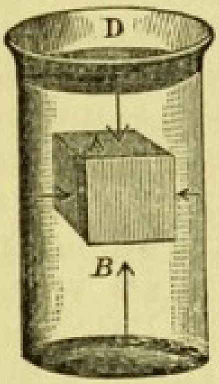

Fig. 5.

111. If the weight of the solid be *equal* to that of the mass of fluid which it has displaced; in other words, if its

density or specific gravity be equal to that of the fluid, it will remain suspended in the liquid wherever it may be placed. If the solid has a *greater* density than the liquid, it will sink, because the pressure of its weight is greater than the upward pressure of the liquid. If the solid has a *less* density than the liquid, the upward pressure of the latter will exceed the weight of the solid; the solid will therefore be forced up to the surface of the liquid with a force equal to the difference between the weights of equal volumes of the solid and the liquid. It is usual to express these effects by stating *that a solid which is plunged beneath the surface of a liquid loses as much of its weight as is equal to that of the liquid displaced.*

112. This principle, which constitutes the foundation of the theory relating to immersed and floating bodies, is known by the name of the principle of Archimedes.

113. The sp. gr. of solids in the mass is determined by suspending them by means of a horsehair from the hook under one of the scale pans; the mass is then weighed in air, the operator having previously taken care to remove any dust or loosely adhering particles. A vessel of pure water at 60° Fah. is arranged in such a manner that the solid, still suspended from the scale pan, can be immersed as nearly as possible in the centre of the vessel, and covered by at least half an inch of water (if air bubbles should adhere to the solid when immersed in the water, they must be removed by means of a feather); it is now to be weighed, and the weight will be less than in air; subtract the weight in water from the weight in air, and the remainder will be the weight lost on immersion; or, in other words, the weight of an equal volume of water; divide the weight in air by the weight lost on immersion, the quotient will be the sp. gr. of the solid.

114. The above method must be slightly modified for solids lighter than water; they are first weighed in air, after that they are connected with a piece of lead heavy enough to sink them, the absolute weight of which, and the weight it loses on immersion, being known. From the weight lost by the combined bodies, deduct the weight lost by the lead, and the remainder will be the weight of the volume of the fluid displaced by the lighter body.

Divide the weight of the light body by the weight of the water it displaces, and the quotient will be its sp. gr.

EXERCISES.

100. Required the sp. gr. of a solid which weighs 36 grs. in air and 26 grs. in water.

101. A solid, whose weight in air is 60 grs., weighs 40 grs. in water and 30 grs. in sulphuric acid; required the sp. gr. of the acid.

102. A piece of metal, weighing 36 lbs. in air and 32 lbs. in water, is attached to a piece of wood, the weight of which in air is 30 lbs.; the weight of the combined solids in water is 12 lbs.; required the sp. gr. of the wood.

115. "It is difficult directly to measure the volumes of solids, unless they have some regular figure. Liquids, on the other hand, adapting themselves to the form of any vessel in which they are placed, admit of measurement by pouring them into vessels of known capacity. Hence it is that the quantities of liquids are usually expressed by measure, while those of solids are commonly expressed by weight. But by the method just explained, liquids supply easy means of measuring the volumes of solids, no matter how irregular the shape of the latter may be, provided only that the solid to be measured will not dissolve in, or be penetrated by, the liquid in which it is immersed. We know, for instance, that an imperial gallon of water weighs 10 lbs., and that its volume is 277·274 cubic inches. Now, when we immerse a solid in water, it displaces a quantity of water equal to its own volume, and the difference of the weight of the solid in air and water is the weight of that volume of water which it displaces; from these data it is evident we can always calculate the volume of a solid. Suppose, for example, the difference in weight of a solid in air and water is 2½ lbs., this is the weight of the volume of water which is equal to its own volume, which it has displaced; therefore, as an imperial gallon of water weighs 10 lbs., and the volume of a gallon of water is 277·274 cubic inches, the volume of the solid in question must be one-fourth of that of an imperial gallon, or 69·318 cubic inches."

116. The sp. gr. of a body forms one of its most important and distinguishing physical characters. The mineral iron pyrites, for instance, is in colour almost exactly like gold; but it is at once distinguished from the precious metal by the difference in sp. gr., an equal bulk of gold being nearly four times as heavy. In the practical arts the sp. gr. of bodies serves two very important purposes—1st, to determine the weight of a body whose volume is known; and 2nd, to determine the volume when the weight is known.

EXERCISES.

103. What will be the weight of a block of limestone containing 12 cubic feet, 1 cubic foot of water weighing 62·5 lbs., the sp. gr. of the stone being 2·64?

104. How many cubic feet are there in a block of coal weighing 1 cwt., its sp. gr. being 1·232?

105. The sp. gr. of bar iron is 7·788; required the weight of a cubic foot.

106. The sp. gr. of flint glass is 3·329; required the weight of a cubic foot.

107. The sp. gr. of oak is 0·845; required the weight of a cubic foot.

108. The sp. gr. of cork is 0·240; required the weight of a cubic foot.

109. The sp. gr. of ice is 0·930; required the weight of a cubic foot.

110. The sp. gr. of silver is 10·474; required the weight of a cubic inch.

111. A solid weighs 49 grs. in air, and 42 grs. in water; required the weight of a cubic foot of the substance.

117. For commercial purposes the sp. gr. of liquids is determined by means of an instrument called the hydrometer; this instrument is not so accurate as the sp. gr. bottle, but it is preferable to it on account of its simplicity and the rapidity with which the experiment can be made with it, and at the same time it is sufficiently accurate for all commercial purposes.

118. "The hydrometer (Fig. 6) in general use consists of a floating vessel of thin metal or glass, having a weight beneath to maintain it in an upright position, and a stem above bearing a divided scale. The use of the instrument

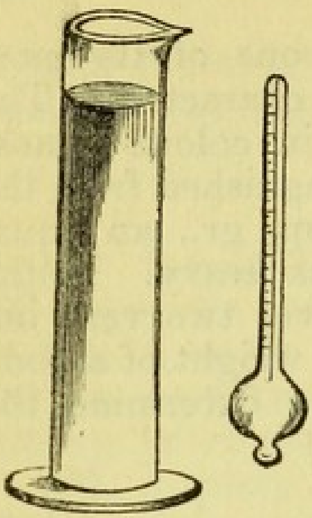

Fig. 6.

is very simple. The liquid to be tried is put into the glass jar represented in the figure, and the instrument floated in it. It is obvious that the denser the liquid, the higher will the hydrometer float, because a smaller displacement of fluid will counterbalance its weight. For the same reason, in a liquid of less density, it sinks deeper. The hydrometer comes to rest almost immediately, and then the mark on the stem may be read off. The graduation of the stem is very commonly arbitrary, two or three different scales being unfortunately in use. These may be sometimes reduced, however, to the true numbers expressing the sp. gr. by the aid of tables of comparison drawn up for the purpose."*

119. The methods pursued in determining the sp. gr. of gases are too complicated to be described here.

120. The subject of atomic weights is explained in the next chapter.

121. The student ought to write out answers to the following questions :—

EXERCISES.

112. Into how many classes are the properties of matter divided?

113. Name the physical properties of oxygen, chlorine, carbon, and mercury.

114. Name the chemical properties of oxygen, chlorine, and carbon.

115. Enumerate the essential properties of matter, and the non-essential properties of matter.

116. What is meant by absolute weight?

117. What is meant by specific weight?

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[*] Fownes' "Elements of Chemistry."

CHAPTER IV.

Affinity causes unlike substances to unite together. Exercises. Chemical force exerted only at insensible distances. Exercises. Formation of compounds by substitution. Exercise. Constancy of composition in chemical compounds. Exercises. Equivalent proportions. Atomic theory. Exercises. A difference in the properties of compounds does not always arise from a difference in their elementary constitution. Multiple proportions. Exercises.

122. *Affinity causes unlike substances to unite together.* Chemical attraction, or affinity, is the force which causes unlike substances to unite together. And the greater the difference in the properties of the substances, the greater will be their tendency to unite together. Exs.—The metals, as a class, differ as widely from the acids in properties as possible; but the acids rapidly dissolve the metals. Acids and bases possess the most opposite properties, yet they always combine when they are brought together.

EXERCISES.

118. Add some nitric acid to some copper filings, the copper will combine with the acid, and become dissolved; the solution of the compound produced by the combination of the acid and metal will be of a beautiful blue colour.

119. Add some sulphuric acid to some iron filings, the iron will combine with the acid and become dissolved.

120. Add some sulphuric acid to some ammonia, in such proportion that the solution, after the addition, has no action upon either blue or red litmus papers, which proves that the acid and base have united.

123. *The compound produced possesses properties perfectly different from those of its constituents.* The new and more complex body produced by the combination of two or more bodies, possesses properties perfectly different from those of its constituents. If, for instance, the blue liquid which has been produced by the action of

nitric acid on the copper, were evaporated to dryness, we should obtain this blue crystalline substance;* or, if we evaporated the solution we have obtained by acting on iron with sulphuric acid, we should obtain this green-coloured salt. Now what relation or resemblance is there between the copper and the nitric acid, and this blue crystalline solid; or between this green crystalline solid and the sulphuric acid and iron? We learn from these examples that there is no resemblance between the properties of a compound and those of its constituents. *The properties of a compound cannot be predicted, either from a knowledge of the properties of its constituents, or from any other source.*

124. *The chemical force is exerted only at insensible distances.* If a sensible distance intervenes between two or more substances, they will not be able to enter into combination, because the chemical force is exerted only at *insensible* distances. For substances to combine, it is necessary, therefore, that they should be in intimate contact, or separated only by immeasurably small distances. On this account, the solid state is less favourable to chemical action than the fluid state; for in the solid state the particles of unlike bodies cannot be brought into that close proximity which is essential for the development of their mutual affinities. The following exercises are given to teach the student the fact that solid bodies can rarely be made to combine by merely mixing them together, but if they are brought into a state of solution, combination will at once take place, if the substances are capable of entering into combination.

EXERCISES.

121. Mix some chloride of mercury and some iodide of potassium together in a mortar; observe that the mixture remains colourless: subsequently dissolve the mixed solid in water, when a scarlet-coloured substance, iodide of mercury, will be produced.

122. Mix some nitrate of lead and some iodide of potassium together in a mortar; observe that the mixture re-

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* Specimens of nitrate of copper and sulphate of iron must be on the lecture table.

mains colourless: then add water, when a beautiful yellow-coloured substance, iodide of lead, will be produced.

125. Another peculiarity of the chemical force is, that it is exerted between different kinds of matter with different degrees of force. Nitric acid, for instance, will oxidize and combine with most of the metals; it oxidizes and unites, for instance, with silver, mercury, copper, lead, and iron; but it unites with these metals with very different degrees of intensity; with silver the combination is less powerful than with mercury; with mercury less powerful than with copper; with copper less powerful than with lead; and with lead less powerful than with iron.

EXERCISE.

123. Place a piece of metallic iron in a solution of nitrate of copper (about a quarter of an ounce of the copper salt in half a pint of water); the nitric acid will leave the copper, and combine with the iron, forming with it nitrate of iron; the metallic copper set free will be precipitated on the metallic iron, which remains uncombined.

126. A chemical compound is distinguished from a mere mixture of substances, or from a simple adhesion of different substances, not only by its possessing properties entirely different from those of its constituents, but by the still more remarkable characteristic that it is always composed of the same elements united in unvarying proportions by weight. We have to remember, then, that bodies always combine in fixed and invariable proportions, and this law, it may be observed, is the basis of chemistry. No circumstances whatever can alter the proportional quantities of the constituents of a compound. Thus common kitchen salt—whether obtained from the salt beds in Poland or from those in Cheshire, wherever found or however prepared, whether by the agency of man or by the operations of nature—is always made up of the two elementary bodies, chlorine and sodium, and in the invariable proportion of 23 parts by weight of sodium to 35·5 parts by weight of chlorine. Substances can, under certain circumstances, assume different states; for instance, carbonate of lime exists both crystallized (marble) and uncrystallized (chalk); water can assume the solid,

the liquid, and the gaseous states. Under all forms and states, however, the chemical composition remains the same. Pure water—whether in the solid state, as hail and snow, or in the liquid state, as rain or dew, or in the gaseous state, as steam—is always made up of the two elementary bodies, hydrogen and oxygen, and always in the proportion of one part by weight of hydrogen to eight parts by weight of oxygen.

127. From these and similar facts we deduce the law that substances always combine in fixed and invariable proportions, which proportions are not interfered with when two or more substances are brought together in other proportions. If they combine, they do so in the very same proportions they would have done, had they been brought together in their natural proportions, the only difference being, that a portion—constituting the excess of one or more of the constituents—remains uncombined. Oxygen and zinc, for example, combine in the proportion of 8 parts by weight of the former to 32 parts by weight of the latter element; 40 parts by weight of the compound—oxide of zinc—being formed. Let us suppose that we brought them together in the proportion of 8 of oxygen to 36 of zinc; the combining proportions of the two elements, nevertheless, would be the same, 8 parts of oxygen combining with 32 parts of zinc, 40 parts of oxide of zinc being formed, and 4 parts of zinc remaining uncombined. To take another supposed case: let us say that they were brought together in the proportion of 9 of oxygen to 32 of zinc, nevertheless 8 parts of oxygen, as before, would combine with 32 parts of zinc, 40 parts of oxide of zinc being formed, and 1 part of oxygen remaining uncombined. Water and lime combine in the proportion of 9 parts by weight of the former compound to 28 parts by weight of the latter, 37 parts by weight of hydrate of lime being formed. Suppose that we added 11 parts of water to 28 of lime, the consequence would be that 2 parts of water would remain uncombined, 37 parts of hydrate of lime being produced; or that we added to every 9 parts of water 31 parts of lime, 37 parts of hydrate of lime would still be formed, whilst 3 parts of lime would remain uncombined.

128. This constancy of composition in chemical compounds, not only as regards their elements, but also as

regards the weight of these elements, will be better understood, perhaps, if we select a few more examples, and arrange them in a different manner.

Water contains in 100 pts.		Hydrochloric Acid contains in 100 pts.	
Oxygen	88·89	Chlorine	97·26
Hydrogen	11·11 × 8 = 88·88	Hydrogen	2·74 × 35·5 = 97·27
	100·00		100·00

Hydrosulphuric Acid contains in 100 pts.		Hydriodic Acid contains in 100 pts.	
Sulphur	94·12	Iodine	99·22
Hydrogen	5·88 × 16 = 94·08	Hydrogen	0·78 × 127 = 99·06
	100·00		100·00

129. It is evident from these examples that the different constituents of a chemical compound are present in different proportions by weight. Thus, in water, there is 8 times more of oxygen than of hydrogen; for if we multiply the quantity of hydrogen contained in that compound by 8, the product will be the quantity of oxygen present in that liquid. In the same way, there is 16 times more sulphur than hydrogen in hydrosulphuric acid; for if we multiply the quantity of hydrogen in 100 parts of that compound by 16, it will give us the quantity of sulphur the compound contains in 100 parts: and so with respect to the other two examples.

130. We may therefore express these facts in the following simple form. To one part by weight of hydrogen there is found—

In Water.	In Hydrochloric Acid.
8 parts of oxygen.	35·5 parts of chlorine.
In Hydrosulphuric Acid.	**Hydriodic Acid.**
16 parts of sulphur.	127·1 parts of iodine.

131. Every 9 parts of water then are invariably composed of 8 parts of oxygen, and 1 of hydrogen; every 36·5 parts of hydrochloric acid are composed of 35·5 parts of chlorine, and 1 part of hydrogen, &c.

132. *Chemical compounds are therefore always constant*

and definite in composition, not only as regards their components or elements, but likewise as regards the quantity by weight of these elements. This is the first of the four great laws of chemical union.

EXERCISES.

124. How much water would be produced from 28 lbs. of oxygen and 5 lbs. of hydrogen, and would either of the elements be in excess?

125. How much hydrochloric acid would be produced from 5 lbs. of hydrogen and 178 lbs. of chlorine, and would either of the elements be in excess?

126. How much hydriodic acid would be produced from 7 lbs. of hydrogen and 1,000 lbs. of iodine, and would either of the elements be in excess?

127. How much hydrosulphuric acid would be produced from 6 lbs. of hydrogen and 80 lbs. of sulphur, and would either of the elements be in excess?

133. "There are two modes in which chemical compounds are formed. The simplest is that where the two substances unite directly." The experiments on the combination of two elements, on the combination of a compound with a further quantity of one of its elements, and on the combination of two compound substances, are all examples of direct combination.

134. "The other mode in which compounds are formed is still more common. It occurs where, in a body already formed, one of the ingredients of that body is *displaced* by another substance, and a new compound results." We have directed the student's attention, in par. 125 and exercise 123, to this mode of producing compounds, viz., by *displacement* or *substitution*.

135. It has been stated (125) that nitric acid will oxidize and combine with most of the metals; that it oxidizes and unites, for instance, with silver, mercury, copper, lead, and iron; but that it unites with these metals with very different degrees of intensity. With silver the combination is less powerful than with mercury; with mercury less powerful than with copper; with copper less powerful than with lead; and with lead less powerful than with iron. If, therefore, mercury were added to the compound produced by the combination of

the acid with silver, the mercury would displace and take the place of the silver; if copper were added to the compound produced by the combination of the nitric acid and mercury, the copper would displace and take the place of the mercury; if lead were added to the compound produced by the combination of the nitric acid and copper, the lead would displace and take the place of the copper; if iron were added to the compound produced by the combination of nitric acid and lead, the iron would displace and take the place of the lead; therefore any metal in the list can displace all the metals which precede it, and can be displaced by each of the metals below it.

136. *Equivalent proportions.*—Mercury replaces silver in the proportion, by weight, of 100 parts of mercury for every 108 parts of silver; copper replaces mercury and silver in the proportion of 31·7 parts of copper for every 100 parts of mercury, or 108 parts of silver; lead replaces copper, mercury, or silver, in the proportion of 103·7 parts of lead for every 31·7 parts of copper, or 100 parts of mercury, or 108 parts of silver; iron replaces lead, copper, mercury, or silver, in the proportion of 28 parts of iron for every 103·7 parts of lead, or every 31·7 parts of copper, or every 100 parts of mercury, or every 108 parts of silver. We will illustrate the proportions in which substances replace and are replaced, by a few more examples:—Sixteen parts of sulphur, we have seen (129), combine with 1 part of hydrogen and form 17 parts of hydrosulphuric acid; if we were to replace the sulphur in hydrosulphuric acid by iodine, we should require 127·1 parts of iodine for every 16 of sulphur, and the compound, after the sulphur had been replaced by the iodine, would not be hydrosulphuric acid; it would be hydriodic acid: if we were to replace the sulphur in hydrosulphuric acid, or the iodine in hydriodic acid, by chlorine, we should require 35·5 parts of chlorine to replace every 16 parts of sulphur, or every 127·1 parts of iodine. From these examples it will be seen that whether a substance, A, combines with another substance, B, by direct combination, or by replacing some other substance with which B is united, it (A) always combines with B in the same proportions by weight in whichever way the combination takes place; thus, chlorine always unites with hydrogen, in the proportion by weight of 35·5 parts of chlorine to every 1 part of hydrogen, whether the chlorine

unites with the hydrogen by direct combination or by displacing some substance with which the hydrogen is united.

137. From these and like facts the second law, which is called *the law of equivalent or reciprocal proportions*, has been deduced—viz., that if a body, A, unite with other bodies, B, C, D, forming with them the compounds A B, A C, A D, the quantities of B, C, D, which unite with A, will also be the quantities in which they unite among themselves, in the event of union taking place to form the compounds B C, B D, C D.[*]

138. *Atomic theory.*—The cause, which renders impossible a combination of the elements in any other than these fixed proportions, is unknown. But a beautiful theory was constructed by Dalton to account for the fact, which, although purely speculative, has been of the utmost service. He supposed all matter to consist of certain small particles which he called atoms, because, according to his

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[*] The apparatus shown in Fig. 7, will be found useful in conveying to the student correct ideas respecting the law of equivalent proportions, and for illustrating chemical changes generally. The apparatus ought to be made of wood, and hung up on one of the walls of the class-room. Directions as to its use:— On the discs A A and B B are to be marked with chalk the symbols and their atomic weights; and on the arms C C the names of the compounds with their atomic weights. The discs B B on the movable arm are for the symbols and atomic weights of the constituents which replace each other: these discs are made to revolve, so that the letters marked upon them can always be kept in their proper position. To illustrate the use by an example,—if the two compounds, A B and C D, when brought together, mutually decomposed each other, A D and C B being formed, we should show these changes on the machine by marking the symbol and atomic weight of A on one of the discs marked A, and the symbol and atomic weight of B on one of the discs marked B, and place these two discs together; on the arm C connected with these discs, we should write the name of the compound A B and its atomic weights. On the other disc A we should write the symbol for C and its atomic weight; and on the disc B the symbol and atomic weight of D; and on the arm C the name and atomic weight of the compound C D. We then move the arm, so that the disc marked D comes underneath that one marked A, and the one marked B under that of C; the names and atomic weights on the arms then require to be altered. When there is only one compound, A B, and this is decomposed when another body, C, is brought in contact with it, the compound A C being formed, and B set free, only one of the discs, A, is required.

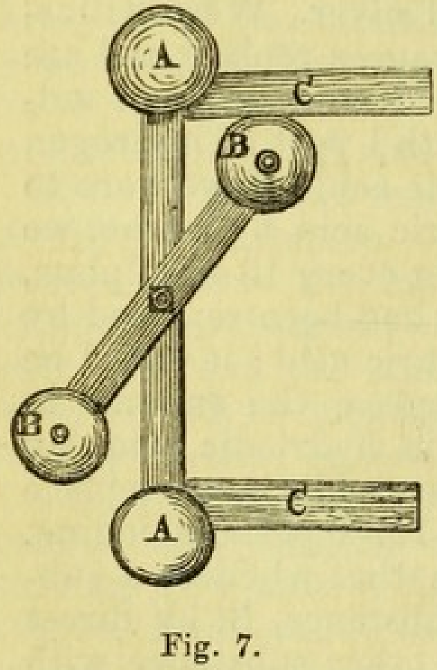

Fig. 7.

idea, they are so minute as to be incapable of division. He likewise considered the atoms of the different elements to differ in weight; if this be admitted, the difficulty of explaining why the elements should always combine, and replace each other, in certain definite proportions, is removed.

139. As these ultimate atoms of matter have never been obtained, their *absolute weight* cannot be determined. The numbers which are given in the TABLE OF ELEMENTS merely express the *relative* weights of the atoms; these numbers being obtained by observing what weight of one element will replace a certain weight of some other element. Thus, experiments have shown that 39 pounds of potassium, or 16 pounds of sulphur, are required to replace one pound of hydrogen. The atomic theory explains these facts, by supposing that one atom of potassium, or one atom of sulphur, replaces one atom of hydrogen, and if we assume that the atom of hydrogen weighs *one*, it follows as a necessary consequence that the atom of potassium must weigh *thirty-nine*, and the atom of sulphur *sixteen;* and thus by taking some one element as the standard of comparison, the relative weights of all the other elements can be determined. Hydrogen has been made the standard in the Table of elementary bodies. The number attached to each element in the Table may, therefore, be called either its *combining proportion*, its *equivalent*, or its *atomic weight*.

140. The figures under the head "atomic weights," in the TABLE OF ELEMENTS, express the quantities by weight of the different elements which unite with one part of hydrogen, or with eight parts of oxygen; they are also the simplest proportions in which the elements can unite with each other. To show how to make use of these numbers, and how useful they are, we will give a few examples and afterwards some exercises.

141. EXAMPLES.—If we desired to know how much potassium could combine with 8 of oxygen, to form the compound substance potash, we refer to the Table of Elements, and we find that 39 stands opposite potassium: this, therefore, is the quantity of that element which will combine with every 8 parts of oxygen; and 47 parts of the compound (potash) will be formed from every 39

parts of potassium and every 8 parts of oxygen. If we desired to know how much bromine could combine with 1 part of hydrogen, we refer to the table, and we find that 80 stands opposite bromine: this, then, will be the quantity which will combine with every 1 part of hydrogen to form the compound hydrobromic acid; and 81 parts of the compound will be formed from every 80 parts of bromine and every 1 part of hydrogen. As 39 of potassium combine with 8 of oxygen, and 80 of bromine combine with 1 of hydrogen, potassium and bromine will combine, if they can enter into union, which they can, in the proportion of 39 of potassium to 80 of bromine. But let us suppose that potassium and oxygen were united, and we desired to know how much sulphur would be required to displace and take the place of the oxygen; on referring to the table we should find 16 opposite sulphur: therefore 16 of sulphur would be required to replace every 8 parts of oxygen in combination with potassium; but it would not only be the quantity to replace every 8 of oxygen when in combination with potassium; but it would be the quantity to replace 8 of oxygen, with whatever element the oxygen might be united. Let us suppose that bromine and hydrogen were united together, and we desired to know what quantity of chlorine would be required to replace every 80 parts of bromine; we refer to the table, and we find opposite chlorine the number 35·5: this, then, is the quantity which replaces 80 of bromine, not only when the bromine is united with hydrogen, but with whatever element it may be united.

EXERCISES.

128. How much zinc will combine with 8 parts of oxygen, and how many parts of the compound (oxide of zinc) will be formed?

129. How much hydrogen will combine with 16 parts of oxygen, and how many parts of water will be formed?

130. How many parts of potassium will combine with 35·5 of chlorine, and how many parts of the compound (chloride of potassium) will be formed?

131. How many parts of lead will combine with 48 of oxygen, and how many parts of the compound (protoxide of lead) will be formed?

132. How many parts of lead will combine with 48 of sulphur, and how many parts of the compound (sulphide of lead) will be formed?

133. In 9 parts of the compound $H\,O$, what quantity of hydrogen is there, and what quantity of potassium will replace it?

134. In 28 parts of the compound $Ca\,O$, what quantity of oxygen is there, and what quantity of sulphur will replace it?

135. In 20 parts of the compound $Mg\,O$, what quantity of oxygen is there, and what quantity of chlorine will replace it?

136. Oxygen and potassium unite, in the proportion of 8 of the former element to 39 of the latter, to form 47 parts of potash. What quantity of oxygen is contained in 100 parts of potash?

137. Bromine and hydrogen unite, in the proportion of 80 of the former element to 1 of the latter, to form 81 parts of hydrobromic acid. How much bromine is contained in 150 parts of hydrobromic acid?

142. *Multiple Proportions.*—Compound substances, differing in their elementary constitution, will obviously possess different properties, but a difference in the *properties* of compound substances does not always arise from a difference in their *elementary constitution;* for example, the native loadstone, and the common rust of iron, are each composed of the elements oxygen and iron, yet they possess very different properties, owing to the different proportions in which the elements are united in the two substances,—loadstone containing, for every 21 pounds of iron, 8 pounds of oxygen, whilst rust contains, for the same amount of iron, 9 pounds of oxygen. The active medicine, calomel, and the deadly poison, corrosive sublimate, are each composed of the elements mercury and chlorine, but in different proportions; calomel containing, for every 35½ pounds of chlorine, 200 pounds of mercury; whilst the corrosive sublimate contains, for the same amount of metalloid, only 100 pounds of metal. This difference in the *properties* of two compounds having the *same elementary constitution,* is due to the fact already stated, that an element may combine with another element in more proportions than one, these different proportions giving rise to as many different compounds,

all distinct in properties, although the elementary constitution of each is the same. This is called the law of "*multiple proportions*," and may be thus expressed: When a body is capable of combining with another body in several proportions, these proportions bear a simple relation to each other. When one body, A, unites with another body, B, in two or more quantities, the quantities of the latter, united with the same quantity of the former, bear to each other proportions which may be represented by one or other of two series :—

1st Series. A unites with 1, 2, 3, 4, 5, &c., atoms of B. The following compounds exemplify this series :—

	A			B	
Carbonic oxide	Carbon	6	...	Oxygen	8 = 8 × 1
Carbonic acid................	Ditto	6	...	Ditto	16 = 8 × 2
Nitrous oxide	Nitrogen	14	...	Ditto	8 = 8 × 1
Nitric oxide	Ditto	14	...	Ditto	16 = 8 × 2
Hyponitrous acid.........	Ditto	14	...	Ditto	24 = 8 × 3
Nitrous acid	Ditto	14	...	Ditto	32 = 8 × 4
Nitric acid	Ditto	14	...	Ditto	40 = 8 × 5

143. This series admits of an easy and satisfactory explanation by the atomic theory; for if we assume, in accordance with that theory, that carbonic oxide is composed of one atom of carbon, and one atom of oxygen, the weight of the former (taking hydrogen as unity) being 6, and the latter 8, it follows that carbonic acid is composed of one atom of carbon = 6, and two atoms of oxygen = 16. The fact of 14 parts of nitrogen combining respectively with 8, 16, 24, 32, and 40 parts of oxygen, is explained in the same way, viz., that the weight of an atom of nitrogen is to an atom of oxygen as 14 : 8, therefore, that 1 atom of nitrogen = 14 is combined in nitrous oxide with 1 atom of oxygen = 8; in nitric oxide with 2 atoms of oxygen = 16; in hyponitrous acid with 3 atoms of oxygen = 24; in nitrous acid with 4 atoms of oxygen = 32; and in nitric acid with 5 atoms of oxygen = 40.

EXERCISES.

138. Every 100 parts of a compound of sulphur and oxygen (sulphurous acid) are composed of 50 parts of sulphur and 50 parts of oxygen. How much oxygen is united with 16 (weight of one atom) of sulphur? and how many atoms of oxygen is it equal to?

139. Every 100 parts of a compound of sulphur and

oxygen (sulphuric acid) are composed of 40 parts of sulphur and 60 parts of oxygen. How much oxygen is united with 16 (weight of one atom) of sulphur? and how many atoms of oxygen is it equal to?

140. Every 100 parts of a compound of phosphorus and oxygen (phosphorous acid) are composed of 56·36 parts of phosphorus and 43·64 parts of oxygen. How much oxygen is united with 31 (weight of one atom) of phosphorus? and how many atoms of oxygen is it equal to?

141. Every 100 parts of a compound of phosphorus and oxygen (phosphoric acid) are composed of 43·66 parts of phosphorus and 56·44 parts of oxygen. How much oxygen is united with 31 (weight of one atom) of phosphorus? and how many atoms of oxygen is it equal to?

142. Every 100 parts of calomel are composed of 84·96 parts of mercury and 15·04 parts of chlorine; and every 100 parts of corrosive sublimate are composed of 73·86 parts of mercury and 26·14 parts of chlorine. What quantity of mercury is combined with 35·5 (weight of one atom) of chlorine in the calomel and the corrosive sublimate? and how many atoms of mercury is it equal to in the two compounds?

144. If hydrogen be made the standard (139), "the definition of a chemical equivalent or combining proportion becomes as follows:—*The combining proportion of a simple substance represents the quantity of that substance which unites with eight parts of oxygen to form a protoxide.*"*

The second series is somewhat more intricate.

2nd Series. A unites with 1, 1¼, 1⅓, 1½, 2½, &c., atoms of B.

The following compounds exemplify this series:—

	A			B	
Protoxide of Iron	Iron	28	...	Oxygen	8 = 8 × 1
Magnetic Oxide of Iron......	Ditto	28	...	Ditto	10 = 8 × 1¼
Magnetic Oxide of Iron......	Ditto	28	...	Ditto	10·66 = 8 × 1⅓
Sesquioxide of Iron	Ditto	28	...	Ditto	12 = 8 × 1½
Hyposulphurous Acid	Sulphur	16	...	Ditto	8 = 8 × 1
Hyposulphuric Acid	Ditto	16	...	Ditto	20 = 8 × 2½

145. When the different quantities of B, which can unite with the combining proportion of A, are multiples by *whole numbers* of the combining proportion of B, this

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* The term protoxide is explained in par. 160.

arises from 1 atom of A uniting with 1, 2, 3, 4, 5, &c., atoms of B; this is exemplified by the compounds in the first series.

146. When the different quantities of B, which can unite with the combining proportion of A, are multiples by *mixed numbers* of the combining proportion of B, this arises from 2 or more atoms of A combining with 3 or more atoms of B; this is exemplified by the compounds in the second series. As 28 of iron unites with 8 of oxygen to form protoxide of iron, 28 must be the combining proportion of iron, and we see that 10 and 10·66 parts of oxygen unite with 28 parts of iron in the magnetic oxides, and 12 parts of oxygen with 28 of iron in the sesquioxide; if 8, the combining proportion of oxygen, be multiplied by the *mixed numbers* $1\frac{1}{4}$, $1\frac{1}{3}$, $1\frac{1}{2}$, the products will be 10, 10·66, and 12. As atoms are conceived to be the smallest particles of matter, they do not admit of division, therefore quarter or half atoms are inadmissible. If, therefore, we assume that protoxide of iron is composed of 1 atom of iron to 1 atom of oxygen (the weight of an atom of the metal being to an atom of the metalloid as 28 : 8), the magnetic oxides cannot be composed of 1 atom of iron and $1\frac{1}{4}$ and $1\frac{1}{3}$ atoms of oxygen, neither can the sesquioxide be composed of 1 atom of the metal and $1\frac{1}{2}$ atoms of oxygen, because these proportions are inconsistent with the supposition on which the atomic theory is based; these and like compounds must, therefore, be composed of 2 or more atoms of A united with 3 or more atoms of B. Before we describe the method for ascertaining the *rational* proportion in which substances are united, we must direct the student's attention to the most frequent proportions in which two elements unite together. Representing, as we have done in the examples, the constituents of a binary compound (a compound composed of two elements) by A and B, the last being the oxygen or electro-negative* constituent, "the most frequent combinations are A + B, A + 2 B, A + 3 B, and A + 5 B. The combination of 2 A + 3 B, is not unfrequent, but 2 A + B, A + 4 B, A + 7 B, 2 A + 2 B, or 2 A + 5 B, are of comparatively rare occurrence. Combination between

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* The term electro-negative the student will find explained in a future lesson.

two elements is not known to occur in more complicated ratios than the preceding, if the compounds of carbon and hydrogen be excepted, which are numerous, and exhibit great diversity of composition, like the compounds of organic chemistry generally, to which they properly belong."—*Graham.*

147. The method for finding the rational proportion of substances united in complex proportions must now be explained to the student. An atom, as we have stated before, is considered to be a particle of matter so small that it is incapable of division; therefore, when we find, by analysis, the elements of a compound united in the proportion by weight of 1 atom of A to $1\frac{1}{2}$, or $2\frac{1}{2}$, or $3\frac{1}{2}$ atoms of B, as these proportions are inconsistent with the supposition on which the atomic theory is based, we get rid of the fractions by doubling both numbers; thus, 2 atoms of A to 3, or 5, or 7 atoms of B, the proportions by weight of the elements, still remain the same, whilst the absurdity of dividing an atom is avoided. When the elements are found to be in the proportion of 1 atom of A to $1\frac{1}{4}$ atoms of B, this is in the proportion of 4 atoms of A to 5 atoms of B; if, therefore, we multiply the 1 atom of A and $1\frac{1}{4}$ atoms of B by 4, we obtain their true atomic proportions: in the same way, if we find 1 atom of A united with $1\frac{1}{3}$ atoms of B, this is in the proportion of 3 atoms of A to 4 atoms of B; if, therefore, we multiply the 1 atom of A and the $1\frac{1}{3}$ atoms of B by 3, we obtain their true atomic proportions. The correct atomic proportions of elements united in complex proportions are obtained by multiplying the quantities of A and B by the denominator of the fraction; find by this rule the atomic proportions in the following exercises :—

EXERCISES.

143. A compound of manganese and oxygen contains these elements in the following proportions:—27·6 of manganese and 12 of oxygen; find the atomic proportions.

144. A compound of manganese and oxygen contains these elements in the following proportions :—27·6 of manganese and 10 of oxygen; find the atomic proportions.

145. A compound of manganese and oxygen contains these elements in the following proportions:—27·6 of manganese and 10·66 of oxygen; find the atomic proportions.

146. A compound of lead and oxygen contains these elements in the following proportions:—103·7 of lead and 12 of oxygen; find the atomic proportions.

147. A compound of lead and oxygen contains these elements in the following proportions:—103·7 of lead and 10·66 of oxygen; find the atomic proportions.

148. It has been proved by numerous experiments that the atomic weight of any compound is equal to the sum of the atomic weights of the elements which compose it; for a compound atom must weigh as much as the individual atoms of the elements comprising it taken together. Ex.—1 atom of hydrogen = 1, and 1 atom of oxygen = 8, and they form, when united, 1 atom of water; therefore the atomic weight of 1 atom of water must be 9, because $1 + 8 = 9$; 2 atoms of iron = 56, and 3 atoms of oxygen = 24, and they form, when united, 1 atom of sesquioxide of iron, therefore the atomic weight of one atom of sesquioxide of iron must be 80, because $56 + 24 = 80$.

149. The laws of reciprocal and multiple proportions apply to the combination of compound bodies as well as to the elementary ones; for the former, as well as the latter, frequently unite in more proportions than one. The answers to the following exercises must be written out by each student.

EXERCISES.

148. The student ought to write out as complete an answer as he possibly can to the following question:—How does chemical affinity differ from the attraction of cohesion?

149. How many modes are there of forming chemical compounds?

CHAPTER V.

CHEMICAL NOTATION* AND NOMENCLATURE.

Advantages which signs possess over words. The signs used in chemistry. Rules for naming chemical compounds.

150. Every one is aware of the advantages which signs possess over words in arithmetic,—they are equally useful and indispensable in chemistry; and he who would be in the least degree acquainted with our science, must understand these symbolical expressions.

151. Chemists designate the elements, and at the same time their combining quantities, by symbols or signs. The symbol O signifies not merely the element oxygen, but also 1 atom, or 8 parts by weight, of that element; the symbol H signifies not merely the element hydrogen, but also 1 atom, or 1 part by weight, of that element. The symbol H O signifies not merely the compound body *water*, but 1 atom, or 9 parts by weight, of that compound; this symbol further indicates that this compound atom is made up of 1 atom, or 1 part by weight, of hydrogen, and 1 atom, or 8 parts by weight, of oxygen. The symbol Fe O represents 1 atom, or 36 parts by weight, of the compound body *oxide of iron;* the symbol further shows that this compound atom consists of 1 atom, or 28 parts by weight, of iron, and 1 atom, or 8 parts by weight, of oxygen.

EXERCISES.

150. What elements do the following symbols stand for? and how many atoms, and how many parts by weight, do the symbols signify?

Ba, Si, Pt, As, Cu, Mn, Ag, Au, Cd, Co, Ni, B.

151. What compounds do the following symbols stand for? and how many atoms, and how many parts by weight, do the symbols signify? Name also the constituents of each compound.

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* "The learner may be here informed, that the particular marks or symbols used in any science,—as, for instance, the *notes* in music, and the characters or symbols 1, 2, 3, &c., in arithmetic,—constitute the *notation* of that science."

BaO, SrO, CaO, MgO, HO, CoO, NiO, ZnO, MnO, AgO, CuO, CdO.

152. Figures require to be added to the symbol of a compound body when either of its elements, or both, are present in more proportions than one. The use of the figures in connection with the symbols can be rendered more intelligible, perhaps, if we employ our former illustration; the words "TO" and "TOO" differ in their orthography, inasmuch as the latter word has one of the letters repeated. From habit we look upon this way of repeating a letter as the only rational one, yet it might be rendered equally plain and efficient, I think, if instead of repeating the letter, we were to place the figure 2 after it in the following manner, "TO_2." We do adopt this method in chemistry for describing how many proportions of either element (if any of them is present in more proportions than one) are present in a compound. Thus, carbonic acid is composed of one atom, or 6 parts by weight, of carbon, and two atoms, or 16 parts by weight, of oxygen; instead of representing the symbol of this compound in this manner, COO, we indicate the two equivalents of oxygen thus, CO_2. Sesquioxide of iron is composed of two atoms, or 56 parts by weight, of iron, and three atoms, or 24 parts by weight, of oxygen; instead of representing the symbol of this compound in this manner, $FeFe\ OOO$, we indicate the two equivalents of iron and the three of oxygen thus, Fe_2O_3. The preceding symbols illustrate the following rule:—When a compound substance contains *more than one* equivalent of any of its elements, a *small* figure indicating the number of equivalents is placed on the *right* hand of the symbol of that element, and applies to that one element of the compound *exclusively*. The figure must be placed either *above* or *below* the line—never *upon* it: it is more usual to place it below.

EXERCISE.

152. State the number of atoms of each element in one atom of the following compounds, and give the combining proportion of each compound:—

AsO_3, AsO_5, PtO_2, AuO_3, Al_2O_3, MnO_2, Pb_3O_4.

153. When a *large* figure is placed upon the line, it multiplies all the elements on the right hand of it, as far

as the first comma, or the first *plus* sign; if placed before a bracket, it multiplies all within that bracket. Ex.—2 H O signifies 2 atoms of water; 2 atoms of the compound body water are composed of 2 atoms of hydrogen and 2 atoms of oxygen.

EXERCISE.

153. Explain the meaning of the figures attached to the following symbols:—

$2\,Ca\,O$, $3\,Na\,O$, $2\,C\,O_2$, $5\,As\,O_5$.*

154. The compounds produced by a combination of the metalloids with the metals are named in the following way,—the termination *ide* is added to the first syllable, or first few letters, of the name of the metalloid; this forms the first word of the compound, then follows the word *of*, and then the *name* of the *particular metal*. Thus, a compound of oxygen and iron is named ox*ide of* iron; a compound of iodine and zinc is called iod*ide of* zinc; likewise brom*ide* of mercury, chlor*ide* of lead, sulph*ide* of lead, &c.

EXERCISE.

154. Name the following compounds:—

$Ca\,F$, $Ag\,I$, $K\,Br$, $Na\,Cl$, $Co\,S$, $Ni\,Cl$.

155. The following *apparent* exceptions to this rule occur. The compounds of the metals with oxygen, chlorine, bromine, iodine, and fluorine, have for a long period been named in the way just stated. But it is only recently that the compounds of the metals with the remaining metalloids have been named in this way; they were formerly named, and still are by some chemists, in the following way,—the termination of the first word in the compound was *ret*, as sulphu*ret of* iron, phosphu*ret of* calcium, &c.

EXERCISE.

155. Name the following compounds, and if they are named in two ways, give both names:—

$Pb\,S$, $Ca\,Cl$, $Ba\,P$, $Ni\,N$, $Fe\,C$, $Fe\,Si$.

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* The comma, the plus sign, and bracketting, are omitted here. They are fully explained in the chapter on the construction of chemical formulæ.

156. The compounds produced by a combination of metalloids with metalloids, are similarly named, as chlor*ide of* sulphur, sulph*ide of* carbon, for example.

157. The following are exceptions to the rule,—the compounds of oxygen with the other metalloids, hydrogen excepted; and the hydrogen compounds of the metalloids, oxygen excepted. The compounds of oxygen and hydrogen are water (the chemical name of which is protoxide of hydrogen) and peroxide of hydrogen. The rules for naming the compounds of oxygen with the other metalloids will be given in another chapter. The compounds produced by the combination of hydrogen with chlorine, bromine, fluorine, iodine, and sulphur, being acid bodies, the rule for naming them will be given in the chapter on acids. Very recently it has been proposed to name these compounds like the compounds of the metals with the metalloids; thus, the compound of chlorine and hydrogen is, according to this recent nomenclature, called chloride of hydrogen; in the same way, bromide of hydrogen, fluoride of hydrogen, sulphide of hydrogen, iodide of hydrogen. The compounds produced by the combination of hydrogen with the other metalloids were named in the following way,—the termination of the first word in the compound was *ret*, and this mode of naming them still continues, although it has been proposed to substitute the termination *ide* for that of *ret;* they are therefore named in both ways; for instance, the compound produced by hydrogen and phosphorus is called either phosphuret of hydrogen, which is the old name, or phosphide of hydrogen, which is the new name; in the same way, carburetted hydrogen or carbide of hydrogen, &c.

EXERCISE.

156. Name the following compounds; if any of them are named in two ways, give both names :—

HS, HBr, ICl, SCl.

158. The compounds formed by the metals uniting with each other are simply termed alloys; no individual names descriptive of the elements composing them have been invented for this class of compounds. Brass is an alloy of copper and zinc, fusible metal is an alloy of bismuth, tin, and lead. When mercury is one of the constituents,

the compound is termed an amalgam, not an alloy; thus, an amalgam of silver is a combination of silver and mercury; an amalgam of tin is one of tin and mercury.

159. When the metalloids unite with the metals in more proportions than one, certain Latin or Greek prefixes have to be employed to distinguish the different combinations. Let the letter M stand for any metal, and suppose oxygen were to unite with it in the following different proportions:—

$$M_2O,\ M\,O,\ M_2O_3,\ M\,O_2,\ M\,O_3,\ M\,O_4.$$

160. The first, containing one equivalent of oxygen to two of metal, is called the *suboxide;* the term *dinoxide* is employed by some chemists instead of the term suboxide. The second, containing one equivalent of oxygen to one of metal, is called the *protoxide* (*protos,* first); this prefix is not applied in the sense of the first or lowest oxide, but is applied to oxides containing one equivalent of oxygen to one of metal. The third would be called the *sesquioxide* (*sesqui,* one and a half) from its containing one and a-half of oxygen to one of metal. The fourth would be called the *binoxide* (*bis,* twice); some chemical writers employ the term deutoxide in place of the term binoxide. The fifth, if a basic or an indifferent body, would be called the *teroxide* (*ter,* three). The sixth, if a basic or an indifferent body, would be called the *quadroxide* (*quadro,* four).

161. Oxides of metals containing three or four proportions of oxygen to one of metal, generally possess acid properties, and are then named after an entirely different rule, according to which the prefix and the term oxide is dispensed with. Thus, $Fe\,O_3$ is an acid; instead, therefore, of calling it teroxide of iron, as would be the case if it were a basic or an indifferent body, it is called *ferric acid;* $Mn\,O_3$ is in like manner called *manganic acid.* The nomenclature of acids will be attended to in another chapter.

162. The prefix *protos* is frequently dispensed with; the oxide $M\,O$ is called simply the oxide, instead of the protoxide; this is especially the case if this oxide is the only known combination of oxygen with that particular metal. The learner must remember, then, that if he hears used, or meets with in chemical writings, the expression, the oxide of this or that metal, it is the protoxide of that

metal, whatever metal it may be. The highest oxide of a metal, not possessing acid properties, is frequently called the peroxide; thus, Fe_2O_3, sesquioxide of iron, is frequently called the peroxide of iron.

163. The same prefixes are applied to distinguish between the different combinations of the other metalloids with the metals, as are applied to the different oxides. Thus, $M\,Cl$ would be called the *protochloride;* M_2Cl_3, the *sesquichloride;* $M\,S_2$, the *bisulphide;* $M\,I_3$, the *teriodide;* $M\,Br_4$, the *quadrobromide.*

164. When the metalloids unite with each other in more proportions than one, *the same Latin or Greek prefixes* have to be employed to distinguish the different combinations, as are employed to distinguish the similar combinations of the metalloids with the metals. The only exception to this rule are the different combinations of oxygen with the other metalloids (hydrogen excepted), for these oxides, being acid bodies, are not so named.*

EXERCISE.

157. Give the names of the following compounds, attaching the proper prefixes:—Fe_2Cl_3 Cu_2I, $C\,S_2$, $I\,Cl_3$, $K\,S_5$, $Ba\,S_4$, $P\,Cl_3$, $P\,Cl_5$, S_2Cl, $Fe\,S_2$.

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* Chapters 14, 15, 16, and 17 are to be studied next. All the exercises must be written out by each member of the class, and the portions to be committed to memory must not be neglected. When these have been completed, the learner must pass on to chapter 21, commencing at the paragraph on Solution.

CHAPTER VI.

ON THE DECOMPOSITION OF SUBSTANCES—SINGLE ELECTIVE AFFINITY—EXERCISES—DOUBLE ELECTIVE AFFINITY—EXERCISES.

SINGLE ELECTIVE AFFINITY. *Substances appear to exercise a choice in combining. Decomposition of binary compounds. Exercises. Heat evolved varies with the combining substances. On the decomposition of ternary compounds. Exercises. Diffusion of gases and vapours. Important part played by this property in the great economy of nature. Double elective affinity. Peculiarity of double elective affinity. Exercises. Formation of compounds by substitution. Order of affinity.*

165. If the learner remembers what has been stated with regard to all chemical experiments and processes—that they are either experiments of combination (synthetical experiments) or experiments of decomposition (analytical experiments), or that they are a combination of the two; that every chemical experiment he witnesses or performs is either synthetical or analytical, or is both synthetical and analytical, he will naturally conclude, that as the previous experimental lessons were on combination, the subject of the present lesson must be on decomposition. This is a correct inference, for the different ways of decomposing substances are discussed in this and several succeeding lessons. We will approach the subject by making a few suggestive remarks. We have seen that substances chemically combine. Now the force which causes them to unite, of course keeps them, after they are united, in that state: therefore, to decompose a compound, that is, to separate it into its constituents, the chemical force, which first caused its constituents to unite, and then kept them united, must be superseded or overcome for the constituents to separate, or, in other words, for the decomposition of the compound to take place. In this lesson we shall show that the affinity of one body for another can be overcome by the stronger affinity which another body possesses for that substance; there must, therefore, be combination as well as decomposition in this and in all cases where affinity is the decomposing agent. The

chemical force not only causes substances to unite in certain definite proportions by weight, but it also causes them to exercise a certain choice, as it were, in combining. Thus, if copper, iron, and potassium were equally presented, so far as physical circumstances are concerned, to the action of oxygen, the oxygen, although it would unite eventually, if in sufficient quantity, with all the three metals, would not unite with all three at once, but would first unite with the potassium; and until every particle of this metal had become united with its proper quantity of oxygen, not a single particle of the metalloid would combine with the other two metals; as soon as the whole of the potassium was oxidized, the oxygen would begin to combine with the iron; and when the whole of the iron had become united with its proper quantity of oxygen, the oxygen would then begin, and not before, to unite with the copper. This example teaches us that the oxygen possesses a greater preference for one element than another, and this is the case with all the other elements; indeed, it is the case with all bodies capable of entering into chemical union, whether elementary or compound.

166. The following general rule embodies the preceding statements: When any elementary or compound body is brought into contact with several others, it will invariably unite with one in preference to the rest; but further to satisfy its affinity, it will not only unite with that one when *uncombined*, but will even disunite it, when *combined*, from its combinations. Thus, if three substances, A, B, and C, were brought together, A and B might each have a tendency to combine with C; but they would not possess this power in an equal degree; the one, therefore, having the strongest affinity, and supposing that were A, would combine with C, forming the compound A C, whilst B would remain uncombined. But supposing that B and C were already combined together, and that A, having a greater affinity for C than what B has, was brought into contact with the compound B C; B C would be decomposed by A, for this body would take away C, and would unite with it, forming a new compound, A C, whilst B, one of the constituents of the original compound, would be set free. Ex.—If iodine be brought into contact with sulphide of hydrogen, it decomposes that compound by uniting with the hydrogen and forming with it iodide of hydrogen, the sulphur being

set free ; bromine decomposes iodide of hydrogen by combining with the hydrogen and setting the iodine free, a new compound, bromide of hydrogen, being formed ; and chlorine decomposes bromide of hydrogen by taking away the hydrogen and uniting with it, a new compound, chloride of hydrogen, being produced. Here is a series of decompositions, depending on the relative power of the affinities of chlorine, bromine, iodine, and sulphur for hydrogen.

167. Chemical affinity is therefore *elective*, as it causes substances to manifest a choice, as it were, for *one* of several others, uniting with that *one* by preference, and to the exclusion of the rest.

168. Elective affinity is either *single* or *double*. It is called single, when a substance added to a compound decomposes it, uniting with one of the elements * of the compound, and setting the other free. The decomposition of sulphide of hydrogen by iodine is an example of single elective affinity.

169. In all cases of single elective affinity, three substances only can be present, and two affinities come into play. The example just quoted may be taken as an illustration ; when iodine is added to sulphide of hydrogen, there are present three elements, viz., iodine, sulphur, and hydrogen, and there are two affinities brought into play, viz., the affinity of the sulphur for the hydrogen, which is termed the *quiescent* affinity, and the affinity of the iodine for the hydrogen, which is termed the *divellent* affinity.

EXERCISES ON SINGLE ELECTIVE AFFINITY.

158. Dissolve some iodide of potassium in water (about a drachm in half a pint) ; add to the solution a small quantity of chlorine water, obtained by passing chlorine gas through water. The chlorine will unite with the potassium, forming with it chloride of potassium ; the iodine, being set free, will impart to the liquid a dark violet tint.

159. Place in a solution of sulphate of copper (about a quarter of an ounce of the copper salt in half a pint of

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* The term element, as here employed, may signify either a proximate or remote element.

water) a piece of metallic iron; the iron will decompose the oxide of copper by taking away the oxygen, forming with it oxide of iron; the metallic copper, set free, will be precipitated on the metallic iron which remains.

160. Throw a fragment of potassium into water contained in a plate; the water will be instantly decomposed by the potassium removing its oxygen, forming with it potash; the intense heat evolved by the combination will inflame the liberated hydrogen. Test the water after the operation is over with *blue* and then *red* litmus paper.

161. Introduce a burning taper (Fig. 8) into a vessel filled with chlorine gas; the chlorine will combine with the hydrogen of the tallow or wax and form with it hydrochloric acid, the carbon will be set free in a finely divided state.

162. The indifference of chlorine for carbon, and its great affinity for hydrogen, may be still more strikingly illustrated by moistening a piece of blotting paper with spirits of turpentine (C_5H_4) and introducing it into a bottle or jar filled with chlorine gas. The turpentine is decomposed; the hydrogen and chlorine combine together and form hydrochloric acid, the formation of which is accompanied with flame, the carbon being liberated in the form of a dense cloud of soot.

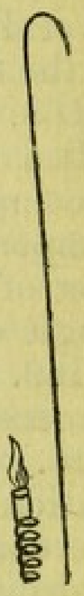

Fig. 8.

163. Add some dilute hydrochloric acid (one part of concentrated acid to four parts of water) to some fragments of zinc; the metal will decompose the acid by uniting with the chlorine, forming with it chloride of zinc, hydrogen being set free.

164. Prepare some sulphide of hydrogen by adding to some fragments of sulphide of iron, placed in an appropriate apparatus (Fig. 21), dilute hydrochloric acid. The sulphide of hydrogen is liberated in its gaseous state, and must be collected in a jar over water; subsequently pass a little chlorine gas into the jar. The chlorine will decompose the compound gas by combining with the hydrogen, forming with it hydrochloric acid; the sulphur will be deposited, and the water will rise in the jar because the hydrochloric acid gas is soluble in that liquid.

165. Prepare some nitrous oxide gas (NO, laughing gas) by placing some solid nitrate of ammonia in a retort, and applying heat; the nitrate is decomposed by heat into this

gas and water. The gas may be collected in jars at the pneumatic trough. A proper regulation of the heat, so as to avoid a tumultuous disengagement of the gas, is the only precaution required in preparing this gaseous compound.

166. Introduce, by means of the deflagrating spoon, a fragment of lighted phosphorus into a jar filled with nitrous oxide; the gas will be decomposed, not by the mere affinity of the phosphorus for the oxygen—this is insufficient—but by the high temperature of the burning phosphorus, and the affinity of the phosphorus for the oxygen; phosphoric acid is consequently formed, and nitrogen set free.

167. Introduce, by means of the spoon, some burning sulphur into a jar of nitrous oxide; the gas will be decomposed by the high temperature of the burning sulphur, and the affinity of the sulphur for the oxygen; sulphurous acid is consequently produced, and nitrogen set free. The sulphur burns in this gas with a beautiful rose-coloured flame.

168. Add to a solution of nitrate of silver a globule of mercury; metallic silver will be thrown down, whilst an equivalent of mercury will enter into its place. Dip into the solution, which now contains nitrate of mercury, a slip of copper, which will dissolve and displace the mercury; precipitate the copper from the solution by lead, and the lead from the solution by zinc. This experiment, in order to be shown during a lecture, had better be divided into the four following experiments:—

1st.—To a solution of nitrate of silver (to form the solution dissolve 1 drachm of the silver salt in 4 or 5 ounces of water) add a globule of mercury; metallic silver will be thrown down, whilst an equivalent of mercury will enter into its place.

2nd.—To a solution of pernitrate of mercury, of the same strength as the silver solution, add a slip of copper; metallic mercury will be thrown down, whilst an equivalent of copper will enter into its place.

3rd.—To a solution of nitrate of copper (half an ounce of the salt dissolved in half a pint of water) add a slip of metallic lead; an equivalent of lead will dissolve and precipitate metallic copper.

4th.—To a solution of nitrate of lead, of the same strength as the copper salt, add a slip of zinc; an equivalent of zinc will dissolve and precipitate the lead in the metallic state.

In these four experiments we have an illustration of the different degrees of affinity which oxygen possesses for metals. For it was the oxide of silver that was decomposed by the metallic mercury, the latter metal taking away the oxygen from the silver, oxide of mercury being formed, and metallic silver being set free; and so with regard to the other three experiments.

169. Throw a fragment of sodium into a plate of water; it will roll along the surface of the water with great rapidity, decomposing the water as potassium does; but the hydrogen set free does not, as in the case of the potassium experiment, take fire, unless a large piece of sodium is employed, and it is kept in one place.

170. Repeat the experiment, by using warm, instead of cold, water, the hydrogen will then take fire.

170. It was stated in the first experimental lesson, that solid substances are necessary for the evolution of light, yet in Expts. 161 and 162 of the present lesson, we saw that a large quantity of carbon was set free, though the light produced was very feeble. This is owing to the heat evolved by the combination of the chlorine with the hydrogen being insufficient to render the carbon incandescent; consequently, one of the conditions stated in the previous lesson is wanting in these two cases; for the brightness or illuminating power of flame depends not only on the presence of solid particles, which may act as radiating points, but also on the degree of heat which is evolved by the combining substances. And that the heat evolved by chemical combination is not the same in quantity or degree in all cases, but varies with the combining substances, is well illustrated by the decomposition of water by potassium and sodium; when it is decomposed by the first of these metals, the heat evolved by the combination of the potassium with the oxygen is sufficient to cause the liberated hydrogen to inflame (combine with the oxygen of the air), but the heat evolved by the combination of the sodium with the oxygen is not sufficient to cause the hydrogen to take fire.

171. Oxygen salts, and similar ternary compounds, are decomposed by compound bodies in the same way that binary compounds are by elementary bodies, viz., by bringing into contact with them some other compound which has a greater affinity for one of the compounds than is possessed by that with which it is already united; decomposition and combination are, in consequence, effected. The student will see by the following exercise that salts are decomposed by adding to them either acids or bases, provided the acids or bases added, have stronger affinities than the acids or bases in the existing compounds, and that, according as acids or bases are added, so acids or bases are set free. Thus, ammonia is liberated from its salts, on the addition of a stronger base: and carbonic acid is liberated from its combinations, on the addition of a stronger acid. To obtain, then, an acid from any of its salts, you add to the salt a stronger acid; in this way nitric and other acids are obtained in their free state: to obtain a base from any of its salts, you add to the salt a stronger base; in this way ammonia, and other bases, can be obtained.

EXERCISES.

171. Add dilute sulphuric acid (one part of concentrated acid to four of water) to a hot concentrated solution of biborate of soda (half an ounce of the powdered salt boiled with two ounces of water) until the solution become sour to the taste; the sulphuric acid decomposes the soda salt, by uniting with the base and forming with it sulphate of soda, which remains in solution, whilst the greater part of the boracic acid set free, crystallizes out as the solution cools.

172. Add to a solution of nitrate of lead (a quarter of an ounce in four or five ounces of water) a solution of caustic soda: nitrate of soda will be formed, which will remain in solution, whilst oxide of lead will be precipitated.

173. Add some lime water to a hot solution of carbonate of ammonia (half an ounce in four ounces of water); carbonate of lime will be formed, and will be precipitated on account of its insolubility in water, whilst ammonia will be evolved.

174. Add some nitric acid, diluted with twice its bulk

of water, to some fragments of marble (carbonate of lime); nitrate of lime will be formed, and carbonic acid evolved. Perform this experiment in the apparatus (Fig. 21); let the exit tube dip into a dry open glass vessel. When the receiving vessel is filled with the gas, remove the one in which the gas is being liberated, but allow the receiver to remain undisturbed for half an hour or so. When a sufficient time has elapsed, a lighted taper will, if introduced within the vessel, continue to burn, proving that the carbonic acid has escaped, and that common air occupies its place.

172. The escape of the carbonic acid is remarkable, inasmuch as it is half as heavy again as the air which occupies its place. To whatever cause the escape may be due, to the same cause must likewise be attributed the pervading uniformity in the composition of our atmosphere. For it has been ascertained from numerous experiments, made on specimens of air brought from distances the most remote, and collected under the most dissimilar circumstances, that the different gases composing the atmosphere are present in the same proportions everywhere. "Air has been collected and examined from the summits of Mont Blanc and Chimborazo, from Egypt and from London, from Paris at the level of the Seine, and from a height of near 22,000 feet." The samples of air from these different localities were found to contain the same proportions of oxygen and nitrogen; the carbonic acid and watery vapour were alone found to differ, and these only in a very slight degree. To what cause, then, is this uniformity in the composition of the atmosphere to be ascribed? The earlier chemists, before carbonic acid was discovered to be an integrant constituent, explained it by supposing that the oxygen and nitrogen were chemically combined. But this was not a correct supposition, for it has since been proved in various ways that the gases forming the atmosphere are *merely mixed* and not *chemically combined*. Such being the case, we should naturally suppose, as the earlier philosophers did, that gases with such different densities would separate, just as oil, water, and mercury would separate, after being shaken together, the lightest occupying the highest stratum, the heaviest

the lowest one, and the one with a density intermediate between the other two, forming the middle stratum. That their specific gravities are very different will be seen from the following numbers:—

Gas.	Sp. gravity.
Air	1000
Nitrogen	972
Oxygen	1105
Carbonic acid	1524

173. If gases obeyed in every respect the law of gravitation, their different densities would cause them to separate, when only mixed together. The uniform composition of the atmosphere is a proof, however, that they do not separate when once mixed. And the last experiment partly established the fact, that a heavy gas will ascend and mix with one much lighter, and that a lighter one will descend and mix with one much heavier. This fact will be rendered more apparent by the following experiment.

EXERCISE.

175. Fill two bottles, which are equal in size, one with carbonic acid, the other with hydrogen. Fix into the mouth of one of the bottles, after it is filled, a piece of glass tube, two or three inches long, by means of a perforated cork; fix in the same way the other end of the tube in the other bottle. Arrange the bottles as in Fig. 9 (the one filled with carbonic acid being lowest), and allow them to remain in that position for a couple of hours or more. It will be found, at the end of that time, that the two gases have mixed together; the carbonic acid, although twenty-two times heavier than hydrogen, having ascended into the upper bottle, and the hydrogen having descended into the lower one, until a uniform mixture has been established throughout the entire apparatus. The presence of carbonic acid in both bottles may be shown by pouring lime water into them, which will become milky immediately, owing to the production of carbonate of lime.

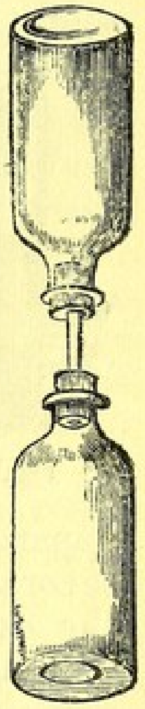

Fig. 9.

174. This penetrating or diffusive property is possessed

by vapours as well as gases; the rapidity with which they diffuse depends upon their different densities, and is therefore unequal; the lighter gases diffusing most rapidly, the heavier more slowly, as will be seen by the following experiment.

EXERCISE.

176. Close one end of a piece of wide glass tube, ten or twelve inches in length, and one or two inches in width, with a plug of plaster of Paris, about half an inch thick. This plug, when dry, is permeated with a multitude of minute pores, which are pervious to gases. This tube (called the diffusion tube), when the plug is dry, is to be filled with hydrogen by displacement: to accomplish this, a plate of glass is placed first of all upon the exterior of the plug; a tube, connected with a bladder, gas holder, or some vessel filled with hydrogen, is then introduced into the diffusion tube until it almost touches the plug; hydrogen is by this means conveyed from the vessel containing it into the tube, and of course it displaces the air contained in the diffusion tube. When the tube is entirely and solely filled with hydrogen, close the mouth of it with a piece of glass, and then transfer it with its mouth downwards into a vessel filled with coloured water, subsequently removing both plates of glass; the tube in its proper position is shown in Fig. 10. The hydrogen and external air pass inwards and outwards through the pores in the plug, but as the hydrogen is lighter than the air, it passes out of the tube more rapidly than the air enters, consequently the water rises in the tube. The water rises so rapidly that it is apparent to the eye, and speedily attains a height of several inches above the water in the exterior vessel. If the experiment be reversed, by filling the diffusion tube with air, and surrounding it with an atmosphere of hydrogen, the water in the tube, in this case, is depressed several inches below the level of the water in the exterior vessel, instead of rising several inches above it, because a larger volume of the hydrogen (the lighter gas) passes inwards than of air outwards.

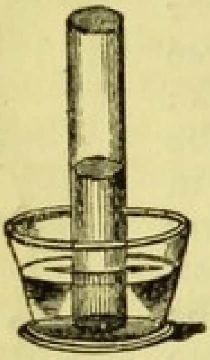

Fig. 10.

175. "The following facts will enable the learner to

form some idea of the unspeakably important part played by this property or quality, inherent in the constitution of all gaseous substances, in the great economy of nature. There are processes constantly going on around us in which gaseous matters and vapours, prejudicial in the highest degree to animal life, are unceasingly evolved; the function of respiration, the burning of wood and coal for fuel, are attended with the conversion of the free oxygen of the air into carbonic acid. By the putrefactive decomposition of animal and vegetable substances, poisonous principles, far worse than carbonic acid, are given off into the air. The volcanic vents, so numerous in both eastern and western hemispheres, discharge, as is well known, almost inconceivable quantities of noxious gas, chiefly carbonic acid, even when all traces of heat have disappeared, and no active eruption of lava has occurred within the historical period, as in the case of the ancient volcanoes of the Rhine."

176. "The chief characteristic of the present condition of society, the crowding together of multitudes of men into towns and cities, and their employment in manufactures of various kinds, in very many of which gases and exhalations of the worst description are copiously evolved; and even without this, the mere aggregation of such a mass of human beings, each one unconsciously consuming the air of heaven and replacing it by poison, would speedily put a stop to life altogether. If the heavy carbonic acid, so copiously generated from these many sources, were simply to obey the natural law of gravitation, and spread itself out upon the surface in such localities, a state of things would often arise only now to be paralleled by the condition of the hold of a slaver."

177. "The oxygen and nitrogen, too, instead of being uniformly mixed throughout the whole atmosphere, as at present, having the energetic chemical powers of the one modified and softened—diluted, as it were—by the other, would form two immense layers of unequal thickness, arranged in the order of their densities, the oxygen below, and the nitrogen above. In such an order of things as this, animal existence would be out of the question, an atmosphere of pure oxygen is as fatal to life as one destitute of that element,—all the phenomena of combustion and oxidation generally would be exalted ten-fold in

power and energy; in fact, the present arrangement of nature could not be maintained in its integrity a single hour."

178. "The equable diffusion of vapour of water through the atmosphere is no less important than that of the carbonic acid. In many warm countries, during a great part of the year, rain seldom or never falls, and it is only from the copious dews deposited in the night that vegetables derive the supply of moisture required for their growth, and to sustain them, by the cooling effects of evaporation, from the scorching rays of the noon-day sun. Were the invisible elastic steam disengaged from the surface of the sea, or other large bodies of water, not subject to the diffusive law in question, it is probable that other and very different phenomena would be observed."

179. "To take another case, not perhaps so striking to the casual observer, but equally important in the eyes of the attentive student. In respiration, the object of which is to bring the blood in contact with the oxygen of the air for the purpose of effecting changes hereafter to be described, the lungs are alternately filled and emptied by the mechanism of the respiratory muscles, internal and external, and the air from without thus enabled to find its way into the minute cells which terminate the last ramifications of the bronchial tubes. Here its oxygen is made to act upon the venous blood, while the latter disengages carbonic acid in place of the oxygen absorbed. Now in the act of expiration, even when forced, the lungs are very far from being completely emptied of air, and that which is thrown out is in a great measure derived from the larger tubes and passages; the ultimate cells, in which all the real business is performed, remain filled with vitiated air, which must be displaced, if the function is to be continued, by other means more efficacious than the gentle pressure of the elastic thorax. Hence it is that diffusion comes into play between the oxygen of the *tubes* and the carbonic acid of the *cells;* the latter is speedily removed and replaced by the former, and expelled from the body by the next following expiration."

180. "Such, then, are some of the leading consequences which follow from this one single property of gaseous bodies,—their diffusibility into each other. We have seen how essential this property is to the present order of

nature, and indeed to our very existence; it is not less pleasing to follow its consequences in their more humble office of administering to our happiness and pleasure."

181. "The perfume of flowers, wet with dew or summer rain, the sweet smell of new-made hay, the fragrance of the pine-forest in the early morning, may all be traced to the same cause—namely, the ready diffusibility of the vapours of the volatile bodies upon which their odours depend. These vapours are extremely heavy, and would, if they merely obeyed the ordinary laws of hydrostatics, fall down upon the porous and absorbent earth, instead of spreading abroad to delight the senses and gladden the heart."*

DOUBLE ELECTIVE AFFINITY. *Peculiarity of double decomposition. Exercises. Formation of compounds by substitution. Order of affinity.*

182. Affinity is termed *double elective* when two compounds, on being mixed together, mutually exchange their constituents, the original compounds being decomposed, and two new ones being produced. Let us take the first exercise (Expt. 158), on single elective affinity, to explain, if explanation be necessary, the preceding sentence. In that experiment, we added chlorine to iodide of potassium, the effect of which was that the iodide of potassium was decomposed, the iodine being set free as the potassium left that metalloid and united with the chlorine. Supposing there had been at the same time some element with which the element set free (iodine) would have united, we should have had *two new* compounds *formed*, and *one* compound *decomposed*. But instead of adding free chlorine, suppose we add a chloride—say chloride of mercury—to the iodide of potassium, what would be the result? In this case we should have two compounds decomposed (chloride of mercury, and iodide of potassium), and we should have two new ones formed (iodide of mercury, and chloride of potassium), for the iodine would pass over from the potassium to

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* Fownes' Actonian Prize Essay. (Churchill.)

The exercises in Chapter XVIII. must be written out by the student before double elective affinity is studied.

the mercury, and the chlorine from the mercury to the potassium; this is an example of double elective affinity, or, as it is also termed, "double decomposition." To take one more example, in Expt. 173 we added lime to carbonate of ammonia, and there was formed carbonate of lime, ammonia being set free. Suppose that instead of free lime we had added some lime salt—say, nitrate of lime—the result would have been, that we should have had carbonate of lime formed, as before, and together with it nitrate of ammonia. The two salts decomposed would be *nitrate of lime* and *carbonate of ammonia*, and the two new ones formed would be *carbonate of lime* and *nitrate of ammonia*. The last-mentioned experiment is likewise an example of double decomposition.

183. "The peculiarity of double decomposition is, that by means of it, reactions may occur which could not have been produced by simple affinity, and which, on the contrary, appear to have been produced in opposition to it. Thus, ammonia cannot decompose nitrate of lime; on the contrary, lime will take nitric acid from ammonia; and yet if we mix a solution of nitrate of lime and carbonate of ammonia together, they decompose each other, nitrate of ammonia and carbonate of lime being formed." In fact, in order to understand the cause of such double decomposition, we must take into account not merely the affinity of the ammonia for the nitric acid, but that of the lime for the carbonic acid. Thus, if the affinity of lime for nitric acid be represented by 80, and that of ammonia for nitric acid be represented by 70, the lime will be the stronger, and can, when by itself, expel ammonia; but if the carbonic acid intervene, and the affinity of lime for carbonic acid be 50, and the ammonia for the same acid be 30, then decomposition must occur; for the forces preventing decomposition are the affinities of nitric acid for lime, and of carbonic acid for ammonia, that is, $80 + 30 = 110$; whilst those tending to cause decomposition are the affinities of nitric acid for ammonia, and of carbonic acid for lime, $70 + 50 = 120$: the latter are the more powerful, the constituents of the two salts consequently exchange places."[*]—*Kane.*

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[*] The student must bear in mind that the numbers here employed are perfectly arbitrary, and used merely for the sake of illustration.

EXERCISES.

177. Add a solution of carbonate of soda (prepare the solution in the proportion of one part of the salt to ten of water) to one of sulphate of copper,—carbonate of copper and sulphate of soda will be produced: the former, being insoluble in water, will be precipitated; the latter, being soluble, will remain in solution.

178. Add a solution of chromate of potash (in the proportion of one part of the salt to ten of water) to one of nitrate of lead,—chromate of lead and nitrate of potash will be formed: the former, being insoluble in water, will be precipitated; the latter, being soluble, will remain in solution.

179. Project a small piece of phosphide of calcium into a plate of water; this phosphorus compound and water mutually decompose each other, lime and phosphide of hydrogen being formed: the first, being soluble in water, will remain in solution; the latter, being a gaseous body, will ascend in bubbles to the surface of the water,—as soon as it comes in contact with the air, it will inflame with a slight explosion. After each explosion a beautiful ring of white smoke ascends from the water. The curious phenomenon of "Will-o'-the-wisp," which is sometimes seen in churchyards, and more frequently in soft marshy places, is probably due to the formation of this hydrogen compound of phosphorus. If the phosphide of calcium has not been recently prepared, employ warm water.

180. Add a solution of iodide of potassium to one of nitrate of lead,—iodide of lead and nitrate of potash will be formed: the former, being insoluble in water, will be precipitated; the latter, being soluble in that liquid, will remain in solution.

181. Add a solution of iodide of potassium to one of chloride of mercury,—iodide of mercury and chloride of potassium will be formed: the former, being insoluble in water, will be precipitated; the latter, being soluble, will remain in solution.

182. Fill a tall stoppered glass jar (Fig. 11), or bottle, with binoxide of nitrogen (for its method of preparation see Expt. 21); add a few drops of sulphide of carbon, and afterwards shake the vessel in such a way as to diffuse the carbon compound in the atmosphere of the jar. When

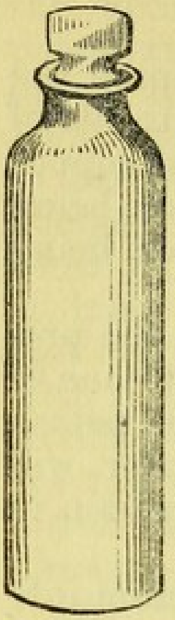

Fig. 11.

this has been done, remove the stopper, and with a lighted taper, which the experimenter must have ready, inflame the gaseous mixture; it will take fire, and be accompanied with a slight explosion. Sulphur and nitrogen will be set free, the former being deposited on the sides of the glass, while carbonic and sulphuric acids will be formed.

184. *Formation of compounds by substitution.* "It is remarkable that compounds are in general more easily formed by substitution, than by the direct union of their constituents; indeed, many compounds can be formed only in that manner. Carbonic acid is not absorbed by anhydrous lime, but readily by the hydrate of lime, the water of which is displaced in the formation of the carbonate. In all cases, likewise, in which hydrogen is evolved during the solution of a metal in a hydrated acid, a simple substitution of the metal for hydrogen occurs.

185. "Combination takes place with the greatest facility of all when *double decomposition* can occur. Thus, carbonate of lime is instantly formed and precipitated, when carbonate of soda is added to nitrate of lime, nitrate of soda being formed at the same time, and remaining in solution. Here a double substitution occurs, lime being substituted for soda in the carbonate, and soda for lime in the nitrate. Such reactions may therefore be truly described as double substitutions as well as double decompositions. They are most commonly observed on mixing two binary compounds or two salts. But reactions of the same nature may occur between compounds of a higher order, such as double salts, and new compounds be thus produced, which cannot be formed by the direct union of their constituents. Thus the two salts, sulphate of zinc and sulphate of soda, when simply dissolved together, at the ordinary temperature, always crystallize apart, and do not combine. But the double sulphate of zinc and soda is formed on mixing strong solutions of sulphate of zinc and bisulphate of soda ($HO, SO_3 + NaO, SO_3$), and separates by crystallization; sulphuric acid with constitutional water ($HO, SO_3 + HO$) being produced at the same time, and remaining in solution. The double

sulphate of lime and soda can be formed artificially only in circumstances which are somewhat similar. It is produced on adding sulphate of soda to acetate of lime, the sulphate of lime, as it then precipitates, carrying down sulphate of soda in the place of constitutional water.

186. "Different hydrates of the same body, such as peroxide of tin, differ sensibly in properties, and afford different compounds with acids, unquestionably because these compounds are formed by substitution. The constant formation of phosphates containing one, two, or three atoms of base, on neutralizing the corresponding hydrates of phosphoric acid with a fixed base, likewise illustrates in a striking manner the derivation of compounds on this principle. Many insoluble substances, such as the earth silica, possess a larger proportion of water, when newly precipitated, than they retain afterwards, and in that state of hydration they may exhibit affinities for certain bodies, which do not appear in other circumstances. Hydrated silica dissolves in water at the moment of its separation from a caustic alkali; and alumina dissolves readily in ammonia, when produced in contact with that substance by the oxidation of aluminum. The usual disposition to enter into combination, which silica and alumina then exhibit, is generally ascribed to their being in the *nascent state;* a body at the moment of its formation and liberation, in consequence of a decomposition, being, it is supposed, in a favourable condition to enter anew into combination. But their degree of hydration in the nascent state may be the real cause of this superior aptitude to combine.

187. "Double decompositions take place without the great evolution of heat which often accompanies the direct combination of two bodies, and with an apparent facility or absence of effort, as if the combinations were just balanced by the decompositions which occur at the same time. It is, perhaps, from this cause that the result of double decomposition is so much affected by circumstances, particularly by the insolubility of one of the compounds."*

188. *Order of affinity.* The elective nature of affinity was noticed by some of the earliest chemists, and they

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* Graham's "Elements of Chemistry," vol. i., 2nd edition.

very naturally concluded that tables might be constructed which would enable one to foretell with accuracy all possible cases of decomposition ; for the purpose of giving more force to the remarks we are about to make, we will contrast the relative affinities which some bases have for hydrochloric acid and for sulphuric acid.

No. I. Hydrochloric Acid.	No. II. Sulphuric Acid.
AgO	BaO
KO	SrO
NaO	KO
BaO	NaO
SrO	CaO
CaO	MgO
MgO	AgO

189. By these tables we see that the base which has the strongest affinity for hydrochloric acid has the weakest affinity for sulphuric acid ; and that the base which has the strongest affinity for sulphuric acid is found but midway among the bases arranged in order of strength for hydrochloric acid. Which column must be taken as representing the true order of affinities ? What principle is there by which these conflicting testimonies of experiment may be brought to correspond ? These questions we will leave unanswered for the present ; and we invite the student's especial attention to the following experimental facts.

190. When a stream of hydrogen is passed over oxide of iron heated to redness, the hydrogen takes away the oxygen from the iron, and the metal is left in its elementary state, whilst the hydrogen unites with the oxygen, and forms with it water. But if water in a state of vapour be brought into contact with metallic iron, strongly ignited, the water is decomposed, the oxygen leaves the hydrogen, and combines with the iron, forming with that metal oxide of iron, whilst the hydrogen is left in its elementary state. To explain these facts by elective affinity, we should, in the 1st experiment, say that hydrogen has a greater affinity than iron has for oxygen ; and in the 2nd experiment, we should say that the affinity of iron is stronger than that of hydrogen for oxygen. It need hardly be remarked that these explanations are contradictory ; and therefore one, if not both, must be incorrect. The affinity

of oxygen for the two elements, hydrogen and iron, must either be *equal* or *unequal;* if equal, the result of both experiments must be determined by modifying circumstances, since neither of these substances ought, in that case, to take oxygen from the other. But if the affinity of oxygen for the two elements is unequal, the decomposition, in one of the experiments, must have been in direct opposition to the tendency of affinity, and it must, therefore, have been produced by other causes, which have overruled the chemical force. To take another example: we noticed, in par. 182, that if carbonate of ammonia in a state of solution be added to nitrate of lime in a state of solution, the two salts will mutually decompose each other, carbonate of lime and nitrate of ammonia being formed. But if nitrate of ammonia and carbonate of lime are mixed in the dry state, and exposed to heat, the two salts mutually decompose each other, carbonate of ammonia, which volatilizes, and nitrate of lime, being formed; therefore, if the chemical changes which took place, when solutions of carbonate of ammonia and nitrate of lime were added together, were produced by the chemical force alone, the changes which ensued on exposing, in the solid state, a mixture of carbonate of lime and nitrate of ammonia to heat, must have been produced in direct opposition to the chemical force.

191. From these examples, it will be seen that the chemical action of two bodies does not *always* arise simply in the order of their affinities; for in some cases, at least, the affinities of some bodies are increased, whilst the affinities of other bodies are weakened. The other forces which act on matter are the promoters, modifiers, and counteracters of the chemical force. In some of the succeeding lessons we shall, therefore, study the influence which HEAT, ELASTICITY, COHESION, LIGHT, and ELECTRICITY exercise upon the chemical force.

192. We are now prepared to understand how far tables on the order of affinity, like the two we have given, are useful. "They are strictly tables of the order of decomposition, and of the comparative force or order of affinity, *in one set of conditions only.*" We have seen, for example, that, under certain conditions, iron will take away oxygen from hydrogen; we have seen that, under other

conditions, hydrogen will take away oxygen from iron: again, we have seen, under one set of conditions, that lime will take away carbonic acid from ammonia: we have seen that, under other conditions, ammonia will take away carbonic acid from lime: consequently combinations and decompositions produced under one set of conditions may not take place, they may even be reversed, under other conditions; and therefore tables of the order of combination and decomposition will only be true for one set of conditions.

CHAPTER VII.

INFLUENCE WHICH HEAT EXERCISES OVER AFFINITY.

The decomposition of chemical compounds impossible if affinity were the sole producing cause of chemical changes. The other forces which act on matter assist in these changes. The influence which heat exerts. Exercises.

193. Affinity, although it plays by far the most important part in all chemical changes, is not, as we have seen, the only influence at work in their production. If this force were the only inducing and controlling cause of chemical combinations and decompositions, all chemical phenomena must have ceased immediately after this world came into existence; since the elements, at the moment of their creation, would have combined according to their degrees of affinity, and the combinations then produced must have been eternally permanent, inasmuch as no elementary or compound body would ever after possess a superior affinity for any of the constituents of these compounds than those with which they were already united; therefore, if affinity were the sole producing cause of chemical changes, the breaking up of these compounds must have been impossible. The beautiful and varied combinations and decompositions which are now constantly taking place in the great laboratory of nature, could not have been in action; all the chemical arts which man has contrived for his advancement in civilization could not have been invented, and our planet, which is now peopled with life and activity, must have been barren and uninhabitable. Chemical affinity cannot, therefore, be all powerful, but must, by external circumstances, be influenced to such an

extent, that in some cases the affinities of bodies must be increased, whilst in others they must be weakened.

194. The other forces which act on matter, are the promoters, modifiers, and counteracters of the chemical force. "For the chemical action of two bodies does not arise simply from their chemical affinities, but results from the combined influences of heat, light, electricity, and other physical agencies, which frequently modify chemical affinity to a remarkable extent. By a change of temperature, an affinity, originally weak, may be made to preponderate over one previously much stronger; by electrical conditions, the strongest and most direct affinities may be overcome, according as the cohesion of the acting bodies may prevail; decompositions, simple or compound, may be produced in opposite ways; and thus, a chemical result is not the simple consequence of affinity directly acting, but is the resultant of a number of forces acting in different directions, and various intensities, of which affinity is but one, although that one which, for our object, is the most important."—*Kane.*

195. It will be needless to give any further experiments for the sake of showing that heat, in many cases, assists in promoting chemical combination, as many of the exercises already given clearly prove this. Thus, the student will remember, that oxygen cannot combine either with carbon or hydrogen without the aid of heat. These, and other experiments already given, show that heat in many cases increases the affinity of bodies for each other; in other cases, however, it acts in opposition to the chemical force, for it either wholly or partially decomposes the compound. In the one case, the compound A B is resolved by heat into its elemental constituents, whilst in the other case it only takes away a part of A from the compound A B, so that a compound A B, containing a smaller quantity of A than the original compound, still remains. Thus the oxides of gold and silver, and sulphide of gold, are entirely decomposed at a high temperature; whilst bisulphide of iron, on being exposed to a strong red heat, loses only one-half its sulphur, the compound, protosulphide of iron, remaining; and peroxide of manganese ($Mn\ O_2$) abandons, when exposed to a red heat, one-third of its oxygen, a complex oxide ($Mn_3\ O_4$) remaining.

196. The temperature required for combination and

that required for decomposition are not, in some cases, far apart. Ex.—If oxygen, or atmospheric air, be passed over anhydrous baryta at a low red heat, it combines with the oxygen, forming with it peroxide of barium; at a bright red heat this last compound is decomposed into oxygen and baryta.

EXERCISES.

183. Introduce some binoxide of mercury into a retort of hard glass. On applying the heat of an argand lamp, the oxide of mercury is decomposed; the oxygen passing off in the state of gas may be collected at the trough, whilst the mercury is volatilized, and, condensing in the neck of the retort, collects in globules, which flow down the tube into the trough.

184. Introduce some red lead (Pb_3O_4) into a hard glass retort, and then heat it to redness; at this temperature the red lead is decomposed into protoxide of lead and free oxygen.

197. Heat acts in the same way on some ternary compounds, resolving them into the binary compounds of which they are formed; this is familiarly exemplified in the common operation of burning limestone, or chalk, by which operation the gaseous constituent, carbonic acid, of the limestone is expelled, whilst the basic substance, lime, usually called quick or caustic lime, remains behind.

198. One of the binary compounds is sometimes either wholly or partially decomposed by the heat, as well as the ternary compound from which it was evolved. Thus, nitrate of potash, when strongly heated, is decomposed into potash and its other binary compound; and this again is decomposed, as soon as liberated, into its two elements, nitrogen and oxygen. Sometimes the ternary compound consists of but three elements, of which only one is expelled, whilst the other two remain united, forming a new and distinct compound.

EXERCISES.

185. Introduce a quantity of dry and finely powdered nitrate of lead into an earthenware or hard glass retort, which is then to be heated to full redness. The red vapours, which will be evolved, are to be conducted into a receiver, carefully cooled by a mixture of snow and salt;

they then condense into a liquid, while a quantity of oxygen escapes, and oxide of lead remains behind in the retort. The nitrate of lead is decomposed by the heat into its two binary compounds, oxide of lead and anhydrous nitric acid, and this latter compound is immediately resolved, by the same agent, into nitrous acid (NO_4), the orange yellow body and free oxygen.

186. Introduce into a wide tube or Florence flask, to which a bent tube is attached, a small quantity of powdered chlorate of potash, and subsequently apply heat. This salt is composed of the two binary compounds, anhydrous chloric acid and potash; when this salt is heated somewhat above its melting point it is decomposed, all the oxygen it contains being evolved in the state of gas, whilst its other two elements, chlorine and potassium, remain combined as chloride of potassium.

199. The complete and partial decompositions just given, as illustrations of the effect of heat in promoting chemical changes, were clearly due to that agent alone; but there are cases in which (although the decompositions are as certainly effected by heat) it plays a less conspicuous part, the decomposition appearing to be effected principally, if not solely, by the superior affinity which a superadded body has for one or the other constituent of the decomposed substance. To guard the student against forming a wrong conclusion as to which is the decomposing agent, a few experimental examples are subjoined.

EXERCISES.

187. Introduce into a jar of nitrous oxide (prepared as directed in Expt. 165) a lighted taper, which burns with increased brilliancy in this gas, and if blown out may be relighted, provided a pretty large portion of the wick remains bright red. The student will be aware that the burning of the candle in this gas must be due either to the combination of the gas with the tallow or wax, or with one or both of its constituents in their free state; or that, the gas being decomposed, the burning is due to the combination of the liberated oxygen with the carbon and hydrogen of the candle. The burning of the taper in this gas is due to the latter cause; the gas is decomposed, and the oxygen thus set at liberty combines with the carbon and hydrogen of the taper, forming with them carbonic

acid and water, whilst the nitrogen remains uncombined. To what cause is the decomposition of the nitrous oxide due? Is it caused by the superior affinity which carbon or hydrogen, or both, have over nitrogen for oxygen?

188. Introduce into a jar of binoxide of nitrogen (prepared as directed in Expt. 73) a lighted taper, which will be immediately extinguished. By contrasting these two experiments, we shall arrive at a proper conclusion as to the agent which caused the decomposition of the nitrous oxide in the first one. If the decomposition of the gas in that experiment were due to the superior affinity which carbon and hydrogen possess over nitrogen for oxygen, we should naturally expect a lighted taper to burn in the binoxide, as it contains more oxygen than the nitrous oxide. As the lighted taper is extinguished in an atmosphere of binoxide of nitrogen, we may conclude that the superior affinity which carbon and hydrogen possess over nitrogen for oxygen, is not the sole nor even the principal cause of the decomposition of the nitrous oxide. To what cause, then, is the decomposition to be attributed? It is evidently the effect of the heat which is being evolved from the burning taper when it is plunged into the nitrous gas; but the heat developed by the burning taper is not sufficient to decompose the binoxide, and therefore the light is instantly extinguished when immersed in that gas. The student must not suppose that all the gas in the jar is decomposed by the heat which the burning taper is evolving at the time of its immersion in the nitrous oxide. The heat which is being thus evolved only decomposes a very small quantity of the gas; the heat, developed by the combination of the oxygen thus liberated with the carbon and hydrogen of the taper, produces a further decomposition; in this way the decomposition of the gas and combustion of the taper proceed simultaneously.

200. The following experiment clearly proves that a much higher temperature is required to effect the combination of phosphorus with oxygen when this latter element is combined than when it exists in the free state, that higher temperature being required to decompose the oxygen compound. For if the superior affinity which phosphorus possesses for oxygen were sufficient of itself to decompose the oxygen compound, no greater amount

of heat would be necessary to inflame the phosphorus in the oxygen compound than in free oxygen.

EXERCISE.

189. Introduce, by means of a deflagrating spoon, a piece of dry but unignited phosphorus into a jar of binoxide of nitrogen, and then touch it with a red hot wire, the heat of which will not ignite it, because it (the heat) is insufficient to decompose the gas; and until this is effected, combination, as before stated, cannot take place between the phosphorus and the oxygen — in popular phraseology, the phosphorus cannot burn. Remove the spoon from the jar, and then apply the red hot wire; it will, when the phosphorus is in contact with the air, cause the metalloid to inflame: introduce the inflamed phosphorus into the jar of binoxide of nitrogen; it will continue to burn, as the heat evolved by the burning phosphorus, at the time of its introduction, is sufficient to decompose a quantity of the gas.

CHAPTER VIII.

INFLUENCE WHICH COHESION AND ELASTICITY EXERCISE OVER AFFINITY.

Cohesion opposes combination. Exercises. With affinity it plays a most important part as a decomposing agent. Exercises. Influence of elasticity in promoting combination. Nascent state of substances. Exercises. The surface action of platinum, charcoal, &c. This action applied. Exercises. Influence of elasticity in promoting decomposition. Substances unite in different proportions at different temperatures. In many cases no chemical action will ensue between a solid and a liquid unless a third substance is present. Laws of Berthollet. Exercises.

201. In chemical combination it is the individual molecules of substances, and not the congregation of those molecules as a mass, which unite together, therefore the force we term affinity must reside in each of these minute particles; consequently, whatever prevents the close approximation of the minute particles of dissimilar bodies must stand opposed to chemical affinity, as this force acts only at insensible distances. Cohesion must evidently be

one of these antagonistic forces, as it binds particles of the same nature so closely together, that it prevents that intimate intermingling of unlike particles which is necessary for the manifestation of affinity; this latter force is therefore promoted by a diminution of the former. Cohesion may be diminished by reducing solid bodies to fine powder, or by bringing them into the fluid state. But the finest dust which can be obtained by powdering substances is rough and coarse compared with the minute division which can be attained by bringing substances into a state of solution; the former state is, therefore, less favourable to chemical action than the latter. Solid bodies are brought into the fluid state, either by dissolving them in some liquid, or by liquifying the solid bodies themselves by heat. The former method is employed whenever the substances are capable of solution, the latter when they are insoluble in liquids.

202. With a few exceptions (Expt. 10) solid bodies in the mass do not combine, or at most imperfectly, but they can sometimes unite even at common temperatures on being simply mixed together. The following example proves that chemical affinity is very much exalted by a diminution of the cohesive force. If metallic iron in the mass be exposed to dry air it will not oxidize; but it takes fire when exposed to the air, if in a state of very minute division, forming peroxide of iron.

EXERCISES.

190. Mix in a mortar very briskly flowers of sulphur and metallic copper in the state of very fine powder, in the proportion of sixteen parts of the former to thirty-two of the latter. These two elements combine during the trituration; the combination is attended with an evolution of heat, and the compound produced is of course sulphide of copper. No combination would take place, if copper in small pieces or turnings were substituted for the powdered metal.

191. Put some tartrate of lead into a green glass tube; contract the open extremity, but do not completely close it; heat the tartrate gradually, so as to decompose it in succession, beginning at the end nearest the aperture. In this way dissipate all that is volatile. Metallic lead in a finely divided state remains, which will inflame the

moment it is projected into the air, and will continue to burn for some time, oxide of lead being produced. By sealing up the contracted aperture of the tube as soon as all the volatile matter is expelled, the powder may be preserved without injury for any length of time.

192. Dissolve some phosphorus in bisulphide of carbon by adding small pieces of phosphorus to that liquid. Draw *rapidly* the outline of some letter or figure with a feather moistened with this phosphorus solution. The bisulphide of carbon evaporates rapidly from the paper, leaving the phosphorus in a finely divided state, which attracts oxygen so rapidly from the air that it bursts into flame, commencing at the part first dry, and spreading rapidly to every part of the paper which has been coated with the phosphorus. If not too much of the liquid be applied the paper will not be inflamed, but only charred, the combustion of the phosphorus not developing a sufficient amount of heat to set the paper on fire.

203. Cohesion invariably opposes chemical combination, which it does, as we have seen, by impeding or preventing that close proximity of the particles of unlike bodies which is essential for the development of their mutual affinities. We have still to learn whether it influences decomposition, and if it does, whether it is an opposing or an assisting agent. No chemical compound, however great the cohesive properties of its constituents individually may be, is decomposed by this agent alone. But along with affinity cohesion plays a most important part as a decomposing agent, where two or more substances are brought together *in solution.* The learner will more readily understand the influence which cohesion exerts in these cases, if we first describe the real or probable chemical changes which ensue in similar cases, when neither cohesion nor any other agent, affinity excepted, comes into play. Let us take, for our example, sulphate of potash and nitrate of soda: suppose we were to mix an aqueous solution of each of these salts together, would the bases and acids *continue combined, as they were originally*, or would the nitric acid leave the soda and combine with the potash, and the sulphuric acid leave this latter base and combine with the soda, nitrate of potash and sulphate of soda being the result; or would each acid be divided between both bases, so that

there would finally be in solution four salts, viz., sulphate of potash, sulphate of soda, nitrate of potash, and nitrate of soda? It is difficult to ascertain, when the salts, which may be produced, are soluble, whether any changes take place or not on bringing two or more of them together. In the only cases in which we are capable of forming an opinion, we find, that when the relative forces are not very unequal, the different acids and bases are distributed amongst each other; from these facts we conclude, that in all cases where the relative forces are not very unequal, the acids and bases are thus distributed, so that when two salts are mixed together, the two acids are divided between both bases, four salts being thus finally contained in solution; in like manner, three salts on being mixed together will give rise to nine salts, and when four are mixed together, sixteen will be produced. Chemists conclude that this is the case, from a few facts, of which the following is one. A solution of sulphate of copper in water is of a rich blue colour, and a solution of chloride of copper in the same liquid of an emerald green. If hydrochloric acid be added to an aqueous solution of sulphate of copper, the *blue solution* is immediately changed to *green*, showing that the weaker acid has divided the oxide of copper with the stronger,—that there is, therefore, present both sulphate and chloride of copper, and that free sulphuric acid and hydrochloric acid are likewise present. The learner will notice that we have limited this distribution of the acids and bases to those cases where the relative affinities *are not* very unequal, and when no insoluble substance is separated, cohesion not coming into play. In those cases where the relative affinities *are very unequal*, and no insoluble compound is formed, the acids and bases are not so distributed, but they are exclusively united, the strongest acid with the strongest base, the weakest acid with the weakest base, &c. And if there be not sufficient acid or base to neutralize all the bases or all the acids, a corresponding quantity of the weakest acid or weakest base, as the case may be, remains uncombined. The truth of this is established by the following experimental facts. Boracic acid colours blue litmus wine-red; sulphuric acid turns it bright red. Now if sulphuric acid be gradually added to an aqueous solution of biborate of soda, which has been coloured blue with litmus, the liquid at first remains blue, because the boracic acid set free unites with the undecomposed biborate, forming a quadroborate or a borate containing a still higher proportion of boracic acid—and all borates have an alkaline reaction; on the addition of more sulphuric acid, boracic acid is set free, and colours the liquid wine-red; and not till all the soda has entered into combination with the sulphuric acid does a further addition of that acid give the liquid a bright red colour; but if sulphuric acid were present, either in the free state or in union with soda as an acid salt, before all the biborate was decomposed, the litmus would have turned a bright red colour. From the same cause, a solution of sulphate of potash or sulphate soda, to which free boracic acid has been added, colours litmus only wine-red, but the addition of $\frac{1}{3,000}$ of sulphuric acid immediately produces the bright red tint. Hence sulphuric acid takes soda from boracic acid, setting that acid free: but boracic acid does not take soda from sulphuric acid, or set that acid free. Blue litmus paper is instantly bleached by chlorine water, but not till after several days by an aqueous solution of iodine. If this latter element be added to a solution of chloride of sodium, the solution only changes the blue colour of the litmus to green (the green colour arising from the yellow of the solution and blue of the paper), whereas a very small quantity of free chlorine would convert this green to the colour of the solution, orange-yellow; as the litmus-paper remains green, it proves that there has been no participation of the metal with the metalloids, but that it has remained exclusively united with the chlorine.

204. Having considered the changes which result from the influence of *affinity alone*, we will now examine those cases where cohesion is exerted, as well as the chemical force. Let us take for our example sulphate of potash and chloride of barium, and assume that the relative affinities of the acids and bases contained in these two salts *are not very unequal.* Suppose then that we were to add an aqueous solution of each of these salts together, there would, if no other force but affinity were to come into play, be produced sulphate of baryta, sulphate of potash, chloride of barium, and chloride of potassium. It is highly probable that such a change really takes place, but as sulphate of baryta is insoluble in water, it immediately

precipitates: this removal of the sulphate of baryta from the solution occasions a fresh distribution of the acids and bases—a further quantity of sulphate of baryta is therefore formed, which also, of course, instantly precipitates; the formation and precipitation of this compound goes forward with a measureless rapidity, and *ceases not* until all the baryta, or all the sulphuric acid, or both, have been precipitated, so that chloride of potassium is the only salt which finally remains in solution, if the baryta and sulphuric acid were present in equivalent proportions. This and like facts prove that the nature of double decomposition, *when it takes place at ordinary temperatures*, depends on the relative solubility of the compounds formed. *In whatever way* the most insoluble bodies can be generated, the decomposition occurs: hence two salts, when dissolved in water, *decompose* one another by double affinity, whenever one, at least, of the new salts is, at the given temperature, *less soluble* (and therefore more coherent) than either of the two original compounds. This law holds good without any exception whatever; in no instance are two soluble salts produced from the mutual action of a soluble and an insoluble salt; on the other hand, two soluble salts often produce a less soluble salt, and an insoluble salt, and very frequently one equally soluble and one insoluble.

205. The influence of cohesion, in determining chemical action, is well illustrated in the following example. A solution of common salt and one of sulphate of magnesia being added together, and then evaporated at ordinary temperates, or a little above, allows both salts to crystallize out unaltered; but at 32° Fah., or at lower temperatures, hydrated sulphate of soda crystallizes out, and the solution retains chloride of magnesium; on gently warming the whole, common salt and sulphate of magnesia are again obtained. But above 122° Fah. the solution again deposits sulphate of soda, though in the anhydrous state. These apparently contradictory results are owing to the different solubility of sulphate of soda at different temperatures; it separates both below 32° Fah. and above 122° Fah., because at these extremes of temperature its solubility is less than that of common salt or sulphate of magnesia; at medium temperatures, on the contrary, it is more soluble than common salt or sulphate of magnesia; consequently these

two salts, at the medium temperatures, remain unaltered. We learn from this last example that the manner in which acids and bases are arranged in a solution cannot be determined from the salts which are obtained on evaporating that solution; ordinary hard water, for instance, contains soda, hydrochloric acid, lime, and sulphuric acid,—the acids and bases will either be distributed, or the strongest acid, sulphuric acid, will be combined exclusively with the strongest base, soda; yet on evaporating the water, the salt which first crystallizes out is sulphate of lime, and on continuing the evaporation, all the sulphuric acid, or all the lime, or both, may be removed in combination with each other, because sulphate of lime is the least soluble salt that can be formed out of these substances.

206. It will be needless to give many experiments to exemplify what has just been stated, namely, that in whatever way the most *insoluble substances* can be produced, *the decomposition takes place*, as Expts. 177, 178, 180, and 181, under the head of double elective affinity, are illustrative of this proposition.

EXERCISES.

193. Add a solution of carbonate of ammonia to one of chloride of calcium, carbonate of lime and chloride of ammonium will be produced; the former, being insoluble, will be precipitated; the latter, being soluble, will remain in solution.

194. Add a solution of carbonate of soda to one of nitrate of lead, carbonate of lead and nitrate of soda will be produced; the former, being insoluble, will be precipitated; the latter, being soluble, will remain in solution.

195. Add to a solution of sulphate of zinc some sulphide of ammonium, sulphide of zinc and sulphate of ammonia will be formed; the former, being insoluble, will be precipitated; the latter, being soluble, will remain in solution.

207. We shall conclude this lesson by reminding the student that as substances may be soluble in water, and insoluble in spirit of wine or some other liquid, the kind of liquid must and does influence chemical action in many cases. Ex.—If carbonate of potash be dissolved in water, and acetic acid be added to it, the carbonic acid will be expelled, and acetate of potash will be formed, which,

being soluble, remains in solution; but if acetate of potash be dissolved in alcohol, and a stream of carbonic acid be passed into the solution, carbonate of potash, because it is insoluble in alcohol, will be formed, and acetic acid set free.

208. Having studied the influence which cohesion exerts over affinity, we must now consider the influence which its antagonistic force, elasticity, exercises. The same order will be followed in this as in the preceding lesson, viz., 1st. Whether elasticity opposes or promotes combination. 2nd. Whether it opposes or promotes decomposition.

209. Cohesion, we have learned, is opposed to chemical combination, from its binding particles of the same nature so closely together, that it prevents that intimate intermingling of unlike particles which is necessary for the manifestation of affinity; elasticity stands opposed to chemical combination on account of the opposite extreme, viz., the wide dispersion of the particles, which likewise prevents that close approximation of the dissimilar molecules which, as a rule, is necessary for the manifestation of affinity. But just as in the case of affinity there were a few solid substances which could combine together in their solid state, on account of their powerful affinities, so there are a few gaseous substances which can combine together in their gaseous state without the aid of any other power but that of affinity; but these are the exceptions, and not the rule, as we shall learn presently. Ex.—If gaseous hydrochloric acid be brought into contact with gaseous ammonia, they will unite,—chloride of ammonium, a solid substance, being the result. But oxygen and hydrogen, chlorine and hydrogen, &c., cannot combine, when brought together in their gaseous state, without the aid of heat (as shown in the first experimental lesson), or light, or electricity, as we shall see hereafter, although they possess a very great affinity for one another. In order to effect their combination independent of the agents just mentioned, we must bring them together in what is termed their *nascent* state—that is, they must be set free from other combinations at the same moment, and in presence of one another.

210. To form ammonia, its elements, nitrogen and hydrogen, must be brought together in their nascent state; they will not combine if presented to one another under any other circumstances.

211. To effect the union of a solid with a gaseous body, it is necessary in a number of cases to bring them together in this way. Thus no chemical combination will take place if a stream of hydrogen be passed into sulphur. If, however, the two elements are set free from other combinations at the same moment and in presence of one another, they combine together and form hydrosulphuric acid. This is also the case between hydrogen and the following substances—phosphorus, carbon, arsenic, antimony, &c.

EXERCISES.

196. Add some dilute sulphuric acid to a few fragments of sulphide of iron, sulphate of iron and *sulphide of hydrogen* will be formed; the former compound is a solid, and being soluble in water, will remain dissolved; the latter is a gas, and with the exception of a small portion which will be dissolved by the water, it will pass away in that state.

197. Add to an aqueous solution of sulphide of hydrogen an aqueous solution of sulphurous acid, the two substances will mutually decompose each other, *water being formed*, and sulphur set free.

198. Add sulphuric acid to a solution of chloride of sodium. Sulphate of soda and *chloride of hydrogen* will be formed.

212. We shall conclude this lesson by proving by an experiment, that gases can unite together at common temperatures when they are not in their nascent state, *provided* they can by any means be brought sufficiently near together.

213. Oxygen and hydrogen gases cannot, except they be brought together in their nascent state, combine of themselves at common temperatures; they remain ununited after being kept mixed for any length of time; but a strip of clean platinum, if introduced into the gaseous mixture, effects their combination. The platinum possesses the power of condensing upon its surface a quantity of each gas. The condensed particles of the two gases are brought into such close proximity that they unite,—the combination giving rise to a fresh condensation by the platinum of the uncombined gaseous mixture: in this way the whole amount becomes at length united. If spongy platinum—

which is a mass of very minute particles cohering slightly together—be employed, it causes a more rapid combination than the metal does in its ordinary state, by condensing a larger quantity of the two gases, which occasions a development of heat sufficient to raise the platinum to bright redness;—at this temperature the two gaseous elements combine instantaneously with explosion.

EXERCISE.

199. This action of platinum has been ingeniously applied in the construction of an instantaneous light apparatus, called after the inventor—Doberiner's lamp, which affords a very nice and safe mode of exhibiting this remarkable property. A glass vessel, *a*, contains dilute sulphuric acid; *b* is a bottle without a bottom, the neck of which is cemented into the cover, *c*; *d* is a piece of zinc hanging from the cover within the bottle, *b*; *e* is a stop-cock, from which the gas issues when the cock is opened, and impinges upon the spongy platinum contained in the little cup, *f*. Hydrogen is evolved by the action of the acid on the zinc; it collects in the bottle, *b*, forcing out the liquid until it has fallen below the metal; the chemical action then ceases, and with it, of course, the liberation of the gas. When the stop-cock is opened, the gas issues from the jet and impinges on the platinum, which already contains in its pores, from being expoesd to the air, a quantity of condensed oxygen, and as it condenses some of the hydrogen impinging upon it, the condensed particles of the two gases combine in the way previously explained. The heat evolved by the combination raises the temperature of the platinum sufficiently high to ignite the hydrogen issuing from the jet. If the jet be closed for a moment only, the platinum condenses in that time, however brief, fresh quantities of oxygen;—as soon, therefore, as the jet is re-opened, the condensed gases again combine, and the hydrogen is again ignited.*

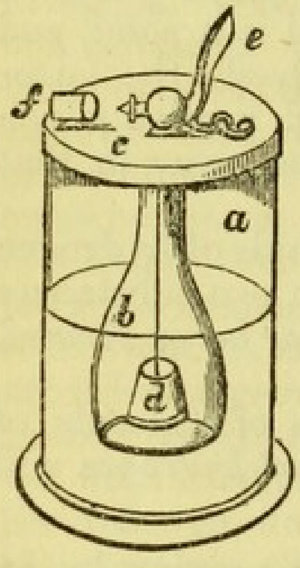

Fig. 12.

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* "When the apparatus is first set up, the common air must be taken from the funnel, by covering the collar with paper, and then opening the stop-cock. The inner bottle is then allowed to fill with hydrogen gas, which

214. Oxygen and hydrogen are not the only gases which platinum can condense; nor is that metal the only substance which possesses this property. Every porous substance, whether elementary or compound, is possessed of it in a greater or less degree: even finely pulverized glass, if heated intensely, possesses it to some extent; but the one which is capable of condensing the greatest variety of substances, is carbon.

215. Of the different varieties of carbon, animal and wood charcoal possess this property in the highest degree; they absorb most, if not all, gaseous bodies, both simple and compound. They absorb of gaseous ammonia ninety times their bulk, of sulphuretted hydrogen fifty-five times, of oxygen nine times, of hydrogen nearly twice their bulk; they also absorb large quantities of the other gases, and likewise watery vapour. They also absorb the colouring, bitter, and odoriferous bodies of most animal and vegetable substances. Whether they absorb them in some such way as they do ordinary gaseous bodies, or the carbon chemically combines with them, is not known.

216. Some of the most important uses of charcoal in the arts, are owing to its possessing this property. Charcoal is employed to deodorize all kinds of feculent matter, which it does by absorbing the noxious gases and all unpleasant effluvia evolved by animal and vegetable matter undergoing putrescent decay. It acts in a similar way when employed to deprive tainted meat of its odour. Its efficacy as a manure is also due to its power of absorbing from the air, and retaining in the soil, those gaseous substances—ammonia in particular—which plants require. Foul water is purified and sweetened by filtration through charcoal; and water will not become impure when kept in barrels which are charred on the inside. A solution of brown sugar, if allowed to percolate through charcoal, is deprived by it, in its passage, of a large quantity of its colouring and other impure matters;—charcoal is therefore used largely in the refining of sugar.

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is let off in the same manner without being allowed to strike upon the platinum. This is repeated once or twice, after which the gas will be pure. The paper is then taken away, and the pure hydrogen is allowed to strike upon the platinum. If the gas does not take fire, it must be inflamed by a lighted paper (not a match), in order to dry the platinum. After that it will act properly."

217. The following experiments will illustrate what has just been stated about the properties of charcoal:—

EXERCISES.

200. Boil an infusion of litmus, or red cabbage, with powdered ivory black, and then pass the liquid through filtering paper; if sufficient ivory black has been added, the liquid will come through the filtering paper perfectly colourless.

201. Boil an infusion of hops with powdered ivory black, and then pass the liquid through filtering paper; if sufficient of the black has been added, the liquid which filters through will be tasteless.

218. For a more detailed account of the properties of carbon, the reader is referred to the special properties of this metalloid, chapter xxii.

219. In studying the influence of elasticity as a decomposing agent, we have to consider—1st, Whether chemical combinations are broken up by this agent alone;—2nd, Its influence in conjunction with heat as a decomposing agent;—3rd, Its influence in conjunction with affinity at common temperatures;—4th, The influence which heat and elasticity exercise in conjunction with the chemical force.

220. 1st.—Some chemical compounds are of so unstable a nature, especially when both their components are gases, that friction, or other slight disturbing influences, are sufficient to effect either their total or partial decomposition. Chloride of nitrogen, which is an oil-like liquid, composed of the two gases, chlorine and nitrogen, affords an apt illustration of this principle: owing to its unstableness, it requires to be treated with the utmost caution. If it be strongly rubbed or struck, or if it be touched with any greasy body, or with phosphorus, it explodes with intense violence; a globule, as large as a pin's head, on being exploded in a tea-cup, shatters it to pieces. It is not, therefore, a fit substance to be experimented with in a class-room. These unstable compounds are generally decomposed with explosion, if they are brought in contact with substances which possess an affinity for one of their constituents, as we shall hereafter learn.

221. 2nd.—Chemical compounds composed of a volatile and non-volatile body, are generally decomposed at high

temperatures. "The expansion occasioned by heat removes the elements of the compound to a greater distance from each other, and thus by diminishing the force of chemical attraction, favours the tendency of the volatile principle to assume the form which is natural to it." We have already had, when discussing the influence of heat, several illustrations of the principle here stated; it will therefore be useless to give new examples, or repeat those already given. There remains, however, one important point to be noticed before we dismiss this part of the subject: it is this—when the decomposition of a body by heat is occasioned by the elasticity of one of its constituents, the volatile body must be allowed to pass away, otherwise, no matter how high the temperature, decomposition cannot be effected. Thus, carbonate of lime at a red heat is decomposed, provided the volatile constituent, carbonic acid, be allowed to escape; but if it be not allowed to escape, the carbonate of lime may be raised to the highest possible temperature, yet it will not suffer decomposition. It does not appear to signify much what kind of an atmosphere surrounds the substance to be decomposed, provided it is of such a nature that it offers little resistance to the substance which has to be expelled. Thus, carbonate of lime will be decomposed as readily in an atmosphere of steam as it will in one of common air. In burning limestone on the large scale, the kiln is so constructed that there is always a continuous draught through the burning lime, which carries off the carbonic acid as it is set free, and thus influences the decomposition. "Decomposition from unequal volatility is therefore checked by pressure, and promoted by its removal, and by everything which favours the escape of vapour,—such as the presence of an atmosphere of a different sort, into which the volatile constituent may evaporate. The occurrence of this decomposition of carbonate of lime by heat depends entirely upon the existence of a foreign atmosphere into which carbonic acid can diffuse."

222. The following often-quoted and apparently contradictory facts may be explained in this way. When iron filings are heated to redness in a porcelain tube, and vapour of water passed over them, the water undergoes decomposition with the utmost facility, hydrogen is rapidly disengaged, and the iron converted into oxide. On

the other hand, oxide of iron, heated in a tube through which a stream of hydrogen is passed, suffers almost instantaneous reduction to the metallic state, while the vapour of water, carried forward by the current of gas, escapes as a jet of steam from the extremity of the tube. It is highly probable, that at a red heat the affinities of iron and hydrogen for oxygen are so nearly balanced, that the nature of the *atmosphere* determines the *chemical change;* an atmosphere of steam offering little resistance to the escape of hydrogen, whilst, on the other hand, an atmosphere of hydrogen offers little resistance to the escape of steam. "In a similar manner, if a current of sulphuretted hydrogen be transmitted in large excess over solid bicarbonate of potash, aided by a gentle heat, the whole of the carbonic acid and water will be displaced from the bicarbonate, and carried forward by the excess of the gas, whilst sulphide of potassium will be formed. But sulphide of potassium, if dissolved in water, and subjected to a current of carbonic acid, will, in its turn, be gradually but completely decomposed; the sulphuretted hydrogen being carried away by the excess of carbonic acid, whilst bicarbonate of potash is formed in the liquid."

223. 3rd.—Elasticity also modifies chemical affinity in a manner analogous to the influence which cohesion exerts over the same force. For just as we have seen the formation of an insoluble substance determining the order of decomposition and combination, so elasticity causes decompositions and combinations to occur in such a way that the most volatile constituent is formed. In all such cases, the same principle of distribution, described under the head of cohesion, may be supposed to hold good. Thus, on adding hydrochloric acid to a solution of carbonate of soda, the first tendency probably is, of the base being divided between both acids; but the carbonic acid, which has been replaced by the hydrochloric acid, immediately assumes the gaseous state,—the consequence is, that at last chloride of sodium is the only salt that remains, the hydrochloric acid having entirely removed the carbonic acid. In the same way, the volatile base, ammonia, is liberated from its combinations, on the addition of a less volatile base.

224. 4th.—Cohesion and elasticity are perhaps the most general and the most powerful controllers of the chemical

force. Cohesion, as a rule, determines the order of decomposition and combination at temperatures below 212° F.—above this temperature elasticity, and not cohesion, determines the chemical changes. This being the case, the student will not be surprised to learn, that at different temperatures exactly opposite decompositions may take place. We have seen, by Expt. 193, that at 212° F., and below that point, a solution of carbonate of ammonia and chloride of calcium are mutually decomposed in the presence of one another, carbonate of lime and chloride of ammonium being formed. But if solid carbonate of lime and solid chloride of ammonium be mixed together, and then exposed to a temperature higher than 212° F., carbonate of ammonia and chloride of calcium will be formed: the former, being volatile, escapes; the latter, being a non-volatile body, remains behind. This reverse decomposition takes place even when the substances are in a state of solution, if the temperature exceeds 212° F. Advantage has been taken of this fact to prevent steam boilers becoming incrusted with the carbonates of lime and magnesia, which are generally present in ordinary spring and river water. This is accomplished by adding to the water in the boiler a quantity of chloride of ammonium, which acts by decomposing and being decomposed by the carbonates of lime and magnesia present in the water; volatile carbonate of ammonia, and the soluble chlorides of calcium and magnesium, being formed. It has been particularly noticed, in a preceding page, that sulphuric acid can, at ordinary temperatures, deprive boracic acid of every particle of its base. If, however, a mixture of sulphate of soda and boracic acid in the dry state be heated to redness in a crucible, the sulphuric acid being volatile at that temperature, and boracic acid not, the latter will expel the former (in consequence of its volatility) from its combination. Silicic acid is set free from its combinations by all the other acids at ordinary temperatures, whereas at high temperatures, and the substances being in the solid state, it expels, on account of its non-volatility, the most powerful acids from their combinations. Thus, when chloride of sodium is thrown upon ignited clay, the silica in the clay unites with the soda, forming silicate of soda; whilst hydrochloric acid is expelled. It is in this way that our common pottery is glazed. Potassium, at a red heat, decomposes oxide of iron, forming potash and metallic iron; at a white heat, on the contrary, potash is decomposed by metallic iron, the products being oxide of iron and vapour of potassium. At a red heat, potassium decomposes carbonic oxide, forming potash and charcoal; at a low white heat, charcoal decomposes potash, producing carbonic oxide gas, and vapour of potassium. These examples, and those which follow, prove, that at elevated temperatures, substances possessing weak affinities displace from their combinations substances possessing much stronger affinities, when the former are non-volatile and the latter are volatile, or when, as in the case of the potash and charcoal, the substances added are non-volatile, but the substances formed (potassium and carbonic oxide) are volatile, at the temperature at which the experiment is made.

225. To obtain the common street-gas from coal, this substance is exposed in retorts to a very high temperature, which gives rise to two gaseous compounds of carbon and hydrogen, viz., light carburetted hydrogen (marsh gas, fire-damp), $C\,H_2$, and olefiant gas, $C_4\,H_4$,—these are the principal constituents of the coal gas. Mr. Young has found that if the coal be distilled at a lower temperature, the principal compound of carbon and hydrogen which distils over is not a gas, but a solid body (Paraffine), at ordinary temperatures. The former examples proved that at different temperatures exactly opposite decompositions may take place,—this example shows that at different temperatures the same elements unite themselves in a different manner.

226. As experiments illustrating this lesson do not form suitable lecture experiments, we shall, on that account, not give any exercises, the examples quoted sufficiently illustrating the propositions announced.

227. We shall conclude this chapter by directing the student's attention to a condition very frequently overlooked, especially by the learner. It is this,—in many cases no chemical action will take place between a solid and a liquid, unless a third substance be present, although this third substance does not contribute any element for the formation of the products. Thus, concentrated sulphuric acid may be added to sulphide of iron, and concentrated nitric acid to carbonate of baryta, yet neither hydrosulphuric acid in the one case, nor carbonic acid in the

other, will be evolved until water (the third substance) be added. These phenomena admit, in these and most other experiments of a similar kind, of the following explanation :—That on the first addition of the solid and liquid together, a slight chemical action takes place, and the small quantity of the solid product which is thus formed, being insoluble in the liquid, falls down as a slight but impervious film, which prevents the further action of the liquid upon the original solid body; but when this film is dissolved by the addition of water, decomposition proceeds. Thus, when sulphide of iron and concentrated sulphuric acid are brought together, a slight quantity of sulphate of iron is formed, which, being insoluble in the acid, remains upon the surface of the sulphide of iron, and prevents the further action of the acid upon the sulphide of iron until water be added to dissolve it as it is formed. As soon, however, as the water becomes saturated with the iron salt, the formation of the hydrosulphuric acid ceases, although the materials from which it is formed, viz., sulphuric acid and sulphide of iron, are still present.

EXERCISES.

202. Add a few strips of zinc and concentrated sulphuric acid together. In a similar vessel place a like quantity of the same metal, and some dilute sulphuric acid (one part of concentrated acid to eight of water), and observe the different action which takes place in the two cases.

203. Add concentrated nitric acid to carbonate of baryta, and in another vessel dilute nitric acid to the same salt.

204. Add concentrated sulphuric acid to a few fragments of sulphide of iron, and dilute sulphuric acid to another portion of the iron compound.

205. Add absolute alcohol, which is saturated with hydrochloric acid gas, to carbonate of potash; to another portion of the potash salt add water in which the same gas is dissolved (ordinary liquid hydrochloric acid), and observe the different behaviour which the salt exhibits in the two cases.

228. Before we close the chapter, we will pass in review the chemical properties of saline combinations;—the greater part of it is only a condensation of what has been already stated on the influence which cohesion and elasticity exercise on the chemical force.

229. *Action of metals upon salts.*—The metal in a salt is displaced by a more oxidizable metal, if the salt be in a state of solution. The action of metals on the metallic oxides in salts, if the salts are in a state of solution, may therefore be foreseen; but it is difficult to generalize upon this action of metals upon metallic oxides, *under all conditions;* for the relative affinity of the metals for oxygen varies greatly with temperature. Thus, potassium decomposes oxide of iron at a red heat, whilst at a higher temperature, as a strong white heat, iron, on the contrary, decomposes oxide of potassium.

230. The following table gives the action of some of the metals upon some of the salts:—

SALTS IN A STATE OF SOLUTION REDUCED BY CERTAIN METALS.

Salts of tin		reduced by iron and zinc.
,, antimony		
,, bismuth		
,, copper	reduced by iron, zinc, and all those which precede copper	
,, mercury		
,, silver	reduced by iron, zinc, manganese, cobalt, and all those which precede silver	
,, platinum		
,, gold		

231. The reaction which acids and bases exert upon salts, and the reciprocal action of salts on each other, may be foreseen from certain general laws, which observation has proved, and which will now be explained. These laws are called Berthollet's Laws.

232. *Action of acids upon salts.*—If the acid which is added to the salt is identical with that already in the salt, it often happens that the salt combines with a new quantity of acid, and a salt is formed with an excess of acid. If sulphuric acid be added to sulphate of potash, the bisulphate of potash is formed. So, also, if a current of carbonic acid gas be passed through a solution of neutral carbonate of potash, the bicarbonate of potash is produced.

233. If the base of the salt does not combine with a greater quantity of acid, the salt often dissolves in the

acid added, especially if the latter be mixed with a large quantity of water. Thus, nitrate of potash dissolves in a dilute solution of nitric acid; but if the liquid be evaporated, the nitrate crystallizes unchanged.

234. If the reacting acid differs from that existing in the salt, decomposition will ensue under several circumstances.

1st. *Decomposition will ensue when, the salt being soluble in water, and being dissolved in that liquid, the reacting acid can form an insoluble compound with its base.* See par 206, and par. 204.

2nd. *An acid can decompose a salt which is in a state of solution, if the acid of the salt is either completely insoluble, or only sparingly soluble, in water.*

3rd. *A salt can always be decomposed by an acid less volatile than that which it contains.*

235. The state of concentration of an acid, and the temperature, exert a powerful influence over these reactions. If a solution of sulphuretted hydrogen be poured into a dilute solution of chloride of antimony, a precipitate of sulphide of antimony is formed. But, if sulphide of antimony be heated with a concentrated solution of hydrochloric acid, chloride of antimony is formed, and sulphuretted hydrogen disengaged.

236. 4th.—*When the acid of a salt, and that employed to react on it, are both gaseous, and at the same time but slightly soluble in water, and when, moreover, their affinities for the bases are nearly equal, the acid which is present in excess will expel the other.* Thus, by passing a current of carbonic acid gas for some time through the solution of an alkaline sulphide, the latter is entirely converted into a carbonate, and sulphuretted hydrogen driven off. Reciprocally, by passing sulphuretted hydrogen for some time through a solution of an alkaline carbonate, it is entiely converted into a sulphide.

237. The vapour of water, at a high temperature, expels carbonic acid from alkaline carbonates, when the latter are heated in platinum tubes in a current of steam, and hydrates are formed. Reciprocally, the alkaline hydrates, heated to the same temperature in a current of carbonic acid, are converted into carbonates.

238. These facts exhibit the influence of mass, the influence of which on chemical affinity is noticed at greater length in a subsequent part of the work.

239. *Action of bases upon salts.*—When a salt is brought into contact with an additional quantity of the same base which it already contains, no reaction ensues, unless the acid of the salt can form a salt more basic than the original one. If potash be added to a solution of sulphate of potash, and the liquid evaporated, the original sulphate crystallizes out unchanged. In other cases, combination ensues; thus, potash added to a solution of bisulphate of potash produces the neutral sulphate. A solution of neutral acetate of lead can dissolve an additional quantity of oxide of lead, and form a basic acetate.

240. If the base added to a saline solution is different from that existing in the salt, the original salt is frequently decomposed, and a new one formed; and the decomposition is determined by circumstances analogous to those which cause the reaction of acids on salts.

1st. *Generally speaking, a soluble salt, in a state of solution, is decomposed, when the reacting base can form an insoluble salt with the acid of the salt.* If baryta be added to a solution of sulphate of potash, sulphate of baryta is precipitated, and caustic potash remains in the liquid. Baryta also decomposes carbonate of potash in a dilute solution, and carbonate of baryta is precipitated. The state of concentration of the liquid exerts great influence over these decompositions; for, if carbonate of baryta be boiled with a concentrated solution of caustic potash, a considerable quantity of carbonic acid is abstracted from it, and carbonate of potash is formed.

2nd. *A soluble salt, containing an insoluble base, is decomposed on adding to its solution a soluble base.*

3rd. *An insoluble metallic oxide sometimes decomposes a salt formed by a base equally insoluble.* Thus, oxide of silver decomposes nitrate of copper in solution, precipitating oxide of copper; and the decomposition is determined, in this case, only by the preponderating affinity of oxide of silver for nitric acid.

4th. *When the base of a salt is volatile, it is generally expelled by a more fixed base,* particularly when assisted by heat.

241. *Mutual action of salts.*—When two salts are mixed together, several phenomena may ensue: we shall distinguish the case in which the two salts are heated without the contact of water, or the *dry* way, and that in which

they are brought into contact in solution, or in the *humid* way.

Mutual action of salts in the dry way.

242. When two salts of the same acid, but of different bases, are heated together, the two salts frequently combine in definite proportions, producing double salts, which crystallize on cooling. In this manner a great number of double silicates may be produced, which, from their beautiful crystallization, present the characters of definite compounds. In the same manner we may obtain, in the dry way, double chlorides and several other double salts; but the combination is often destroyed upon dissolving the compound in water, the two original salts crystallizing separately.

243. *When two salts of different acids and bases are heated together, and when, by the mutual interchange of acids and bases, a new salt more volatile than the first two can be formed, its formation is generally determined by this circumstance.* (See par. 223.) It frequently happens, as we have before noticed (par. 224), that the reactions thus produced in the dry way between two salts are precisely the reverse of those which take place in an aqueous solution.

Mutual action of salts in the humid way.

244. The solutions of two salts which have the same acid or base, are generally without action upon each other. Sometimes, however, the two salts unite and form a double salt. Sulphate of alumina, for instance, combines with sulphate of potash, forming a double salt, known by the name of *alum*. Chloride of potassium combines with perchloride of platinum, and produces a double chloride of platinum and potassium.

245. *Two soluble salts in a state of solution mutually decompose each other, when they can, by the interchange of these acids and bases, form an insoluble salt* (par. 206), *or a salt less soluble than either of the two original salts* (par. 204).

246. *An insoluble salt may sometimes be decomposed by boiling it for a long time with a soluble salt.* This occurs whenever the base of the original insoluble salt can form an insoluble salt with the acid of the reacting soluble salt.

To render the decomposition complete, a large excess of the soluble salt must in the generality of cases be used.*

247. The student ought to write out answers to the following questions:—

EXERCISES.

206. Chlorine, we have seen, combines with phosphorus, with antimony, and with some other metals, at the ordinary temperature of the atmosphere; is it probable that at some lower temperature combination will not take place between the chlorine and one or the other of these elements? Give reasons for the opinion expressed.

207. Is the order of affinity *constant* under all conditions?

208. What is meant by the nascent state?

209. Name some of the properties of charcoal.

210. Refer to the list of acids given in the chapter on acid substances, and then say which, if any, of the following acids would set free sulphuric acid from sulphate of potash at a red heat:—hydrochloric acid, phosphoric acid, nitric acid, silicic acid, boracic acid.

211. Enumerate some of the circumstances which affect the order of decomposition.

212. Name the several circumstances under which decomposition will ensue when acids are added to salts.

213. Will any change take place when sulphuric acid is added to nitrate of potash and heat applied?

214. Name the several circumstances under which decomposition will ensue when bases are added to salts.

215. Under what condition would it be possible for nitric acid to decompose sulphate of potash?

216. Ammonia decomposes chloride of lead in solution, and precipitates oxide of lead; is it probable that oxide of lead will decompose chloride of ammonium under some conditions?

217. Carbonate of lime is insoluble; lime therefore removes carbonic acid from potash when carbonate of potash is in solution. What conditions are necessary to render this decomposition complete, and what must be guarded against in order to prevent the potash taking back the carbonic acid from the lime?

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* This summary of Berthollet's laws has been extracted mainly from the "Cours Elémentaire de Chemie," par M. V. Regnault.

218. Name the several circumstances under which two salts in a state of solution will interchange their acids and bases.

219. Name the several circumstances under which two salts in the solid state will interchange their acids and bases.

CHAPTER IX.

PRACTICAL APPLICATION OF THE PRINCIPLES CONTAINED IN THE PRECEDING CHAPTERS.

Table showing the solubility of the basic oxides. Exercises. Table showing the solubility of salts. Exercises.

248. The object of the present chapter is to make the student *apply* the knowledge he has acquired in the previous lessons.

249. Soluble salts, containing either insoluble acids or bases, are decomposed on adding to their solutions bodies possessing the same characters as the insoluble constituents, with the exception of being soluble. Ex.—Persalts of iron are decomposed with the precipitation of the peroxide of that metal by the soluble bases.

250. All the bases, with the exception of *potash, soda, ammonia, baryta, strontia,* and *lime,* are insoluble in water. They are all non-volatile, with the exception of ammonia, which is not included in the table. Most of them, on being precipitated from their salts, combine with one or more atoms of water to form hydrates. Some of these hydrates possess a different colour to what the same oxides do when anhydrous. Many of them are likewise soluble in the volatile alkali or the fixed ones. It is, therefore, necessary for the student to perform a course of experiments, in order to become practically acquainted with these facts.

251. The following table shows the colour of the different hydrated oxides, and their solubility or insolubility in the volatile alkali or the fixed ones. In performing these experiments, the experimenter must carefully compare this table with one given in chapter xiv., which gives the colour* of the basic oxides in their anhydrous state.

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* The colour of precipitates is a very important study, as it supplies a character by which many substances may be distinguished.

TABLE SHOWING THE SOLUBILITY OF THE BASIC OXIDES AND THEIR HYDRATES.

Names.	Symbols.	Names.	Symbols.
Soluble in water.			
Hydrate of potash Hydrate of soda } *white*	KO, HO NaO, HO	Hydrate of baryta Hydrate of strontia Hydrate of lime } *white*	BaO, HO SrO, HO CaO, HO
The rest are insoluble in water.			
Soluble in ammonia and the fixed alkalies.			
Hydrate of zinc (*white*) - - - - - - - - - - -			ZnO, HO
Insoluble in ammonia and the fixed alkalies.			
Hydrate of the sesquioxide of iron (*reddish brown*)	Fe_2O_3, 3HO	Suboxide of mercury (*forms no hydrate*)	Hg_2O
Hydrate of bismuth (*white*)	BiO, HO	Hydrate of the protoxide of mercury (*yellow*)	HgO, HO
Insoluble in ammonia, soluble in the fixed alkalies.			
Hydrate of alumina Hydrate of the protoxide of tin Hydrate of the peroxide of tin Oxide of antimony } *white*	Al_2O_3,3HO SnO, HO SnO_2, HO SbO_3	Hydrate of the sesquioxide of chromium (*bluish green*). (This oxide is insoluble in boiling solutions of the fixed alkalies.)	Cr_2O_3,3HO
		Hydrate of lead (*white*). (This hydrate is only very slightly soluble in the fixed alkalies.)	PbO, HO
Soluble in ammonia, insoluble in the fixed alkalies. The presence of ammoniacal salts prevents some of them from being completely precipitated by the fixed alkalies.			
Hydrate of cobalt (*pale red*)	CoO, HO	Hydrate of copper (*whitish green*). (If the fixed alkalies are added to cold solutions of copper salts, the hydrate is precipitated; if added to boiling solutions, the anhydrous oxide is precipitated.	CuO, HO
Hydrate of nickel (*green*)	NiO, HO		
Oxide of silver (*forms no hydrate*)	AgO		
Hydrate of cadmium (*white*)	CdO, HO		
Insoluble in ammonia and the fixed alkalies, but in the presence of salts of ammonia the volatile alkali cannot precipitate them, and the fixed alkalies only do so in part.			
Hydrate of magnesia (*white*)	MgO, HO	Hydrate of protoxide of iron is of a white colour, which, on exposure to the air, finally becomes red, owing to its being converted into the peroxide.	FeO, HO
Hydrate of manganese (*white*), speedily becoming brown by absorbing oxygen from the air, and becoming converted into a higher oxide	MnO, HO		

Ammonia does not precipitate the hydrate from solutions of peroxide of mercury, but a white precipitate having the following composition ($Hg\,NH_2 + Hg\,Cl$); the fixed alkalies likewise throw down the same precipitate, if salts of ammonia are present, but in the absence of these salts they precipitate the hydrate.

252. The metallic oxides and their hydrates, which are soluble in water, and not volatile, may be prepared in three ways—1. By burning the metals in dry air or oxygen gas. 2. By decomposing those of their salts, the acids of which are volatile, by heat. Nitrates and carbonates are the salts particularly employed for this purpose. 3. By dissolving some of their salts in water, and adding to that solution a base which will combine with the electro-negative body, and form an insoluble salt. By the first two methods the oxides are obtained in their anhydrous, and the third in their hydrated state. The first method, from the difficulty with which the metals themselves are obtained, is never employed in practice; and as potash and soda cannot long be preserved in their anhydrous state, even if kept in stoppered bottles, these two bases are never prepared by the second method. The third process is, therefore, the only one which can be employed for preparing them. Anhydrous potash, soda, baryta, and strontia cannot be obtained from their hydrates by heat, as the hydrated water cannot be expelled by simple ignition. The term *caustic,* when applied to potash and soda, as caustic potash, &c., signifies the hydrates of these oxides; but it is only applied to baryta, strontia, lime, and magnesia in their anhydrous state.

253. The insoluble oxides are obtained in their anhydrous state in several ways: sometimes by oxidizing the metals at elevated temperatures; frequently by decomposing those of their salts (the acids of which are volatile) by heat; and not unfrequently by depriving their hydrates of water, as the hydrates of the insoluble oxides can be rendered anhydrous by heat. They are always obtained in their hydrated state by decomposing some of their soluble salts by the alkalies or alkaline earths.

254. The experiments in this chapter ought to be made by each of the students; and they ought to conduct the operations in test tubes. When want of room, or other causes, prevent the students from performing the experiments for themselves, the teacher ought to perform them, if the class is not too large, in test tubes, in order to teach the students the quantities and modes of manipulation adopted in analytical inquiries. Dissolve the

solid substances in water,* in the proportion of one part of solid to ten of water; and dilute the acids and ammonia in the proportion of one of acid or ammonia to four of water, and use these dilute solutions always, unless expressly directed to use the concentrated. Caustic soda and caustic potash can be used indiscriminately; and they may be used as obtained from the operative chemists.

EXERCISES.

220. To a solution of sulphate of magnesia add ammonia, which will precipitate a portion of the magnesia as hydrate. To a solution of the same salt add chloride of ammonium and then ammonia; in this case the ammonia will not produce a precipitate, as the oxides, which are insoluble in ammonia, and yet not precipitated by it in the presence of ammoniacal salts, form with these salts double soluble salts, from which combinations the ammonia cannot precipitate them.

221. To a solution of alum add caustic soda, until the precipitate which first forms is re-dissolved; then add hydrochloric acid until the solution manifests an acid reaction, and finally ammonia in excess.

222. To a solution of sesquichloride of chromium, add a cold solution of caustic soda, until the precipitate which first appears is re-dissolved; then boil the solution until the hydrate once more precipitates.

223. Add caustic soda to a solution of protosulphate of iron. Boil another portion of the solution of the iron salt with a few drops of nitric acid until it becomes peroxidized, which will be indicated by the solution becoming yellow; when this is attained, add caustic soda in excess. Observe the difference in colour between the two precipitates.

224. Take three portions of a solution of sulphate of copper; to one add ammonia, until the precipitate which is first formed re-dissolves. To the second portion add caustic soda in the cold. Boil the third, and add to it caustic soda.

225. Mix together a solution of a persalt of iron (obtained as in Expt. 223), and a solution of sulphate of alumina (common alum can be employed); add caustic soda to the mixed solution to precipitate the iron; boil and filter.

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* Distilled water ought to be employed; but if that cannot be obtained, rain water must be used.

To the filtrate add hydrochloric acid in excess, and lastly, ammonia, to precipitate the alumina.

255. We have seen, that if an insoluble substance can be formed by a combination of any of the proximate or remote elements in the substances added together, chemical decomposition and combination invariably take place. Thus, if a solution of nitrate of baryta and a solution of sulphate of magnesia be added together, sulphate of baryta, from its insolubility, will be produced; whilst the nitric acid and the magnesia, being set free in the presence of each other, will combine and form nitrate of magnesia. *Sulphuric acid and baryta cannot, therefore, be present in the same solution.*

256. The following table shows the solubility of different *neutral* salts. To ascertain the solubility of any salt by it, find the name of the base in the upright column, and that of the acid in the line at the top; the number placed at the point where the two rows meet shows whether the salt formed by their combination is soluble or otherwise. "The figure 1 means that it is soluble in water; 2, that it is insoluble in water, but soluble in hydrochloric or nitric acid; and 3, that it is insoluble in water and acids; 1—2 signifies a substance difficultly soluble in water, but soluble in hydrochloric or nitric acid; 1—3, a body difficultly soluble in water, and of which the solubility is not increased by the addition of the acids; and 2—3, a substance insoluble in water, and difficultly soluble in hydrochloric acid and in nitric acid. Wherever the deportment of a substance with hydrochloric acid differs materially from that which it exhibits with nitric acid,"* it is noticed in page 131.

257. The use of this table will become apparent by the following example. If it were required to know whether any precipitation would take place, and if so, what chemical changes must ensue, on adding an aqueous solution of carbonate of ammonia and one of chloride of calcium together, we should find, by examining the table, that carbonate of lime was insoluble in water; these two salts would, therefore, be mutually decomposed, and two new ones formed, whenever aqueous solutions of the two salts were brought together.

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* "Qualitative Analysis," by Dr. Fresenius.

TABLE SHOWING THE SOLUBILITY OF SALTS.

Bases. / Acids.	Arsenious.	Arsenic.	Boracic.	Carbonic.	Chloric.	Chromic.	Hydrochloric.	Hydriodic.	Hydrosulphuric.	Nitric.	Oxalic.	Phosphoric.	Silicic.	Sulphuric.
Potash	1	1	1	1	1	1	1	1	1	1	1	1	1–2	1
Soda	1	1	1	1	1	1	1	1	1	1	1	1	1–2	1
Ammonia	1	1	1	1	1	1	1	1	1	1	1	1		1
Magnesia	2	2	2	2	1	1	1	1		1	2	2	2–3	1
Lime	2	2	2	2	1	1	1	1	1–2	1	2	2	2–3	1–3
Baryta	2	2	2	2	1	2	1	1	1	1	2	2	2–3	3
Strontia	2	2	2	2	1	2	1	1	1	1	2	2	2–3	3
Alumina	2	2			1	2	1			1	2	2	2–3	1
Sesquioxide of Chromium		1	2	2	1	2	1			1	1	2	2–3	1
Oxide of Zinc		1–2	2	2	1		1	1	2	1	2	2	2–3	1
Oxide of Manganese		2	2	2	1	1	1	1	2	1	2	2	2–3	1
Protoxide of Iron	2	2	2	2	1		1	1	2	1	1–2	2	2–3	1
Peroxide of Iron		2	2		1	1	1	1	2	1	1–2	2	2–3	1
Oxide of Nickel	2	2	2	2	1	1	1		2	1	2	2	2–3	1
Oxide of Cobalt	2	2	2	2	1	2	1		2	1	2	2	2–3	1
Oxide of Antimony	2	2				2	1–2		2		1–2			2
Suboxide of Mercury	2	2	1	2	1–2	2	3	2	2	1–2	2	2		1–2
Protoxide of Mercury	2	2		2	1	1–2	1	2	2	1	2	2		1
Oxide of Lead	2	2	2	2	1	2–3	1–3	2	2	1	2	2	3	3
Oxide of Copper	2	2	2	2	1	2	1	2	2	1	2	2	3	1
Oxide of Silver	2	2	2	2	1	2	3	3	2	1	2	2		1–3
Protoxide of Tin		2	2			2	1	2	2		2	2		1
Peroxide of Tin							1		2	1				1
Oxide of Bismuth		2	2	2		2	1	2	2	1–2	2	2	3	1

258. The sulphides of cobalt and nickel are difficultly soluble in hydrochloric acid, but are readily decomposed by nitric acid.

259. The protosulphide and bisulphide of tin are decomposed and dissolved by hydrochloric acid; by nitric acid they are each converted into binoxide, which is insoluble in an excess of the acid.

260. Sulphide of copper is difficultly decomposed by hydrochloric acid, but with facility by nitric acid.

261. Sulphide of silver is only soluble in nitric acid.

262. Bisulphide of platinum is not affected by hydrochloric acid; boiling nitric acid converts it into a soluble sulphate of the binoxide of platinum.

263. *Reactions which serve to discover the acid of a salt.*—We shall now direct the student's attention to the way the acid or electro-negative element of a salt can be ascertained.*

264. *Carbonates.*—The neutral alkaline carbonates, as will be seen by referring to the Table, are the only neutral carbonates which are soluble in pure water. Many of the insoluble carbonates dissolve in water containing free carbonic acid, from which solutions they are precipitated on boiling, the free acid being expelled. It is in this state that most of the lime and magnesia, in spring and river waters, exists. The incrustations which are formed in the vessels in which such waters are boiled are due to the precipitation of these carbonates, occasioned by the removal of the free carbonic acid. Carbonic acid is best detected in waters by adding to them *lime water;* by this means, not only is the CARBONATE OF LIME which is formed precipitated, but also that which pre-existed in the solution. This process is employed on a large scale for softening hard waters (waters impregnated with earthy matter).

265. The carbonates are decomposed by all free acids soluble in water (hydrocyanic and hydrosulphuric acids excepted) with evolution of carbonic acid. To *detect* carbonic acid, which is in combination with a base, add to the solution or solid substance under examination hydrochloric acid, and warm the solution, if sufficient gas for

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* The experiments indicated under each class of salts ought to be performed.

detection cannot be procured without. Should any gas be evolved, allow it to accumulate by placing the thumb on the mouth of the test-tube, and afterwards decant it (taking care not to allow any of the liquid to pass over along with it) into another test-tube half filled with *lime water*. A white precipitate of CARBONATE OF LIME will be produced if carbonic acid is present.

266. All the carbonates, with the exception of those of the alkalies, lose their acid upon ignition, the metal being left either in an oxidized or uncombined state, according to its greater or less affinity for oxygen. All the carbonates, without exception, are decomposed when heated to a very high temperature with charcoal, carbonic oxide being disengaged.

267. The alkaline carbonates and bicarbonates affect test-paper in the manner of a free alkali.

268. *Nitrates.*—All the neutral nitrates, as will be seen by the Table, are soluble in water; a few basic salts are soluble in that liquid. Heat decomposes this class of salts, affording products which are rich in oxygen, and which powerfully assist combustion. In consequence of this property, the nitrates deflagrate on hot coals, and often detonate when heated with powdered charcoal. The alkaline nitrates, when subjected to a gradually increasing temperature, disengage at first pure oxygen, and are changed into nitrites (MO, NO_3). Heated still further, they are entirely decomposed, evolving nitrogen and oxygen. The other nitrates disengage oxygen and deutoxide of nitrogen (NO_2), or oxygen and hyponitric acid (NO_4). When those formed by soluble bases are decomposed by heat, they leave a strongly alkaline residue.

269. When nitrates in the solid state are heated with *concentrated sulphuric acid*, in the presence of *copper turnings*, binoxide of nitrogen is evolved, which, in contact with the air, forms red fumes, owing to its conversion into nitrous acid. This experiment ought to be conducted in a narrow test-tube. The colour is best observed by looking into the test-tube lengthways.

270. *Chlorates.*—All the chlorates, as will be seen by the Table, are soluble in water. They are all decomposed by heat. Those of the alkalies and alkaline earths disengage oxygen, yielding a residue of chloride which is *neutral*, while the corresponding nitrates under the same

circumstances leave a strongly alkaline residue. The chlorates of the other metallic oxides disengage by heat a mixture of oxygen and chlorine, leaving an oxide or oxychloride.

271. The chlorates are energetic supporters of combustion, deflagrate on heated coals, and produce violent detonations when heated with very combustible bodies, such as charcoal, sulphur, and phosphorus. To detect this acid, add to a small quantity of the solid substance under examination a few drops of *concentrated sulphuric acid* in the cold. The chlorate will be decomposed, SULPHATE OF POTASH and PERCHLORATE OF POTASH ($KO, Cl O_7$) being formed, along with a GREENISH-YELLOW COLOURED GAS (chlorous acid, $Cl O_4$) which escapes. The application of heat must be avoided; and the quantities operated upon should be small, to prevent any loud and violent explosion taking place.

272. *Chlorides.*—Sub-chloride of mercury and chloride of silver are the only chlorides which are completely insoluble in water, as will be seen by the Table.

273. A metallic chloride, treated with sulphuric acid, disengages hydrochloric acid. When a chloride is heated with peroxide of manganese and sulphuric acid, chlorine gas is evolved, which may be recognized by its odour and greenish-yellow colour. Chlorides dissolved in water give with nitrate of silver a white precipitate, which assumes a violet tinge by exposure to light; the chloride of silver is insoluble in acids, but soluble in ammonia.

274. *Bromides.*—A bromide treated with sulphuric acid disengages hydrobromic acid, and also vapours of bromine, which impart a brown colour to the acid gas. If the bromide be heated with a mixture of sulphuric acid and peroxide of manganese, bromine only is disengaged. Nitrate of silver produces in solutions of the bromides a yellowish-white precipitate of bromide of silver, which is insoluble in acids, but sparingly soluble in ammonia.

275. *Iodides.*—The iodides treated with sulphuric acid instantly produce a considerable deposit of iodine; and if the mixture be heated, intense violet vapours are disengaged. The reaction is due to the decomposition of oil of vitriol by hydriodic acid, water and sulphurous acid being formed, and iodine set free. If the iodide be mixed with peroxide of manganese, red lead, or with peroxide

of lead, upon heating the mixture with sulphuric acid, iodine only is evolved, but no sulphurous acid.

276. Iodine, in a free state, forms with starch, even in highly dilute solutions, a purple precipitate of iodide of starch. If the iodine is in a state of combination with hydrogen, or any metal, it is necessary to liberate it before applying the starch test. The iodine may be liberated from hydrogen or the metals by nitric acid, or chlorine; if chlorine is added, an excess of it must not be employed, as it forms a colourless compound (chloride of iodine) with iodine.

277. *Sulphates.*—Most of the sulphates, with the exception of the sulphates of baryta, strontia, and lead, are soluble in water, as will be seen by the Table. The sulphates of the alkalies, alkaline earths and sulphate of lead, are the only salts of this acid which are not decomposed on simple ignition; the other sulphates are decomposed, and generally yield a gaseous mixture of sulphurous acid and oxygen. Some sulphates, however, are decomposed at so low a temperature, that the sulphurous acid and the oxygen remain united, and are disengaged in the state of sulphuric acid. All the sulphates are decomposed by carbon, assisted by heat; the products vary with the nature of the base and the temperature.

278. Sulphuric acid and the soluble sulphates give in a state of solution with a solution of a salt of baryta a white precipitate of sulphate baryta, which, from its insolubility in acids, is at once distinguished from all other baryta salts; any soluble salt of baryta, in a state of solution, is therefore the best and most delicate test for sulphuric acid.

279. *Sulphites.*—The sulphites of the alkalies and alkaline earths, are changed into sulphates and sulphides on being heated in a close vessel.

$$4\,(KO,\ SO_2) = 3\,(KO,\ SO_3) + KS.$$

The other metallic sulphites disengage sulphurous acid, and the oxide remains as a residue. Heated with carbon, they give products similar to those of the sulphates. Concentrated boiling nitric acid changes the sulphites into sulphates. Chlorine produces the same change on the sulphites in solution. The soluble sulphites also absorb oxygen from the air, and are changed into sulphates.

280. The sulphites may easily be recognized by the characteristic odour of sulphurous acid which they emit when treated by muriatic acid, or by dilute sulphuric acid, which evolution is not accompanied by a separation of sulphur.

281. *Sulphides.*—Sulphur, like oxygen, frequently forms several compounds with the same metal, so that we may have monosulphides, bisulphides, tersulphides, &c. A monosulphide, heated with dilute sulphuric acid, or with hydrochloric acid, disengages sulphuretted hydrogen, which is easily recognized by its odour, and no sulphur is deposited. A polysulphide also disengages sulphuretted hydrogen on being heated with dilute sulphuric acid, or hydrochloric acid; but in addition to the evolution of the sulphuretted hydrogen, a deposit of sulphur is formed. The evolution of sulphuretted hydrogen on the addition of hydrochloric acid, is at once characteristic of a sulphide; and when the quantity of sulphuretted hydrogen is so minute that the smell fails to afford a sufficient proof, it may be detected by holding a piece of paper, moistened with a solution of any soluble salt of lead, over the mouth of the test tube, as a brown or black coating of sulphide of lead will be formed upon the paper.

282. When the sulphides of the heavy metals are heated in contact with air, sulphurous acid is evolved: the metal being left, in some cases, uncombined, and in others as an oxide. The sulphides of the alkalies and alkaline earths are converted by this process into sulphates. Oxidizing agents convert the sulphides into sulphates.

283. *Phosphates.*—The alkaline phosphates are the only phosphates which are soluble in water; all the others are insoluble in it, but readily dissolve in an acid liquid. The phosphates evince no apparent reaction with oil of vitriol, and are thus instantly distinguished from all salts which disengage acid vapours under the same circumstances.

284. Nitrate of silver produces, in aqueous solutions of the phosphates, a yellow precipitate of phosphate of silver ($3\ Ag\ O,\ P\ O_5$).

285. *Arseniates and Arsenites.*—Sulphuretted hydrogen produces, in acidified solutions of these salts, a yellow precipitate, soluble in ammonia; the precipitate is formed immediately in solutions of the arsenites, but only after the lapse of some time in the solutions of the arseniates.

286. *Borates.*—The borates are not decomposed on ignition, they all, *even the acid salts*, manifest an alkaline reaction. Boracic acid turns turmeric paper brown, like an alkali; a borate may therefore be detected by adding hydrochloric acid to the solution of it, and then dipping a piece of turmeric paper into it, and afterwards drying the paper at a gentle heat; if it dries of a distinctly brown tint, boracic acid is present.

EXERCISES.

Required to know whether any precipitation will occur when the following substances are added together; and if so, what chemical changes must ensue:*—

226. If an aqueous solution of sulphate of copper were added to one of nitrate of lead?

227. If an aqueous solution of sulphate of magnesia were added to one of nitrate of baryta?

228. If hydrochloric acid were added to an aqueous solution of protonitrate of mercury, the solution of the mercury salt containing a small quantity of free nitric acid?

229. If an aqueous solution of nitrate of potash were added to one of chloride of calcium?

230. If an aqueous solution of oxalate of ammonia were added to one of chloride of calcium?

231. If an aqueous solution of chloride of sodium were added to one of nitrate of lead?

232. If an aqueous solution of phosphate of soda were added to an hydrochloric acid solution of chloride of calcium?

233. If sulphide of ammonium were added to an aqueous solution of sulphate of copper?

234. If an aqueous solution of chromate of potash were added to one of chloride of barium?

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* The student must state whether any precipitation will occur, and if so, what chemical changes will ensue, before the experiment is made. He must also be made to generalize them; for instance, if he states that sulphate of lead will be precipitated when an aqueous solution of sulphate of copper be added to one of nitrate of lead, he must then say whether an aqueous solution of any soluble sulphate, on being added to a solution of nitrate of lead, would produce a precipitate of sulphate of lead; and then he must say whether sulphate of lead would be formed on adding a solution of any soluble sulphate to a solution of any soluble salt of lead: he must be made to generalize every question which admits of it in this way.

235. If an aqueous solution of sulphate of magnesia were added to one of nitrate of potash?

236. If an aqueous solution of carbonate of ammonia (any of the carbonates of ammonia will do, it need not be the monocarbonate) to one of chloride of calcium?

237. If an aqueous solution of carbonate of soda (any of the carbonates of soda will do) were added to one of protosulphate of iron?

238. If an aqueous solution of chloride of ammonium were added to one of sulphate of zinc?

239. If an aqueous solution of chromate of potash were added to a nitric acid solution of nitrate of baryta?

240. Prepare some sulphide of manganese from the chloride.

241. Dissolve some soluble salt of baryta in water, and prepare from that solution the phosphate, chromate, carbonate, and sulphate of baryta; for this purpose divide the solution into four separate portions; add to one of the four portions a soluble phosphate, to another a soluble chromate, to a third a soluble carbonate, and to the remaining portion a soluble sulphate.

242. Prepare anhydrous oxide, hydrated oxide, and sulphide of copper, from a salt of that metal, which is soluble in water.

243. Prepare a small quantity of sulphate, carbonate, and chloride of lead, from a salt of that metal which is soluble in water.

244.* Prepare some sulphate of baryta from the carbonate.

245. Prepare some carbonate of zinc from the sulphide.

246. Dissolve a salt of baryta and a protosalt of mercury, which can exist together without decomposition, in an appropriate quantity of water; throw down the mercury from the solution containing the two salts, by adding to the solution some acid base or salt, which will precipitate it either as insoluble oxide or as an insoluble salt; filter off from the precipitate thus formed, and to the filtrate (the liquid which passes through the filter), which ought, if sufficient of the substance employed to precipitate the mercury were used, only to contain the baryta

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* Before soluble salts can be prepared from insoluble ones, the latter must, by acids or other means, be brought into a state of solution.

(disregarding the substance employed to precipitate mercury), add some acid base or salt which will precipitate the baryta.

247. Dissolve a salt of peroxide of mercury and one of lime in water, and separate them in a similar manner.

248. Dissolve a salt of lime, a salt of zinc, and a salt of peroxide of iron, and separate them in a similar manner.

249. A manufacturing chemist has a quantity of impure chloride of ammonium, which he desires to purify; the impurity is perchloride of iron: if he were to dissolve the impure ammonia salt in water, could he precipitate the iron in such a way that chloride of ammonium would be the only substance remaining in solution?

287. In each of the three following tables the properties of three bases are contrasted; the student * must perform the different experiments pointed out in each table, carefully noting the reactions which the reagents give with each base, and explaining by diagrams the decompositions produced; after he has done this he must devise a method, or if more than one could be adopted, all the methods which could be employed, for the detection and separation of the three bases named in each table if they were present or were supposed to be present in a solution.

TABLE III.

OXIDE OF SILVER. ($Ag O$).	SESQUIOXIDE OF IRON. ($Fe_2 O_3$).	LIME. ($Ca O$).
1. *Hydrochloric acid* precipitates silver from its neutral and acid solutions in the form of chloride ($Ag Cl$), because chloride of silver is insoluble in neutral and acid solutions.	1. *Hydrochloric acid* produces no precipitate in solutions of sesquioxide of iron, because sesquichloride of iron is soluble.	1. *Hydrochloric acid* does not precipitate lime from its solutions, because chloride of calcium is soluble.
2. *Ammonia* precipitates oxide of silver from its solutions; but an excess of ammonia redissolves it.	2. *Ammonia* precipitates sesquioxide of iron from its solutions, and it is not redissolved by an excess of ammonia.	2. *Ammonia* does not precipitate lime from its solutions.

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* If from want of room or other causes the students cannot make the experiments for themselves, the teacher ought to have large diagrams of the tables suspended in the class-room, and after he has made the experiments, he ought to make each student state in writing all the different methods which could be adopted for the separation of the three bases.

TABLE III. (*continued*).

OXIDE OF SILVER. (AgO).	SESQUIOXIDE OF IRON. (Fe_2O_3).	LIME. (CaO).
3. *Oxalic acid* produces in neutral, but not in ammoniacal solutions, a precipitate of oxalate of silver, as oxalate of silver is soluble in ammonia.	3. *Oxalic acid* does not precipitate sesquioxide of iron from its solutions, as oxalate of the sesquioxide of iron is soluble.	3. *Oxalic acid* precipitates lime as oxalate from its neutral and alkaline solutions.

TABLE IV.

OXIDE OF COPPER. (CuO).	ALUMINA. (Al_2O_3).	BARYTA. (BaO).
1. *Hydrosulphuric acid* precipitates copper from its acid solutions as sulphide (CuS).	1. *Hydrosulphuric acid* does not precipitate alumina from its acid solutions.	1. *Hydrosulphuric acid* does not precipitate baryta from its solutions.
2. *Ammonia* precipitates copper from its acid solutions, but an excess of ammonia redissolves the precipitate.	2. *Ammonia* precipitates alumina from its solutions in the form of hydrate ($Al_2O_3, 3HO$), and an excess of ammonia does not redissolve it.	2. *Ammonia* does not precipitate baryta from its solutions.
3. *Sulphuric acid* produces no precipitate in solutions of copper, because sulphate of copper is soluble.	3. *Sulphuric acid* produces no precipitate in solutions of alumina, because sulphate of alumina is soluble.	3. *Sulphuric acid* precipitates baryta from its solutions, because sulphate of baryta is insoluble.

TABLE V.

OXIDE OF SILVER. (AgO).	OXIDE OF COPPER. (CuO).	OXIDE OF ZINC. (ZnO).
1. *Hydrochloric acid* precipitates silver from its neutral and acid solutions as chloride.	1. *Hydrochloric acid* causes no precipitate in solutions of copper.	1. *Hydrochloric acid* causes no precipitate in solutions of zinc.
2. *Hydrosulphuric acid* precipitates silver from its acid solutions as sulphide (AgS).	2. *Hydrosulphuric acid* precipitates copper from its acid solutions as sulphide (CuS).	2. *Hydrosulphuric acid* does not precipitate zinc from its acid solutions.
3. *Sulphide of ammonium* precipitates silver from its neutral and alkaline solutions as sulphide.	3. *Sulphide of ammonium* precipitates copper from its neutral and alkaline solutions as sulphide.	3. *Sulphide of ammonium* precipitates zinc from its neutral and alkaline solutions as sulphide (ZnS).

CHAPTER X.

INFLUENCE WHICH LIGHT EXERCISES OVER AFFINITY.

Analysis of the sunbeam. An association of three different principles. The influence which heat, light, and actinism exercise over affinity. Production of photographic pictures. Action of light in producing mechanical changes. Lakemaker's partiality for a fine bright day when he makes his colours. The different colours substances assume under different rays. Influence of light in the germination of seeds and the growth and flowering of plants. The proportion of the three principles in the sunbeam varies with the seasons. Exercises.

288. In noticing the chemical effects of light, we will commence by considering the changes a ray of light undergoes when transmitted through a flint-glass prism; it is not only refracted and bent out of its path in passing through this medium, but also, instead of there being one colourless spot of light upon the screen behind, there is a series of coloured spots overlapping each other. At the upper part of this image (or spectrum, as it is called) will be the most refrangible, and at the lower part the least refrangible ray,—the colour of the upper, or most refrangible one, will be *violet*, and the lower, or least refrangible one, will be *red;* the intermediate ones, commencing from the violet end, being *indigo, blue, green, yellow*, and *orange*, all graduating imperceptibly into each other. Sir Isaac Newton, who devised and first performed this experiment, inferred from it that white light is composed of seven prismatic colours, the rays of which are differently refrangible by the same medium, and hence capable of being thus separated. It is now generally believed that there are only three primary colours—red, yellow, and blue—in light, and that by their combination the other four are produced.

289. Heat is associated with light, and it has been found by experiment that this power is unequally diffused over the spectrum,—it gradually increases from the violet to the extreme red, but the maximum temperature exists

some distance beyond the red, out of the visible part of the spectrum, whilst the greatest amount of light exists in the yellow ray. This led to another discovery, perhaps still more interesting, viz., that the chemical action, due apparently to light, was due neither to that principle nor heat, but to another, which has been named the actinic force,—this is most powerful in the violet ray, and a little beyond out of the visible part of the spectrum, and least in the red ray and that part where the heating power is the greatest.

290. A sunbeam, then, is an association of at least three different principles, namely, light, heat, and actinism, or chemical force; and by the use of coloured transparent media, we can, to a certain extent, separate these principles from each other. If in the path of a sunbeam we place a piece of glass, coloured green with oxide of copper, or if that is not at hand, a glass filled with a solution of chloride of copper, we intercept but little light or actinism, while nearly all the heat is prevented from penetrating it. When we employ a sheet of yellow glass, stained with oxide of silver, light passes through it freely, but the actinic force is intercepted to such a degree that substances which speedily undergo chemical change when exposed to ordinary light, remain unaltered, if kept for any length of time in the light transmitted by this glass. A sheet of dark blue glass, stained with cobalt, intercepts a large per-centage of light, but none of the actinic force. A red glass allows the heat rays to pass freely, but obstructs a considerable quantity of the rays of light.

291. How few out of the vast multitudes who stop each day to admire the photographic portraits which are exhibited in our cities and towns, and even in our villages, would believe that there could be any relation between these beautiful sun-drawn pictures and the blackness produced by *caustic* and the inks for marking linen; but how would their astonishment, amounting to incredulity, be changed to admiration, if told that it was from observing this blackening effect of nitrate of silver, when used to remove warts, and mark linen, that our countryman Wedgwood was led to conceive the happy idea of applying it to the production of sun-drawn pictures. He moistened white paper, or white leather, with a solution of nitrate of silver, and then, with the leaf, or whatever he

wanted to copy, superposed, he exposed it to the light; all the parts which were uncovered became black, whilst those which were screened remained white, and thus he was able to copy anything he wished,—but it was a negative copy, the lights and shades being reversed. But this reversing of the lights and shades was the least difficulty he had to encounter; he could not overcome the difficulty of preventing the whole surface of the paper from turning black when exposed to the light, for he was not able to dissolve out all the unchanged silver salt; therefore, as soon as they were exposed to daylight, the unshaded or white parts turned black,—thus the sun-drawn pictures which he obtained faded as quickly as they were formed. Here, however, was the germ which was afterwards in its maturity to astonish an admiring world, but it had as yet to be fed and watered by the labours of scientific men. It was to shoot forth, but not by casualty or accident, but by the elements employed in its creation,—zeal, intellect, and labour,—it was the production of genius, and from no other source could it derive its nourishment. At length the way of rendering the sun-drawn pictures permanent is discovered,—it then comes forth from the philosopher's sanctuary, clothed not, it is true, in perfect beauty, but distinguished by such loveliness that a host of talented admirers devote themselves to complete its perfection. "This discovery enables us to use the sun as the painter of pictures, which she exhibits and enlivens with her glory." By the aid of these sun-wrought pictures, the emigrant, as he leaves his native land, can not only take with him the correct forms and features of the friends he leaves behind, but so perfect is the process, that the outward manifestations of a mother's tender and affectionate feelings, and a father's subdued but poignant grief, can even be portrayed. So perfect has the art become, that objects the most evanescent, scenes the most fleeting, that are once and but for a moment witnessed in the world's kaleidoscope, can be depicted with unerring fidelity.

292. We have now to study the influence which light exerts over affinity, and we shall do so by considering—1st. Whether it opposes or promotes combination. 2nd. Whether it opposes or promotes decomposition. 3rd. Whether combinations accompanied by decompositions are brought about by this agent.

293. Heat, we have already seen, in some cases assists, and in others overcomes, the chemical force; we shall of course be prepared to find that the heat rays of the sun act in the same manner as artificial heat; how the light and actinic rays act we have yet to learn.

294. The combinations brought about by the agency of light are confined principally to the gases.

Ex. 1.—Chlorine and hydrogen, if mixed together, do not unite and form hydrochloric acid at ordinary temperatures, *if kept in the dark;* but they combine with explosion if exposed to sunshine, and more slowly in diffused daylight. So susceptible is a mixture of these two gases to light, that even the light emitted by a taper is sufficient to make them unite; it is, therefore, not surprising that the combination of these gases may be effected in every part of the spectrum, as the actinic power is diffused over the whole of the rays, though in different degrees. The combination is, however, effected with the greatest speed by the extreme blue and indigo rays, where the actinic power is the most intense. We have said that these two gases do not combine together in the dark. It has been found that if chlorine, *which has been exposed to light,* be mixed with hydrogen in the dark, they will combine.

Ex. 2.—If equal measures of chlorine and carbonic oxide be mixed together, and exposed to light, especially sunshine, they unite, a compound ($C\,O\,Cl$) called chloro-carbonic acid or phosgene gas (light-produced gas) being produced. No experiments have yet been made to ascertain in what part of the spectrum these gases most readily unite.

295. The preceding examples show that the actinic force in light in some cases assists combination; we have now to consider it as a decomposing agent. Concentrated nitric acid changes from a white to an orange-coloured liquid on exposure to light (the same change is produced by heat), owing to its being decomposed into nitrous acid and free oxygen; this effect is produced behind white and blue, but not behind orange-coloured glasses. Some metallic oxides, as gold and silver, are completely decomposed; others, such as the oxides of mercury, give up part of their oxygen and part of the metal, a higher oxide remaining. Terchloride of gold, dissolved in water, de-

posits flakes of gold when exposed to the sun. Chloride of silver, which is of a white colour, changes when exposed to the direct rays of the sun or to ordinary daylight, first to violet, and then to black, giving up at the same time a portion of its chlorine; it blackens under violet, blue, and bluish-green glasses; under yellowish-green and yellow glasses it remains almost unchanged; under orange-coloured glasses it only becomes of a faint-red tint, after a considerable time. The bromide and iodide suffer similar changes. The nitrate of silver suffers no change, unless it be in contact with organic matter; it is then decomposed by light, metallic silver being separated.

296. The decomposition of salts of silver by light has been applied (as before intimated) with beautiful results to the production of pictures, Nature being the sole artist. A more interesting experiment could scarcely be exhibited to a class of students than one of these sun-drawn pictures. The following, though not the most sensitive, is easy of execution; great care is, of course, required in all the manipulations; and also as to the purity of the materials used, their correct proportions as to weight and measure, and the absolute cleanness of brushes, cloths, &c., for the least dirt or grease will give rise to the most perplexing failures. Take a sheet of the best writing-paper (perfectly clean), having a smooth surface, and a close, even texture. Dissolve fifty grains of chloride of sodium in one ounce of distilled water, wash the paper in this solution, and then press it between blotting-paper, and then dry it. A solution of nitrate of silver, in the proportions of 120 grains to an ounce of distilled water, is then carefully applied, by means of a soft brush, over one side of the sheet, drying the sheet between each wash in the dark, and at a little distance from the fire. It is now ready for use, anything superposed as a leaf will be copied perfectly; "the light passing through the leaves delineates every ramification of these nerves; the portions to which the light arrives become dark, whilst that under the object remains white, and thus the most delicate and complicated outlines of foliage or fibres may, by a few minutes' exposure to the solar rays, be fixed upon the paper with a degree of accuracy inimitable by the hand." To render such a drawing permanent, all the undecomposed silver salt must be removed, as it would decompose on exposing

the picture to light, and thus the blackness would become uniform over the entire surface. This is effected by soaking the drawing first of all in clean water, it must then be immersed for a few minutes in water to which a little chloride of sodium has been added, subsequently in a solution of hyposulphite of soda, and finally, well soaked in another vessel of clean water. It is then dried. The rationale of the process is this,—the chloride of sodium and nitrate of silver are mutually decomposed, chloride of silver and nitrate of soda being formed in the paper; this chloride of silver is decomposed by the light into its elements, and this is found to take place more readily if a little nitrate of silver be present: hence the second dip into the silver solution. In the copying of any body, as a leaf, for instance, the parts of the paper underneath those parts of the body which are impervious to light, remain white, whilst the other parts of the paper become more or less blackened, according as a greater or less amount of light reaches the surface of the paper; the degree of blackness depending upon the quantity of the silver salt decomposed. By dipping it first in plain water, the greater part of the unchanged nitrate of silver is removed; it is then immersed in a solution of chloride of sodium, in order to convert any nitrate of silver which may remain into chloride: if this was not done, when the chloride came to be removed by the hyposulphite of soda, the nitrate of silver would blacken, because it becomes gradually transformed into black sulphide by hyposulphites; the hyposulphite solution dissolves out the unchanged chloride, and the last immersion in clean water is to get rid of the hyposulphites.

297. The class of photographs named, after the inventor, Daguerreotypes, differ in the material used; as the *canvas* for the picture, a metallic plate (silvered copper) being used in the place of paper. "It is essential to success that the silver should be brought up to the most perfect polish. This is best done by polishing with cotton dipped in sweet oil, and finely levigated Tripoli powder, or rotten stone. The cotton is to be frequently changed, and great care must be taken that the plate is not touched by the fingers. Dry cotton and very fine Tripoli dust must be used to

complete this part of the process. The plate is then subjected to the heat of a spirit-lamp, or a charcoal fire, for a few minutes, and cooled as speedily as possible, by placing it on a mass of metal or a stone floor: the object of this is to remove the organic film which the oil has left on the plate. The plate, when cold, should be finished off with cotton, dipped in a solution of one part of nitric acid to sixteen of water, then with dry and clean cotton, and lastly, rubbed upon a velvet buffer. It is then exposed to the vapour of iodine, until a gold-coloured pellicle of iodine, of excessive tenuity, is deposited upon it. In this state, it is very sensitive to light. On the success, or otherwise, of the iodine operation everything depends. The plate, when viewed by a weak artificial light, should present a perfectly yellow and brilliant surface. Several plans have been suggested, by which the iodine may be made to attack the plate equally; but all of them require, on the part of the operator, the closest care and attention. The simplest method is to place in the bottom of a box pieces of iodine, and cover them with a piece of gauze, stretched on a frame which fits the box. The polished plate is placed a short distance above the gauze. The cover of the box being closed, all is allowed to remain in this state for two or three minutes, when, on removing the plate, it will generally be found that the required fine yellow surface is produced. The prepared plate is now placed in the dark chamber of the camera obscura, and being properly adjusted, it is exposed to the agency which is to impress upon it the required images. The length of time necessary for the production of the best effects, varies with the state of the illumination, the kind of image to be copied, the condition of the plate, and other things which can only be arrived at by experience. The plate being removed from the camera obscura, no image should be visible upon it. A change has taken place; but as the colour of the plate is not altered, that change cannot be seen. If the plate in any part is browned by too long an exposure, the lights of the picture are injured. To develop the hidden picture, the plate is placed in a box, at the bottom of which is a little mercury, so arranged that the heat of a spirit-lamp may be applied until the temperature of the mercury is about 167° F. The lamp is then removed; and the plate, which is watched through a glass in the side of the box, by the light of a taper, allowed to remain until the picture, in all the beauty of its minor details, is perfectly brought out. It is then removed; and it has to be subjected to the operation of fixing, or of rendering the plate of metal insensible to any further solar agency. The fixing may be effected in several ways,—the following is the best: The plate is first placed in clean cold water, and then into a solution of hyposulphite of soda, in which it is moved to and fro, until all the yellow colour is completely gone. It is then removed, placed in an inclined position, and boiled rain water, cooled so as to be just warm, poured over the plate in a continuous stream. Any drops of water which may remain on the plate, must be removed by forcibly blowing over it. The process is now completed, as far as preventing the further action of light is concerned. The picture is formed of the finely divided silver, amalgamated with the mercury deposited over those parts on which the chemical change has been effected, represented by the high black polished face of the silver. This picture can, of course, be immediately destroyed by a touch; it is therefore necessary to protect it at once, by a glass or some other means."—*Hunt.*

298. Hunt's explanation of the process * appears to me to be the most probable—the iodine combines with the silver, forming iodide of silver; this is immediately decomposed, when exposed to radiant action, into its elements, the metallic silver remains on the surface in a finely divided state: the liberated iodine attacks and combines with the silver beneath. And the amount of silver which has been combined with the iodine, and liberated again, "bears an exact relation to the amount of radiant force which has been acting along certain lines. The vapourized mercury immediately unites and forms an amalgam with this silver; and thus are formed the high lights and middle tints of a Daguerreotype picture. If the iodine, which is then combined with the under surface of silver, is allowed to attack the mercury, a very poor result will be obtained: hence the advantage of immediately removing the iodide of silver by the fixing agent employed."

299. We have now to consider the combinations accom-

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* See Second Edition of his "Researches on Light."

panied by decompositions, which are brought about by the actinic force. Water, in which chlorine is dissolved, is gradually decomposed on exposure to light, hydrochloric acid being formed, and oxygen evolved. If an aqueous solution of bichloride of platinum, after it has been neutralized by the addition of lime and then filtered, so as to free it perfectly from all insoluble matter, thus rendering it bright and clear, be mixed with lime-water in the dark, no precipitation, or scarcely any, takes place; but on exposure to sunshine it instantly becomes milky, and a white or yellowish-white precipitate speedily falls. It has been proved by experiment that the formation of this precipitate is solely due to the actinic influence, that the heat and light-giving rays are not concerned in its production. If a solution of sulphate of copper and one of bichromate of potash be mixed together, the solution will remain perfectly clear in the dark for a considerable time; but if exposed to sunshine, a rapid effervescence ensues in a few minutes, and a greenish-yellow substance precipitates.

300. Even when light or actinism produces no *chemical* alteration, but the same chemical changes take place in its presence as occur in the dark, still the mechanical changes may be different; thus, if a coloured precipitate be produced in the presence of light or actinism, and a similar precipitate be produced in the dark, the richness of hue of the former will be much superior to that of the latter. "If a solution of bichromate of potash is exposed to sunshine, it acquires a property of precipitating several metals as chromates, differing many shades from the colours produced by a similar substance prepared and kept in the dark. If the actinized solution be poured into a solution of nitrate of silver, the chromate of silver formed is of a much more beautiful colour than that given by a solution which has not been exposed to the sun. A like effect will take place in precipitating chromate of mercury with actinized and non-actinized solution of the chromate of salt." The sunbeam is therefore as energetic in disturbing the molecular as the chemical arrangements, so that it is highly probable that no substance can be exposed to the sun's rays without undergoing a molecular and frequently a chemical change. It is found, for instance, that if a plate of metal or wood be covered with a thin

coating of any resinous or gummy substance, and then exposed to light, that the solvents of the resinous or gummy substance will have a different effect after its exposure to what they had before. If previously soluble in alcohol, it will be found that this fluid, after the exposure, will only dissolve off the parts on which the light acted; if previously soluble in an essential oil, that this fluid, after the exposure, will only dissolve the parts in shadow, and not those exposed to direct light. But the disturbing influence is not confined to organic or perishable substances—it equally changes the most durable; the hard rock and the durable metal being influenced by it. It has been proved that darkness restores the substances thus influenced to their original condition; the hours of darkness are, probably, as necessary to the inorganic, as night and sleep are to the organic kingdom, for continued light would, most probably, prove as destructive to the one as the absence of sleep would to the other.

301. We have already noticed that certain yellow-coloured glass,—and we may here add that many yellow-coloured solutions have the same effect,—deprive the sunbeams transmitted through them of the greatest part of their chemical influence, but of little light or heat. A coloured atmosphere acts in the same manner; most photographists have observed that the richness of tint and shade vary with the brightness of the sun and the clearness of the atmosphere at the time of exposure. "It is probable," says Sir John Herschel, "that other atmospheric relations than those which refer to the extinction of the merely luminous rays, are concerned in this phenomenon. The tint of coal smoke is yellow (as may be seen in perfection in a London November fog), and more than one instance of the *intense* power and capricious singularities of very pale yellow media, in their action on the *chemical rays*, will come hereafter under our notice. In the locality from which this is dated (Slough), a light easterly wind brings with it abundant smoky haze from London, to which rural prejudices assign the name of 'blight,' and attribute an insect origin. *On such occasions, when the sky has been otherwise cloudless, I have been continually at once annoyed and surprised by the slowness of photographic action, and by the fugitive nature of its results under the process of fixing.*" It has been observed by

Daguerre, and almost by every photographist since the announcement of his discovery, that the sun, two hours after it has passed the meridian, is much less effective in the photographic process, than it is two hours previously to its having reached that point. May not this depend upon an absorptive power of the air, which we may reasonably suppose to be more charged with vapour two hours after, than two hours before, noon?"—*Hunt.** Persons employed in the making of colours, termed Lakes, always prefer a fine bright day for the precipitations; indeed, I believe as a rule, they never make them on a dull, cloudy day. This has been hitherto, and probably is still considered, by some scientific men, an ignorant prejudice; but the most recent discoveries in this department of science, as the preceding illustrations show, go to prove that the Lake-maker's partiality has truth for its basis. It is also believed amongst practical men, that the richness of hue in dyeing silks cannot be attained in England as in France. If this is a fact, cannot we, although we may not be able to obtain the same hue by ordinary means, do so by making the actinic force more serviceable?

302. We must not omit to notice what at present is so interesting, but which, when the principles come to be understood, will prove not only so interesting, but so valuable, viz., the different colours substances assume under the different rays. Thus Hunt has obtained with chloride of silver, when the sunshine has been favourable, a range of colours very nearly corresponding with the natural hues of the prismatic spectrum. "Under favourable circumstances, the mean red ray leaves a red impression on the paper, which passes into green over the space occupied by the yellow rays. Above this, a leaden blue is discovered, and about the mean blue ray, where the action is greatest, it rapidly passes through brown into black, and through the most refrangible rays it gradually declines into a bluish brown, which tint is continued through the invisible rays." So that it is highly probable we shall ere long compel the sun to fix on the photograph the natural and varying colour of objects. It appears that the *kind* of soluble chloride employed for converting the silver into that salt (chloride), has something to do

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* Hunt's "Researches on Light," Second Edition.

with the formation of these colours. Hunt found that he could only obtain the above results when he employed as the soluble chloride, either chloride of ammonium or chloride of barium. The following Table shows the influence the soluble chlorides, in conjunction with the coloured rays, exercise over the colour the silver salt assumes :—

	Under Blue.	Green.	Red Glass.
Chloride of ammonium .	Olive-brown	Pale brown	Deep orange
,, potassium . .	Bright purple	Sky-blue	Red
,, sodium . . .	Purple	Blue	Red-brown
,, barium . . .	Purple	Black	Pale red
,, calcium. . .	Rich violet	Pale blue	Reddish
,, manganese .	Rich brown	Reddish	Yellow
Protochloride of iron . .	Red	Colourless	Leaden
Sesquichloride of iron . .	Blue	Yellowish	Yellow-green

303. The chemical changes brought about by the agency of man are so rapidly effected that it is probable the different forces in the sunbeam exert little or no influence at the *moment* of chemical change: we may, perhaps, except the decomposition of the compounds of silver, &c., but even such compounds as these require, in order to be completely decomposed, that a very small quantity of material be spread over a large surface, so as to bring each individual molecule in contact with light; these conditions cannot of course be complied with when large quantities of substances have speedily to be decomposed or combined; dyeing is, perhaps, the only operation performed by man on a large scale, in which the forces associated in the sunbeam exercise a controlling agency. We must, therefore, look to the operations of Nature, if we would learn the different effects heat, light, and actinism produce. By the aid of the Daguerreotype plate, and ordinary photographic papers, we have discovered that a dissimilar action is exerted by the rays at the two extreme ends of the spectrum. "On the light-coloured salts of silver on paper, the rays above the green darken, while for a considerable time those below the green protect the paper from change. That is, they not merely do not blacken themselves, but they retard, and in many cases entirely check, the action of rays which do

produce that chemical change which is indicated by darkening the white surface. The effects upon the Daguerreotype plates are similar to those." The red rays, especially, appear to exert an antagonistic influence to the actinic force. The following is a singular illustration:—On one occasion, M. Claudet endeavoured to take an impression of the sun, when seen as a red globe through a mist. The Daguerreotype plate was sensibly affected by the diffused daylight on every part, but where the sun's image fell there was not a trace of an image. The solar rays, in this example, protected the plate from the influence of the diffused daylight, which was sufficiently active to produce a chemical change over every other part of the sensitive surface. It has been found that under the brilliant sun and clear skies of the south, where it was thought that photographs would be obtained of the greatest beauty, photographic paper is less sensitive than it is in England; at Mexico, twenty minutes and half an hour are required to produce effects which in London occupy about a minute. "This can only be explained on the supposition that the intensity of the light and heat of those climes interferes with the action of the actinic rays on the sensitive preparations which were employed."*

304. The chemical changes involved in the germination of seeds and the growth of plants, are described in another part of the book, but we must notice them here, though briefly, in order that we may understand the kind of influence heat, light, and actinism exercise over chemical action. "Germination cannot take place at the freezing point of water, and at 212° F. all vitality is destroyed. If seeds are kept quite dry, they will not germinate, although the other conditions are fulfilled. All seeds do not germinate at the same seasons,—some requiring a more elevated temperature than others, which fact explains the cause of the different periods at which we find the plants springing from the soil." During germination the seed absorbs oxygen, and gives out carbonic acid; but this change can only take place in the absence of light: hence the necessity of covering seeds with a thin layer of soil in order to protect them from this agent.

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* Hunt's "Researches on Light," Second Edition.

Hunt, to whom we are indebted for much that is known in this department of science, divided a portion of soil into four; in each he planted a seed,—one he screened with a yellow, another with a red, a third with a blue glass, and the remaining one he left unscreened; he found under the yellow, which admitted the light, but excluded the actinic force in a great measure, that germination was entirely prevented. Under the red glass the germination was not entirely prevented, but comparing it with the one under the normal condition, it was greatly retarded; whilst under the blue glass, which excluded a great portion of the light rays, but admitted the actinic, germination was considerably quickened, the seed germinating many days earlier in this compartment than the one in the unscreened portion. Indeed, Mr. Hunt obtained the most satisfactory evidence, that under the influence of the rays which passed the blue glass, germination was set up at a depth below the surface of the soil, at which under the ordinary condition it did not take place. Lawson, the celebrated seedsman of Edinburgh, now employs blue glass on a commercial scale, for determining the vitality of seeds and accelerating germination.

305. As soon as the leaf-buds of any plant appear above the soil, the plant ceases to absorb oxygen and give out carbonic acid; it now begins to absorb carbonic acid and give out oxygen. But to effect this it requires the aid of light; if kept under a blue glass, no further formation of leaves takes place; it does not increase in diameter, but continues to elongate, until at last it attains an enormous length. Whereas, if a young plant which has just put forth its bud-leaves, be covered with a yellow glass, it shoots forth, forming an abundance of wood and leaves. But neither under yellow or blue glasses will plants flower or produce seed; for the development of their reproductive organs they require the heat rays, which will not penetrate these coloured glasses, but are freely transmitted by red-coloured glass; under this kind of glass they flower in splendid profusion. "Yet this is not simply an effect of heat, since the same temperature may be maintained under all the circumstances; yet if the red rays are obstructed, flowers will not form. It is therefore evident that this very remarkable property must depend upon some function peculiar

to this class of rays."*—*Hunt.* This explains why we are not able to obtain the same results in our hot-houses as in tropical climates.

306. "By experiments of this kind, it has been proved that *germination* is accelerated by actinism, or the chemical power of the sunbeam; the *growth of the plant* (lignification) by light, the luminous power; and *flowering* by heat," or rather, those peculiar thermic rays which are transmitted by red-coloured glass, and to which reference has just been made.

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[*] Plants in stove houses become more or less scorched in autumn: to prevent the Palms, in the large Palm-house, in the Royal Botanical Gardens, at Kew, being thus affected, Mr. Hunt suggested that the glass used in glazing should be free from oxide of manganese, and be coloured with oxide of copper to a pea-green tint. This has had the desired effect; the glass thus prepared obstructs the passage of those peculiar heat-rays which produce the scorching.

CHAPTER XI.*

INFLUENCE WHICH ELECTRICITY EXERCISES OVER AFFINITY.

Excitation by friction. Electric spark. Conductors and non-conductors. Attraction and repulsion. Theories with regard to the nature of electricity. Excitation by chemical action. Voltaic circle. The different action acids have upon two metals separately and conjoined. Application of this principle. The essential elements for the formation of a voltaic circle. Upon what the direction of the current depends. Disadvantages of the ordinary acid battery. Smee's and Daniell's batteries. The electricity developed by friction and chemical action essentially the same. Quantity and intensity. Influence which electricity exercises over affinity. Exercises. Arrangements of the elements in the decomposing cell. Attractive power supposed to reside in the wires. The supposition shown to be erroneous. The wires only paths for the ingress and egress of the fluid. Explanation of terms. Summary of the more important principles. Definite nature of electro-chemical decomposition. Electrotype and electro-plating.

307. If a piece of dry glass rod be rubbed very briskly for a short time with a piece of dry silk, the rod will acquire the power of attracting light bodies, as bits of paper, light downy feathers, &c., and afterwards of repelling them. In the dark, the rod will, immediately after it is rubbed, appear faintly luminous, and if the finger be held to it, a small spark will be seen to pass from it to the finger, which will be attended with a slight snapping noise; if held near the cheek, it will cause a feeling as if a spider's web had been drawn across the face. These properties were first discovered in amber,

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* This chapter must not be regarded in the light of a treatise upon electricity; it has only been entered upon for the purpose of rendering the student, who has had no prior acquaintance with the subject, capable of understanding the influence which this agent exercises over affinity.

which substance was called by the Greeks *electron:* hence the unknown cause of these and other remarkable phenomena, produced when certain substances are rubbed, has been called electricity.

308. Glass, or any substance which has acquired the properties above described, is said to be electrically excited; the spark is called the electric spark; and the motion to and from the rod by the light bodies, is called electrical attraction and repulsion. All substances may be made to assume electric properties by friction, "but in many substances the electricity disappears as fast as it is formed. We cannot, for example, excite a rod of metal like one of glass, by holding it in the hand and rubbing it. If, however, the metallic rod has a glass handle, it can then be excited, and will retain its electricity," because the glass, owing to its non-conducting properties, prevents the electricity from the metal escaping by means of the operator's body to the earth—which is the great reservoir to which all free electricity endeavours to return. "Substances are arranged into two classes,—*conductors* and *non-conductors*, or *insulators.* Metals are the best conductors, because electricity travels along them with the greatest facility. Glass, resin, sulphur, dry air, &c., are called non-conductors, because electricity travels along them with difficulty. The bodies in which electricity is excited are called *electrics*, and in general, the best electrics are the worst conductors, and *vice versâ.*" Ice is a non-conductor of electricity, and by rubbing a stick of ice, it becomes excited; but it must not melt upon the surface, for liquid water, although inferior to the metals in conducting power, is yet so excellent a conductor, that it allows the electricity to pass away as quickly as it is developed. For this reason, a body cannot be electrically excited, if it, or the rubber, or both, be damp, because the moisture conducts away the electricity as quickly as it is developed: hence the necessity of drying carefully the substances which are by friction to produce electricity, and, also, the drier the atmosphere, the more excited will the rubbed body become. Insulators must, for the same reason, be kept free from damp, for if the thinnest layer of moisture be deposited upon their surface, the electricity from the insulated body will escape. "Such is the principle of the electric machine, in which a cylinder or plate

of glass is rubbed on a cushion of silk, and the electricity collected on a cylinder of metal, called the conductor, which is supported on a glass pillar, and so insulated. The cushion must be in full communication with the earth by a wire or chain, otherwise the evolution of electricity soon ceases;" the cause of its cessation will be presently explained.

309. If a glass rod, after it has been excited, be held near two down feathers, or elder pith balls, suspended from the ends of a long piece of silk thread, they will be attracted by and adhere to it; but after a time they will spring from it, and they will not for some time hang down loosely as before, but will repel each other: as soon as they assume their natural position, they will be again attracted by the glass, if held near them, and afterwards repel and be repelled as before. The experiment is thus explained:—When the feathers adhere to the glass, they rob it of a portion of its electricity, which renders them similarly electrified; they are then repelled from it, and repel each other, because *like electricities, or bodies similarly electrified, repel each other, but unlike attract:* after a time, the electricity with which they were charged escapes into the atmosphere, and they then regain their natural state. All electrified bodies, after the lapse of a longer or shorter time, lose their electricity, and resume their condition of electrical quiescence.

310. If a disc of wood, into which a glass handle is fitted, be covered with a few folds of silk, and this be rubbed against a piece of glass, the operator holding the silk rubber by the glass handle, so as to keep the silk insulated, it will be found, after rubbing for a short time, that the silk will exhibit electrical properties, as well as the glass; it will attract light bodies, it will exhibit the phosphorescence, in fact, all the other properties. Yet the electricity of the silk differs from the electricity of the glass; for, after the pith balls have been repelled by the glass, because they have become similarly electrified, they will be attracted by the silk, if it is held near them; and when they are repelled by the silk, they will be attracted by the glass; further, if on one side of a ball or feather, suspended by a silken string, the excited glass, and at the other, the excited silk, be held at equal distances, the ball or feather will remain unmoved; whereas,

if either one or the other be removed, it will instantly be attracted by the one which remains.

311. "Most philosophers have assumed the existence of a peculiar *electrical fluid* as the cause of the various electrical phenomena which present themselves to our notice. In more fully explaining the properties of this fluid, there are two principal theories propounded,—the one supposing that there is but *one*, the other, that there are *two electrical fluids*.

312. "According to the first supposition, viz., that there is one fluid, the particles of this fluid are considered to be repulsive to each other, but attract, and are attracted, by the particles of matter; and when combined with the latter, they lose their repulsive tendency towards one another. All terrestrial bodies contain this electrical fluid, but their capacity for it varies; when any substance contains that quantity which answers to its capacity, no electrical action is observed, and the body is in a state of *electrical indifference;* but if the fluid be in either *redundancy* or *deficiency*, this quiescence is disturbed, and the body is electrified. A body may therefore be electrified, either by adding to its electricity, or by subtracting from it; or lastly, by the fluid, which was previously distributed equally throughout it, being accumulated in one direction, so that a redundancy is created in one part whilst a deficiency exists in the other. Bodies positively electrified have a tendency to give out to other bodies the excess of their electricity; those which are negatively electrified endeavour to withdraw the fluid from others, to supply their deficiency." Suppose a body, A, negatively electrified, to be brought into the neighbourhood of a body, B, positively electrified. The excess of electric fluid in B repels the fluid still remaining in A towards the end furthest from B, thus leaving the nearer end of A more negative than before,—and at the same time the redundant ponderable matter in A attracts the electric fluid in B towards itself, thus rendering the nearer end of B more positive, and the further end less positive, than before.

313. "If this view be adopted, the operations of electricity will be found closely to resemble those of heat.

314. "According to the other hypothesis, all electrical phenomena result from the action of two electrical fluids diffused throughout the universe. These fluids are

assumed to be extremely rare, imponderable, and expansive in the highest degree. The particles of each, by virtue of this last-named property, mutually repel each other, and in this respect the two fluids are perfectly equal. The particles of the one fluid are, however, supposed to have an attraction for those of the other; they therefore combine when no obstacle stands in the way; and when united in exactly equal quantities they lose their expansive force. To one of these fluids has been given the appellation of *positive electricity*, + E; to the other, that of *negative*, — E; they are both *antagonist electricities*, and this opposition is termed their *polarity*. If both the fluids exist in equal proportions in any body, no electrical action happens, but the body is in a state of *quiescence*. A body is *positively electrified*, either by imparting to it some free positive electricity, or its condition of indifference is disturbed by withdrawing from it a portion of its negative electricity; it is negatively electrified if the converse happen. A body may appear electrical on two opposite sides; for one may have positive, and the other negative electricity. This electrical state obtains, if a portion of its neutral electricity be resolved, so that the positive electricity is accumulated at one extremity, and the negative at the other. If the cause ceases which excites this disturbance, the fluids again combine, and the body is restored to a state of quiescence. Lastly, according to this view, all electrical phenomena are owing to the tendency of these antagonist fluids to combine in equal quantities, and in the property of their particles, mutually to repel each other and neutralize each other's effects.

315. "Whatever may be the cause of the various electrical phenomena, we must regard our earth as an inexhaustible storehouse of electricity. It is, in a manner, a great reservoir, from which the fluid issues, or may be procured in various quantities, and to which it again returns from electrical bodies on its surface."—*Peschel's Physics*.

316. Any two dissimilar bodies, when properly rubbed, become, like the glass and silk, oppositely electrified; a stick of sealing-wax, and a piece of dry flannel, for instance, when rubbed together, become excited,—the resin assumes the same state as silk when this material

has been rubbed against glass, and the flannel the same state as the glass.

317. It will, from what has been now stated, be easily understood why the cushion of the electrical machine must be in perfect communication with the earth; if it were insulated, only so much electricity as equals the quantity of quiescent electricity contained by the glass and silk could be developed by the friction—the positive electricity would accumulate in the glass, the negative in the silk;—when, therefore, the positive electricity which the glass had thus acquired was removed by the conductors, the supply of electricity must cease. To obtain a permanent supply, it is necessary that one of the rubbed bodies should be kept in a state of electrical quiescence: for this purpose the rubber is always in direct communication with the earth, which supplies it with positive electricity as quickly as it is removed by the glass.

318. By the aid of the Leyden jar, we can collect and accumulate large quantities of electricity. The jar is nothing more than a glass bottle, coated inside and outside with tin-foil; it has fitted to its orifice either a wooden or a cork stopper, through an opening in which, a stout wire passes to the bottom of the jar, touching the tin-foil coating, and terminating outside in a metallic knob. If this knob be made to touch the conductor of the electrical machine when this is in action, the developed positive electricity passes into the interior of the jar, and there accumulates; this excess of positive electricity in the inner coating, repels, by a peculiar action called *induction*, the positive electricity of the external coating, which escapes to the earth. The accumulation of positive electricity in the inner, and negative in the outer, coating of the jar, proceeds until the tendency of the two to combine is so intense, that they either pass through the glass, or they creep over the mouth from the edge of the one tin-foil coating to that of the other, and thus the jar discharges itself. Of course, in practice, the operator does not allow this to take place,—he, by the aid of a wire fitted with a glass handle, discharges the jar by connecting for the moment the two coatings together by means of this wire; a brilliant spark, accompanied with a loud noise, passes between the knob of the jar and the wire of the discharging rod.

319. We have now to notice another, and perhaps the most fertile source of electrical development, viz., chemical action. When a piece of common commercial zinc is placed in dilute sulphuric acid, it speedily dissolves,—sulphate of zinc being formed, and hydrogen set free, which is evolved at the surface of the zinc; but if the zinc be rubbed over its surface with a little mercury, the acid will have, if any, a very slight action upon it. If a piece of copper be introduced into the acid along with this amalgamated zinc, the acid will still have no action on the latter metal, unless the two are made to *touch each other* either in or out of the liquid, or by the intervention of a metallic wire, or any good conductor of electricity; the acid, when contact has thus been established between the two metals, will rapidly dissolve the zinc,—the hydrogen escapes, not as before from the surface of the zinc, but from that of the copper; the acid does not act upon the latter metal. The solution of the zinc goes on as long as the metallic contact is unbroken, but when this occurs it instantly ceases; this simple arrangement (Fig. 13) is called a galvanic or voltaic circle. A current of positive electricity continually circulates during the contact from the zinc through the liquid to the copper, and from the copper along the conducting wires to the zinc, as indicated by the arrows in the figure. A current of negative electricity, agreeably to the theory of two electric fluids, traverses the apparatus in the reverse direction.

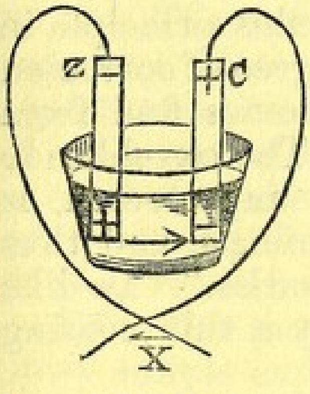

Fig. 13.

320. Not only does the electric current, generated by the contact of two metals, increase the disposition of one of the two to combine with some element, like oxygen and chlorine, of the liquid in which they are immersed, but it decreases, in like ratio, the disposition of the other metal to combine with such elements; in fact, if this latter metal were already combined with either oxygen, chlorine, or any similar metalloid, it would, on its connection with the other metal, be disunited from it. Davy beautifully applied this principle to prevent the corrosion of the copper sheathing of ships. Copper undergoes rapid cor-

rosion in sea-water, owing to the chlorine of the chlorides in the water and atmospheric oxygen combining with it, and forming an oxychloride of copper. But if the copper be in contact with zinc, or any metal which has a greater affinity for these elements, then the chemical action takes place between this other metal and these metalloids, the copper remaining intact. "Davy found that the quantity of zinc required thus to form an efficient voltaic circle with copper was very small. A piece of zinc as large as a pea, or the head of a small round nail, was found fully adequate to preserve forty or fifty square inches of copper; and this, wherever it was placed, whether at the top, bottom, or middle of the sheet of copper, or under whatever form it was used. When the metallic protector was from $\frac{1}{40}$th to $\frac{1}{50}$th, there was no action on the copper; with smaller quantities, such as $\frac{1}{200}$th to $\frac{1}{460}$th, the copper underwent a loss of weight which was greater in proportion as the protector was smaller; and as a proof of the universality of the principle, it was found that even $\frac{1}{1000}$th part of cast iron saved a certain proportion of the copper.

321. "Unhappily for the application of this principle in practice, it is found that unless a certain degree of corrosion takes place in the copper, its surface becomes foul from the adhesion of sea-weeds and shell-fish. The oxychloride of copper, formed when the sheathing is unprotected, is probably injurious to these plants and animals, and thus preserves the copper free from foreign bodies." In like manner, iron is protected from rusting by a thin coating of zinc.

322. Copper and zinc are not the only metals which can form a voltaic circle; any two dissimilar metals, when placed in a liquid which dissolves only one of them, will answer, but the more dissimilar the two metals are in their chemical relations, the greater the intensity of the electricity produced. Thus the more prone the one metal is to unite with oxygen and bodies like it, and the less prone the other is to combine with these, the better the galvanic arrangement.

323. "The essential elements of an arrangement by which a current of electricity may be produced, are, therefore,—First, two bodies—one simple, and one compound—which act chemically upon one another, in such a way that the simple element shall be substituted for a constituent of

the other (hydrogen in one example) which shall be expelled; and second, a conducting substance, which is indifferent in a chemical point of view, and only furnishes a route for the fluids of the actual elements to recombine continually with each other. In the example we gave, this conductor was a slip of copper. It is not necessary that this conductor should be a metal,—any conducting material, such as charcoal, will answer. 'But it is not even necessary that it should be a solid; it is only for convenience that the ordinary conducting plates and wires are metallic;' for a current is obtained by one metal and two liquids, provided the liquids are such that a stronger chemical action takes place on one side of the metal than on the other. Nay, a plate of metal, with two portions of the same liquid, but of different strengths, forms a simple circle; and even the same liquid, of but one strength, if one side of the metal be more rapidly acted on by it than the other, will produce a current." This may be effected, for example, by having one side rough, the other polished.

324. The reason why commercial zinc is so readily acted upon by dilute sulphuric acid, is owing to its containing small quantities of iron, which form with the zinc, when it is immersed in the acid, numerous voltaic circles. Pure zinc is very slowly acted on by dilute sulphuric acid, but if fused with about 2 per cent., or rather less, of iron filings, it is as readily dissolved as commercial zinc.

325. The passage of the current may be shown by a very simple experiment. "If a slip of zinc be bent, as in B, and a bit of paper moistened with iodide of potassium be laid upon it, and the wire from the copper, A, be then brought to touch the upper surface of the moistened paper, the current passes in the direction of the arrow, and iodine is evolved at the point of contact of the wire. If the surface of the paper next the zinc plate, B, be examined, it will be found to be alkaline, from free potash. Thus the chemical action of the current, which will hereafter assume so important a position, may here be simply used as a test of its having passed.

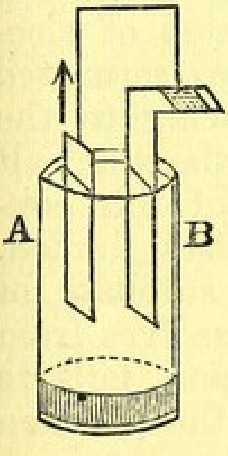

Fig. 14.

326. "The direction of the current depends upon the

nature of the chemical action which is produced at the period of its passage; and on this principle is founded one of the most cogent and reasonable arguments in favour of the idea that the current is produced by the chemical decomposition, and not by the contact of the metals, as has been maintained. Thus, if a slip of iron and a plate of copper be immersed in muriatic acid, the action is altogether on the iron, and the current passes from the copper to the iron at the point of contact. But if the metals be immersed in a strong solution of ammonia, which acts upon the copper but not upon the iron, the current is produced in the reverse direction. If persulphide of lime, dissolved in water, be used as the exciting fluid with iron and copper, the current is from the copper to the iron through the fluid; but on using zinc and copper with the same fluid the direction of the current is reversed; in the first case, the copper, and in the last, the zinc, is acted on: with acid solutions the copper would have escaped action, and the current should be in both cases from the iron or zinc, to it, through the liquid."

327. We stated in a preceding paragraph (319) that the chemical action would go on, and electricity be developed, as long as the contact between the two metals was unbroken; by this we did not mean the student to suppose, that if a strip of zinc and one of copper were placed in dilute sulphuric acid, and contact established, nothing would stop or interfere with the formation of sulphate of zinc and the development of electricity but the breaking of the contact—for it is self-evident that if all the sulphuric acid or all the zinc were expended, the dissolving of the zinc must cease, and with it the evolution of electricity—further, as soon as the liquid becomes saturated with sulphate of zinc the action ceases, owing to the liquid being unable to dissolve any more of the zinc salt (see par. 227). But long before a battery of this construction ceases from any of the three causes named, the efficacy of the battery decreases as the sulphate of zinc increases. Because the zinc salt, as it dissolves from the plate, being heavier than the acid solution, falls to the bottom; hence, in a very short time, the solution becomes of different densities, and this induces (as we have already noticed in par. 323) a galvanic action to be established between the lower and upper portion of the

zinc plate. A battery of this kind also becomes impaired from some of the hydrogen decomposing some of the sulphate of zinc, sulphuric acid being formed and metallic zinc set free, which is deposited on the copper. This weakens the electric current, both by inducing a galvanic action between the zinc and the copper upon which it is deposited, and by its tendency to send a current of electricity in an opposite direction to the main current, thereby neutralizing to a great extent the original power of the circle. Some of these defects have been greatly lessened by using silver plates covered with a thin layer of spongy platinum* in place of the copper; this, which is called Smee's battery, is arranged in the following way:—Two amalgamated plates of zinc are clamped to a piece of wood, and between these two plates is fixed the platinized silver plate. The two metals thus arranged are inserted in a vessel of dilute sulphuric acid.

328. An ordinary acid battery is most active when first brought into play; its power gradually diminishes, and at last ceases, although the acid may not be saturated; this arises from the reduction of some of the sulphate of zinc by the liberated hydrogen, and the deposition of the zinc, thus set free, on the copper plate. This disadvantage has been obviated by causing the hydrogen to be absorbed by a solution of sulphate of copper; it reduces this salt, like the one of zinc, sulphuric acid being formed and metallic copper set free, which is precipitated upon the surface of the copper plate, thereby not only maintaining but improving the surface of this plate during the evolution of a constant current of electricity. This arrangement has been called after the inventor, Daniell's battery, or from the constancy and uniformity of the current maintained, the constant battery. "A cell of this battery consists of a cylinder of copper three inches and a half in diameter, which experience has proved to afford the most advantages between the generating and conducting surfaces, but which may vary in height according to the power which it is wished to obtain. A membranous tube, formed of the gullet of an ox, is hung in the centre by a

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* It has been ascertained, that if the surface of the negative element is roughened, the evolution of hydrogen is much facilitated; Mr. Smee, therefore, in his battery, deposits the platinum in powder on the negative plate, thus obtaining myriads of conducting points for the hydrogen.

collar, and a circular copper plate, resting upon a rim, is placed near the top of the cylinder, and in this is suspended by a wooden cross bar a cylindrical rod of amalgamated zinc, half an inch in diameter; the cell is charged with eight parts of water, and one of oil of vitriol, which has been saturated with sulphate of copper; and portions of the solid salt are placed upon the upper copper plate, which is perforated like a colander, for the purpose of keeping the solution always in a state of saturation. The internal tube is filled with the same acid mixture without the copper. A tube of porous earthenware may be substituted for the membrane with greater convenience, but probably with some little loss of power." The action of this battery is similar to the simple one we first described; the zinc is dissolved by the acid, the sulphate of zinc is prevented from mixing with the copper solution by means of the porous diaphragm; the hydrogen set free decomposes its equivalent of sulphate of copper, sulphuric acid being formed, and metallic copper precipitated on the copper plate.

329. The electricity evolved by chemical action, and that developed by friction, are essentially the same; by the first of these two modes we obtain a much greater quantity than can be developed by the other, yet, from its state of continued recombination, it has much less intensity; its intensity is so low that it can only pass through good conductors; pure water, through which frictional electricity passes with rapidity, almost completely intercepts the current from a simple circle, and the wires through which it is conducted may be touched by the hands, yet no shock will be received. To increase the intensity, a number of pairs of the metal plates are connected together in the following way:—We will suppose, for the sake of illustration, that three pairs of Daniell's plates, each of them being, of course, in separate vessels, are to be connected; it matters not which metal we commence with, provided we link it with the opposite one in the next: say we commence with the zinc in the first vessel, this we connect with the copper in the second, and the zinc in the second with the copper in the third; the zinc in the third and the copper in the first are unconnected with the others, a copper wire is therefore soldered to each of these two plates, and by means of

these wires we connect these two plates together, and so complete the circuit (Fig. 15). The quantity of electricity which circulates in this arrangement only equals that which would be produced by one pair of plates, because the positive electricity of the copper in the second cell is neutralized by the negative electricity of the zinc in the first cell; in the same way, the copper in the third is neutralized by the zinc in the second, so that it is only the amount of electricity liberated upon the copper in the first, and the zinc in the third, that passes along the terminal wires.

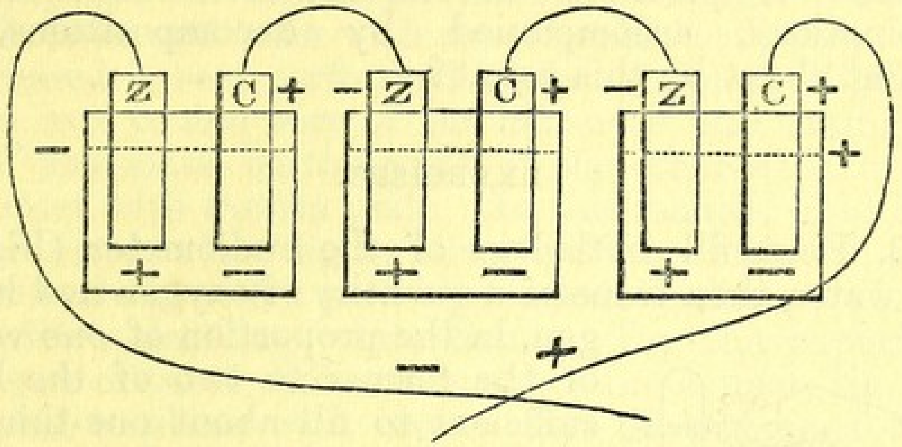

Fig. 15.

330. Although the quantity of electricity which circulates along the terminal wires of any number of pairs of plates (arranged in the way described) is not larger than circulates along the wires from a single pair, yet its intensity, that is to say, its velocity and power, far exceeds that generated by a single pair, no matter what their size.

331. "When the current of electricity is retarded by means of an insufficient conducting medium, the centre of the conductor becomes hot, and thus the most brilliant effects of heat and light may be produced; even the most refractory metals, as gold and platinum, being, when in thin foil or wire, dissipated actually in smoke. By terminal points of well-burned charcoal this phenomenon is beautifully produced, the ignition being totally independent of combustion, for it takes place *in vacuo*, or in carbonic acid gas; and when the points are separated from one another to a certain distance, the interval becomes occupied by a splendid arch of light, formed by the inductively excited particles of charcoal, which, in a state

of intense ignition, abandon the positive, to attach themselves to the negative extremity of the conductor."

332. We have now to study the influence which electricity exerts over affinity, and we shall do so by considering—1st. Whether it promotes combination? 2nd. Whether it promotes decomposition? 3rd. Whether combinations, accompanied by decompositions, are brought about by this agent?

EXERCISES.

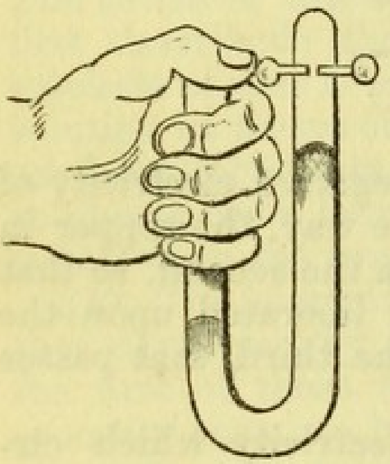

Fig. 16.

250. First fill both legs of the eudiometer (Fig. 16) with water, then transfer a quantity of oxygen and hydrogen, in the proportion of one volume of the former to two of the latter, sufficient to fill about one-third the longer leg; "then, being placed upright, part of the fluid in the open leg is displaced by inserting a glass rod, or in some other manner. The open leg being grasped by the hand, the thumb is to be placed tightly over the aperture, so as to close it, and at the same time to touch one of the wires; a spark taken from the conductor of the electrical machine to the other wire passes through the gas, inflaming it, and is conducted off by the thumb and hand. The gas, in expanding, depresses the fluid beneath it, whilst the air in the part closed by the thumb, acts as a spring to restrain the violence of the explosion. If a charge from a jar is to be passed, then the thumb must not be allowed to touch the wire whilst closing the aperture; when the jar is charged, the wire connected with the outer coating is first to be hooked upon the eudiometer wire nearest the thumb, and securely retained there, so as not to slip during the experiment, and then the knob of the jar is to be brought to the other wire, and the gas will be inflamed." The oxygen and hydrogen combine and form water, and if the proper proportions are employed, no gaseous residue remains behind, but if either of the gases is in excess, the excess remains uncombined.

251. Explode in the same way equal measures of chlorine and hydrogen; hydrochloric acid will be produced.

252. Explode in the same way one measure of oxygen and two of carbonic oxide; carbonic acid will be produced.

253. If thin metallic leaves be subjected to the action of an electric current, either from the machine or battery, they inflame and burn with considerable brilliancy. The experiment is best performed by fixing a plate of polished tinned iron to one wire of the battery,* and taking up a leaf of any metal on the point of the other wire, bring it in contact with the tin plate. In this manner gold burns with a vivid white light, silver with an emerald green, copper and tin with a pale bluish, lead with a purple, and zinc with a dazzling white flame. Try the experiment with each of these different metals; the copper, tin, lead, and zinc combine with the oxygen of the air, forming oxides, and perhaps the gold and silver are also oxidized. These metals may be fused and volatilized even *in vacuo,* and in close vessels filled with gases which put a stop to the chemical process of combustion, such as nitrogen and carbonic acid. Therefore their volatilization in air, and the evolution of light which attends it, is no proof that they undergo combustion, that is to say, oxidation.

333. These, and all other combinations—brought about apparently by the electric force, are, with one exception, considered to be produced, not by that force, but by the heat which is always elicited with it—the exception is the combination of nitrogen with oxygen. If electric sparks are made to pass for a long time through a mixture of these two gases, they combine and form nitric acid. And as these two gases have never yet been made to unite by the application of heat from any of its ordinary sources, it is considered that their combination must be due solely to the electric agent.

334. We pass on to notice the influence of electricity as a decomposing agent.

EXERCISES.

335. Before describing the experiments, we must ob-

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* Employ a Smee's battery of from two to six pairs of plates.

serve that, if the terminal wires, either from a simple or compound circle, instead of being placed in contact, are dipped into a liquid, which can conduct the electricity, it circulates exactly as if the wires were in contact with each other, and that it decomposes the liquids through which it can circulate. The liquid in which the wires dip is termed the decomposing cell; the cell of the battery is termed the generating cell.

254. Let the terminal wires of a Smee's battery, consisting at least of six pairs of plates, be placed by means of the *connectors* A B, in communication with the platinum plates P P. The tubes are filled with water, which is rendered a better conductor by the addition of some sulphuric acid, and inverted in the vessel E, filled with the same fluid over the platinum plates P P. Immediately connection is made with the battery, the platinum plates will become covered with bubbles of gas, which being evolved, will rise in the tubes in unequal proportion, rather more than twice as much gas being collected in a given time in one tube, than in the other. The smaller volume is oxygen, the larger volume is hydrogen; the former is *always* evolved at the surface of the platinum plate, where the current of positive electricity enters the fluid in E, and the hydrogen *always* at that surface where it leaves the fluid. As these gases are evolved from the decomposed water, their volumes ought to be to each other as two to one; the reason why they are not precisely in this proportion is to be found in the partial solubility of oxygen in water; and hence, on this account, the volume obtained is rather below the true quantity. The student will observe that the gases are evolved from both plates, simultaneously; and although at each instant but a single molecule of water is decomposed, the hydrogen being evolved from one, and its oxygen from the other plate, the gases are not observed to pass from P to P, the fluid between these plates being free from bubbles.

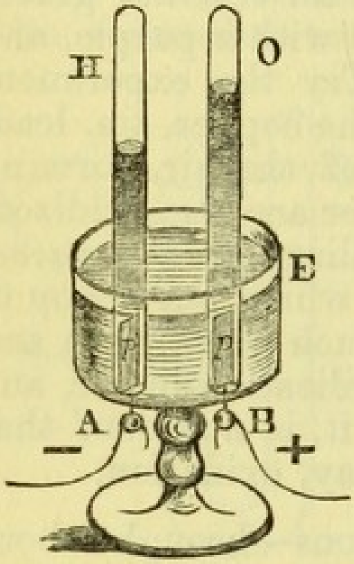

Fig. 17.

255. Fill the V tube (Fig. 18) with a weak solution of sulphate of soda, coloured blue with some vegetable pigment, as blue cabbage liquor. A plate of copper foil soldered to a copper wire is inserted at each end, and connected by the binding screws with the galvanic battery. The sulphate of soda is soon decomposed: the soda will be disengaged at that end of the tube where the electricity leaves the fluid, and will colour the liquor *green;* the sulphuric acid will be set free at the other end, that is, where the electricity enters the fluid, and will colour the liquor *red*, whilst the central portion of the tube will retain its blue colour. Transpose the wires from the battery so that the negative wire shall be in the red fluid, and the positive in the green; after a short time they will both recover their original blue tinge, and then that which had before been red will become green, and the green will turn to red.

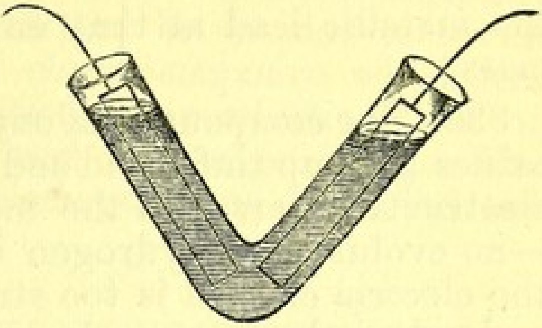
Fig. 18.

256. Fill the V tube with a solution of iodide of potassium, containing some starch paste; the iodide will be decomposed: the iodine will be disengaged at that end of the tube where the electricity enters the fluid, and will colour the starch blue; the potash will be disengaged at that end of the tube where the electricity leaves the fluid. If a piece of red litmus paper be inserted in this end it will be coloured blue, from the presence of the free alkali. Transpose the wires as before, and in a short time the potash will appear at the end where the iodine first appeared, and the iodine at the end where the potash was first eliminated. One pair of plates is sufficient to decompose the iodide.

257. Introduce into the V tube hydrochloric acid coloured blue, with a solution of sulphate of indigo; the acid will be decomposed: the chlorine will be disengaged at that end where the electricity enters, and will render the liquid colourless by bleaching the indigo; the hydrogen will be evolved at that end of the tube where the electricity leaves the fluid.

258. If the terminal wires of the battery be dipped

into a cup containing fused chloride of lead, the lead compound will be decomposed; the chlorine will be disengaged at that end where the electricity enters, and the metallic lead at that end where it leaves the fused mass.

336. The compounds of oxygen acids with heavy metallic oxides give up their acid and oxygen at the end where the electricity enters, and the metal where it leaves the fluid —no evolution of hydrogen taking place, excepting when the electric current is too strong, and its action is partly exerted on the water. In the case of some metallic salts (those of manganese, lead, and silver), the oxygen liberated at the positive pole combines with the metallic oxide there situated, and forms with it a peroxide, which is precipitated. If the terminal wires are formed of the same metal as that contained in the solution, the acid and oxygen which collect at the wire where the electricity enters, dissolve as much metal from the wire as they have lost, and so reproduce the original salt; thus the liquid remains unaltered in strength, and the wire by which the electricity enters loses a quantity of metal equal to that which is deposited at the opposite wire.

EXERCISE.

259. Insert the terminal wires, which must be platinum, in a solution of sulphate of copper; metallic copper will be deposited on the wire by which the electricity leaves the fluid, the acid will collect and the oxygen be evolved at the wire by which it enters. Perform the same experiment, the terminal wires being copper; in this case it will be found, that wire by which the electricity enters loses as much metal as is deposited on the wire by which the electricity leaves the fluid; the solution therefore retains its original composition.

337. Any one who witnesses these experiments cannot fail to notice, that in the decomposition of compound substances by the galvanic current, certain elements invariably appear at one wire of the battery, and others as constantly at the other. Thus hydrogen, the metals, and their oxides, range themselves at the negative wire, or that by which the electricity leaves the fluid, and are therefore electro-positive, *as like electricities repel each other, but unlike*

attract; whilst oxygen, sulphur, chlorine, iodine, &c., and the acids, range themselves on the positive wire, or that by which the electricity enters, and are therefore electro-negative. Thus all substances may be divided into two classes; those being termed electro-negative which are evolved at the positive wire, and those which appear at the opposite wire being termed electro-positive. The more commonly occurring elements thus classified are ranged as in the following list:—

Electro-negative.			Electro-positive.
Oxygen.	Antimony.	Lead.	Hydrogen.
Fluorine.	Silicon.	Tin.	Carbon.
Chlorine.	Boron.	Bismuth.	Aluminum.
Bromine.	Mercury.	Cobalt.	Magnesium.
Iodine.	Chromium.	Nickel.	Calcium.
Sulphur.	Platinum.	Iron.	Strontium.
Nitrogen.	Gold.	Manganese.	Barium.
Phosphorus.	Silver.	Cadmium.	Sodium.
Arsenic.	Copper.	Zinc.	Potassium.

338. The most powerfully negative bodies are placed in the first, and those most powerfully positive in the fourth column, these being connected by the intermediate columns. Any substance in the list is positive with regard to those which precede it, and negative with regard to those which follow it. Thus, hydrogen is negative to all in the fourth, but positive to all in the three preceding columns, and so on.

339. It was considered that this separation of the constituents of a compound substance, and the attraction of some of them to one of the terminal wires, and of the others to the other, was due to an attractive and repulsive force possessed by the wires—hence they were called *poles*, "from a notion of their exerting attractive and repulsive energies towards the elements of the decomposing liquid, just as the poles of a magnet act towards iron; and they were further distinguished by the terms *positive* and *negative*. The following singular and often quoted expe-

riment appeared at the time this theory was propounded to be a complete confirmation of its truth.

EXERCISE.

260. Let three cups, A B C, be placed side by side, and be connected by means of pieces of lamp-cotton moistened with a solution of sulphate of soda. Let A be filled with a solution of sulphate of soda, B with a solution of dilute sulphuric acid, and C with water. Let the positive wire (platinum) of a battery dip in A, and the negative in C, the positive current will, of course, enter the fluid in A, passing on through the fluid in B and C, and escape by the wire in this latter cup: the current in its conduction will decompose the sulphate of soda; the acid will remain in A, but the soda will appear in C, although to reach this vessel it must pass through the free acid in B.

340. It was considered at the time this curious transfer of substances was discovered, that the affinity of the acid in B was overcome, or was less powerful for the soda, than the negative pole in C, consequently the soda passed through the acid in B and reached C, on account of the superior attraction for it which the negative pole exercised. It was found that if a solution of nitrate of baryta were used in place of the solution of sulphate of soda in A, the baryta salt would be decomposed, the baryta would pass into B, but would go no further, because it combined with the sulphuric acid, for which it was considered to have a stronger affinity than for the negative wire.

341. But the constituents of the decomposed substances are not attracted by the wires, they are simply disengaged at the boundaries of the decomposed substance, and it is only when the wires form this boundary that the constituents are evolved upon them. Thus, if in Expt. 260, the cup B had been filled with water instead of sulphuric acid, the soda would have remained in that vessel and not have passed over into C, because it would have been the boundary of the decomposed substance. When B contained a substance with which it could combine, and the compound thus produced was capable of being decomposed by the electric fluid, then the boundary was

not in B, but in the vessel C—hence the reason of the soda reaching this latter vessel. That the constituents of a substance that is being decomposed are evolved at its bounding surfaces is well illustrated in the following experiment:—

EXERCISES.

261. If a vessel be filled with a solution of sulphate of soda, and the wires, terminating in plates, of a battery in action be inserted, the acid will collect upon the one and the alkali upon the other plate; but if, by means of pieces of bladder, the vessel be divided into three compartments, A, B, and C, and the central one being filled with a solution of sulphate of soda, dilute nitric acid is poured into those at the side in which the plates are placed, in order to afford a conducting medium, no acid or alkali appears at the metallic poles when the current passes, but these substances are evolved upon the inner surfaces of the bladder; it is only when, by mechanical filtration, some of the solution of sulphate of soda passes into the divisions A and C, that the slightest trace of sulphuric acid or of soda can be found upon the metallic plates.

262. "By the electricity of the machine the same principle can be demonstrated. If a slip of paper, moistened with a solution of iodide of potassium, be held near the insulated prime conductor of the electrical machine, whilst in action, and the rubber be connected with the ground, so as to ensure a continuous discharge of positive electricity into the air, iodine will be evolved in quantity upon the point of the paper nearest the prime conductor, whilst hydrogen and potash may be traced as far as any liquid conductor, admitting of their passage, goes. Here there is nothing that can be termed a pole, the iodine is discharged upon the limiting surface, which is here that of the atmospheric air."

342. The terminal wires must only be looked upon as paths for the ingress and egress of the electric fluid—hence Faraday has proposed to call them electrodes, which term signifies a way. But he does not limit the meaning of the term to wires, but he calls the bounding surfaces of any substance electrodes, whether it be air, water, metal, &c., which serves to convey an electric current into

and from the liquid to be decomposed. The surface of the decomposing liquid, where the elements make their appearance, he terms *anode,* signifying upwards, and *cathode,* denoting downwards. The anode is where the current is supposed to enter; the cathode, where it leaves the decomposing liquid. Compound bodies, capable of being decomposed by the electric current, are termed *electrolytes*, that is, to unloose by means of electricity; decomposition by the direct action of electricity is termed *electrolysis.* "The elements of an electrolyte are called *ions*, signifying going; *anions* are the ions which appear at the anode, and are usually termed the electro-negative ingredients of a compound, such as oxygen, chlorine, and acids; and the electro-positive substances, hydrogen, metals, alkalies, which appear at the cathode, are *cations.* Whatever may be thought of the necessity for some of these terms, the words electrode, electrolyze, and electrolyte are peculiarly appropriate, and are already in use."

343. "The separation of the ions takes place only in the immediate neighbourhood of the electrodes, not at any part of the liquid, at a distance from them. Ex.—If a solution of common salt, coloured with infusion of blue cabbage, be divided into three portions by two membranous partitions—the electrodes dipping into the outermost divisions—the colour of the liquid changes in these divisions alone, not in the middle."

344. If the electrodes are of such a nature that either of them can combine with the *ion,* which is liberated upon it, the electrolyte will be more easily decomposed than if no combination could take place between them, as the following experiment proves:—

EXERCISE.

263. Let the conducting wires belonging to a single pair of plates (copper and zinc) terminate with platinum plates; let these latter plates be immersed in a vessel containing the same solution, which is used in the generating cell. The current will be too weak to decompose the liquid in the decomposing cell, consequently no current will pass from the one electrode to the other. Perform the same experiment, using copper electrodes in

the place of the platinum ones, sulphuric acid being the solution employed in both cases. The current will now pass, and bubbles of hydrogen gas will be evolved at the end of the cathode, whilst the oxygen will combine with the anode.

345. The following is a summary of the more important principles connected with electrolysis :—

1. In order to decompose a compound, its particles must be in such a condition as to move freely amongst each other ; this is effected either by dissolving the compound in some liquid, or by fusing it. All compounds which are decomposable when dissolved in water, behave in the same manner when fused. It is necessary for the electrolysis of a substance, which must, as we have noticed, be in a liquid state, that the electric current should pass through it ; in other words, an electrolyte must be a conductor of electricity. To transmit an electric current through a liquid, dip the terminal wires of the battery into it.

2. Substances which cannot be electrolyzed do not allow a current of electricity to pass through them.

3. "The alliance between conduction and decomposition is so constant, that the latter may be regarded as a means by which voltaic currents are transmitted through liquid compounds."

4. All compound gases are non-conductors, and are therefore not decomposed by electricity.

5. Compounds in the solid state are non-conductors, and are consequently not decomposed. Ex.— Water, which conducts an electric current, and is decomposed at the same time, ceases to conduct, and therefore ceases to be decomposed, when it passes into ice.

6. Most binary compounds, consisting of single equivalents of the two elements composing them, have been proved to be electrolytes, and probably all compounds of this order are.

7. Substances which consist of a single equivalent of one element, and two or more equivalents of another, are not electrolytes. Ex.—Bichloride of tin is not an electrolyte. But in making this statement, it is necessary to distinguish between primary and secondary decom-

position. Water is an electrolyte, its hydrogen being delivered up at the — and its oxygen at the + electrode. A solution of hydrochloric acid is likewise an electrolyte, being resolved into chlorine and hydrogen. But nitric and sulphuric acids and ammonia are not electrolytes, though the first and last are decomposed by secondary action. Thus, on subjecting nitric acid to voltaic action, the water of the solution is electrolyzed, and its hydrogen arriving at the + electrode, decomposes the nitric acid, water being there reproduced and nitrous acid formed. So, in a solution of ammonia, the oxygen of the decomposed water unites at the + electrode with the hydrogen of the ammonia, and nitrogen gas is evolved. Very numerous secondary actions are occasioned in this way, because the disunited elements are presented in a nascent form, which is, as we have already seen (par. 209), peculiarly favourable to chemical action; and in many instances the electrode itself, which is commonly metallic, is chemically attacked."

8. Most of the salts are decomposed without reference apparently to the proportions in which they are united. In the electrolysis of the oxygen salts of the alkalies, and alkaline earths, the oxide and hydrogen are disengaged at the cathode, the acid and oxygen at the anode; but in the electrolysis of the oxygen salts of the heavy metallic oxides, the metal alone is deposited at the cathode, whilst the acid and oxygen are evolved at the anode.

9. Chemical compounds differ as to the intensity of the electric current required for their decomposition; as the following, as well as previous experiments, prove :—

EXERCISE.

264. If the terminal wires belonging to a single pair of plates (copper and zinc) terminate in platinum plates, and these are immersed in a solution of iodide of potassium, whilst sulphuric acid is the exciting liquid in the generating cell, the current will have sufficient intensity to pass through the solution, decomposing the iodide, evolving the iodine at the surface of the platinum plate connected with the copper, and the potash at the platinum plate in connection with the zinc. Yet, as we saw by Expt. 263, the current was not sufficiently intense to

decompose water: to decompose this liquid by a current so weak, we were obliged to aid it by chemical affinity; we employed for the positive electrode a metal with which the oxygen could combine. The order of easy decomposition in the annexed substances is as follows:—Solution of iodide of potassium; fused chloride of silver; fused protochloride of tin; fused chloride of lead; fused iodide of lead; solution of hydrochloric acid; and water acidulated with sulphuric acid. The order of decomposition represents the order of conductibility. If, therefore, the body to be decomposed has a very low conducting power, its electrolysis will be effected only by employing a battery consisting of a great many pairs of plates, as *intensity* is required to overcome the resistance which arises from the low conducting power of the liquid. If, on the contrary, the electrolyte be a good conductor of electricity, the chemical decomposition will be accelerated by increasing the *quantity* of the electric fluid. If we diminish the resistance of the electrolyte itself to conduction, the chemical action will be accelerated.

10. The conduction of the electric current in the generating as well as in the decomposing cell, depends on chemical decomposition, consequently electrolytic substances are the only ones capable of acting as exciters in the generating cell.

346. An atom of any electrolyte requires for its decomposition the same *quantity* of electricity as an atom of any other; thus, the *quantity* of electricity which will decompose one atom of water, will decompose an atom of chloride of lead, one of oxide of silver, one of sulphate of soda, or an atom of any electrolyte. If, therefore, all electrolytes were equal in conductibility, they would be decomposed with equal facility.

347. Our countryman, Spencer, conceived the happy idea of employing the metal, which is always deposited at the cathode in the electrolysis of the heavy metallic oxides, to the copying of moulds, &c. In this way, exact copies of almost anything can be taken in metal, even the most fragile plants, and in the same way the baser metals can be plated with gold or silver; the former process is called electrotyping, the latter electroplating.

348. The preceding experiments contained so many

illustrations, that combinations, accompanied by decompositions, are produced by the electric agency, that it will be needless to give any further examples.*

Influence of mass in the formation of chemical compounds.

349. We have seen (par 203), that if three bodies, A, B, and C, are mixed together, one of which, C, is capable of combining with either of the other two, and forming with them compounds AC, BC, that if the relative affinities *are very unequal*, and no *insoluble or gaseous substance* can be formed, C, if it is present in sufficient quantities to combine with *only* one of the two, *will not* be distributed between the A and B, but that it will be exclusively combined with the one for which it has the greatest affinity: we have seen, for example, that soda is not distributed between sulphuric acid and boracic acid, but that it unites exclusively with sulphuric acid; also, that sodium is not distributed between chlorine and iodine, but that it unites exclusively with chlorine; to these examples we could add numerous others, to confirm the fact that when the relative affinities are very unequal, C, if present only in sufficient quantity to combine with one of the two, is not distributed between A and B. But we have seen (par. 203) also that if the relative affinities *are not* very unequal, and no insoluble substance can be formed, that C is distributed between A and B. When this is the case, the question arises *in what proportion* will C enter into combination with A and with B.

350. Berthollet, who was the first to direct attention to the influence of quantity on chemical affinity, considered that chemical union differed from mechanical cohesion only in being exerted between particles of different substances; he denied the existence of the power entitled elective affinity, and he asserted that in those cases where certain bodies combined in preference to others, the source was to be found in the accidental and external circumstances. He considered that a body C divides itself between the bodies B and C in the proportion of their quantities. "He argued that not only would

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* The teacher might give a series of experiments on electrotyping and electroplating.

C be divided between A and B, but that in proportion as the quantity of one of these bodies, A, preponderated over the other body, B, the proportion of AC in the mixture would be increased, while, of course, that of BC would be diminished. If, on the other hand, the proportion of B were increased, the quantity of the compound BC would be augmented, whilst that of AC would be proportionately lessened, the body C dividing itself between A and B in a proportion represented by the product of its affinity for each of these elements multiplied into their mass."

351. We have seen (par. 203) that this idea of Berthollet's is not correct when the relative forces are very unequal, and no insoluble or gaseous compound can be formed, as C in that case is not distributed between A and B, but that it is exclusively united with the one for which it has the strongest affinity, however much the other body may exceed this one in quantity. We have seen (par. 203) that when the relative affinities are not very unequal, distribution takes place; but how far the quantities of the different bodies influence the result is yet undetermined, except in one or two cases, which we shall notice presently; this is to be regretted, as there can be little doubt that quantity plays a most important part in the formation of chemical compounds in large manufacturing operations.

352. We have already directed the attention of the student to the fact that sulphide of potassium is converted into carbonate by passing carbonic acid gas through it for some time, and reciprocally that carbonate of potash is converted into sulphide by passing sulphuretted hydrogen through it for some time (par. 236). Also that the vapour of water at a high temperature expels carbonic acid from potash, hydrate of potash being formed; reciprocally, hydrate of potash is converted into carbonate by passing over it carbonic acid (par. 237). These opposite decompositions could be accounted for in the same way we have accounted for the oxidation of iron in an atmosphere of steam, and the reduction of oxide of iron in an atmosphere of hydrogen (par. 222). But some chemists ascribe each of these opposite combinations and decompositions to the influence of quantity on chemical affinity.

353. Bunsen has investigated the influence of quantity on chemical affinity in some cases where the products of combination were at once removed from the sphere of action, as by the formation of gaseous compounds. "The following is the law deducible from Bunsen's experiments: —1. When two gaseous bodies, A, B, are mixed with a third body, C, and fired by means of the electric spark, the body C takes from A and B quantities which always stand to one another in a simple atomic relation: so that for 1 atom of AC, 1, 2, 3, or 4 atoms of BC are produced; for two atoms of AC, 3, or 5, or 7 atoms of BC are formed. If one atom of the compound AC and one of BC be formed in this manner, the mass of A may be increased in the presence of B up to a certain point without any change in that atomic proportion; but if a certain limit be passed, the relation of the atoms, instead of being as 1 : 1, suddenly becomes as 1 : 2, or as 1 : 3, or as 2 : 3, and so on.

354. "When a body, A, acting upon an excess of any compound, B C, reduces it, so that A C is formed and B is set at liberty; then, if B in its turn can reduce the newly-formed compound, A C, the final result is that the reduced part of A C is in simple atomic proportion to the unreduced part. In the case of these reductions, also, the mass of one of the ingredients of the mixture may be increased up to a certain point without altering the relative proportions of the compounds obtained; but, if increased beyond this limit, a sudden alteration in the relative proportions of the product occurs, but these proportions still admit of being represented by simple ratios.

355. "M. Debus arrived at substantially the same results as those indicated by Bunsen for gaseous mixtures, by precipitating a mixture of lime and baryta water, by small proportions of solution of carbonic acid, and by similar experiments upon a large excess of a dilute solution of the mixed chlorides of calcium and of barium, to which a dilute solution of carbonate of soda was added.

356. "In the experiments of Bunsen, it must be recollected that the first products of the chemical combination are immediately removed from the sphere of action: carbonic acid, and carbonic oxide, and water, will not mutually react upon each other; and in the experiments of Debus,

the carbonates of the earths, being insoluble, are at once withdrawn from further action with the mixture."*

357. The student must write out answers to the following questions; he must then pass on to chapters xix. and xx., and write out the exercises there given.

EXERCISES.

265. What are the necessary elements for making a voltaic circuit?

266. In charging a Leyden jar by means of an ordinary electrical machine, explain fully the whole process which goes on, beginning with the rubber and ending with the jar.

267. What does the direction of the galvanic current depend upon?

268. What means are there of obtaining from a voltaic battery electricity approaching in its intensity to that of electricity obtained by friction?

269. State what is meant by the terms electro-negative and electro-positive.

270. What is meant by the terms electrolyte and electrolysis?

271. Give a summary of the more important principles connected with electrolysis.

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* Miller's "Elements of Chemistry," part 2nd.

CHAPTER XII.

THE INDUCING ACTION WHICH SOME SUBSTANCES POSSESS AT THE MOMENT OF CHEMICAL CHANGE.

Friction as an inducer of chemical action. Exercises. Some substances undergoing combination induce others to do the same. A slightly different class—two compounds, which separately are quite stable, when brought together are both decomposed. Exercises. Some substances, in the act of decomposing, induce others to do the same. Putrefaction, Fermentation, and Decay. Distinction between putrescible and fermentescible bodies. Relation as to quantity between the ferment and the fermentescible body. A certain temperature required in fermentation. At different temperatures different substances are formed. Preservation of food. Bread-making. Manufacture of beer and wine. Germination. Malting. Does the vital influence prevent putrefaction, &c.? Necessary conditions for the decay of organic substances.

358. Chemical changes are produced in some substances when they come in *contact* with certain other substances, these latter substances not contributing any of their constituents to those undergoing the *change*, or abstracting *any* from them, but causing the change by *contact* only. This chapter will be devoted to an investigation of the *changes* produced in this way.

359. Compounds, in which one of the elements is present in a great many proportions, are generally unstable, being either partially or totally decomposed by the slightest disturbing influence. Friction will frequently be sufficient to decompose compounds of this nature, especially if there be in their neighbourhood a substance which possesses an affinity for the redundant element. This fact must be familiar to all—for who has not caused a lucifer match to ignite by friction. The inflammable substance of the matches is a mixture of chlorate of potash (the noiseless matches contain nitrate of potash in the place of the chlorate), phosphorus, sulphur, and gum. Chlorate of potash contains no less than six atoms of oxygen; it is, when mixed with substances, like phos-

phorus and sulphur, having a great affinity for oxygen, easily decomposed, giving up its oxygen to these bodies.

EXERCISES.

272. Mix briskly in a mortar, about four grains of powdered chlorate of potash, two grains of charcoal powder, and the same quantity of flowers of sulphur. The substances will re-act upon one another, the reaction being attended with flame and a slight noise.

273. Mix four grains of powdered chlorate of potash, and six grains of flowers of sulphur, very intimately on paper by means of a knife, then divide the powder into three parts. Introduce one part, by means of a knife, into a wine glass containing concentrated sulphuric acid, it will immediately take fire. Place another part in a dry mortar, and then rub very briskly,—slight explosions, accompanied with light, will ensue. Wrap the rest of the mixture in a little tin-foil, lay it on an anvil or a piece of iron, strike it with a hammer, and a loud report will be produced.

274. Mix equal parts of powdered chlorate of potash and powdered white sugar—say about twenty grains of each, on paper. Place the mixture upon a plate, and touch with a glass rod which has just been dipped in strong sulphuric acid, it will immediately burst into a flame.

275. Powder coarsely a few crystals of nitrate of copper, lay them on a piece of tin-foil, add enough water to make them into a paste, and then quickly fold up the tin-foil, doubling the sides and corners well together, so as to exclude air ; in a short time, nitrous acid gas (NO_4) will force its way out of the packet, and the tin-foil will take fire.

360. But the unstableness of chemical compounds does not always arise from one of their constituents being present in a great many proportions, for the most unstable and explosive compounds are some of the nitrogen compounds,—as the iodide. Several of these decompose with explosion, without the action, apparently, of any disturbing influence ; on this account it would be improper, except by those accustomed to chemical manipulation, to exhibit their properties on the lecture table,—

for this reason, they will be passed by without further notice.

361. Some substances are induced to combine merely from the circumstances of other substances undergoing combination in their presence,—in other words, a body in the act of chemical combination, has the power of inducing the same kind of activity in another body, and causing it to combine with a third body, thereby forming a compound which, under the circumstances, would not have been formed without the presence of the first body. Ex.—Nitrogen gas does not by itself combine with oxygen, even when heated; but if a mixture of nitrogen and hydrogen be set on fire, the hydrogen burns, producing water, and a portion of the nitrogen combines at the same time with oxygen, producing nitric acid. Pure copper does not oxidate in water mixed with sulphuric acid, but when combined with zinc and nickel—metals which decompose acidulated water, or when combined with three times its weight of zinc only, it oxidates and dissolves completely along with the other metals. Platinum, when alone, does not oxidate and dissolve in nitric acid; but when alloyed with silver, it becomes soluble in that acid. Wet peat-earth gradually absorbs oxygen gas; if the latter be mixed with hydrogen, a portion of the hydrogen enters into combination with the oxygen, which it would not do in the absence of the peat-earth.

362. We shall see, presently, that just as some substances in the act of combining, induce others to enter into combination, so, likewise, a compound in the act of decomposition, may cause others in its vicinity to decompose. Before doing so, we shall notice the following slightly different class, namely, that two compound substances, which apart are perfectly stable, may, by being simply brought into each other's presence, be both decomposed.

EXERCISES.

276. Add a solution of bichromate of potash to a strong nitric or hydrochloric acid solution of peroxide of barium; a violent effervescence and escape of oxygen ensues,—owing to the chromic acid being decomposed into sesquioxide of chromium and oxygen, and the peroxide of barium into the protoxide and oxygen.

277. Add a solution of permanganate of potash to a strong nitric or hydrochloric acid solution of peroxide of barium, and, as in the preceding case, a violent effervescence and escape of oxygen ensues; protoxide of barium, a lower oxide of manganese, and free oxygen being the result.

278. Add a little oxide of silver to an acetic acid solution of peroxide of barium; oxygen will be again evolved, owing to the oxide of silver being totally decomposed, and the peroxide of barium being decomposed into protoxide and free oxygen.

363. The preceding and following facts show that the affinity existing between the different elements of some compounds is so feeble, that the bond of union between them is easily overcome. There are substances, for instance, incapable of undergoing any chemical alteration of themselves, which, if brought into contact with substances undergoing chemical change, either of transformation or decomposition, are induced by the contact to undergo like alterations. These changes are, according to their character, termed Putrefaction, Fermentation, or Decay.* When the change is attended with evolution of fœtid gases, the process is called putrefaction; when the evolved gases are without odour, it is called fermentation. This class of changes is confined almost entirely, if not exclusively, to organic bodies; a few inorganic compounds, indeed, undergo spontaneous decomposition, causing, by this act, other substances in their neighbourhood to do the same, but this is the nearest resemblance which inorganic chemistry affords to the changes which occur in the putrefaction and decay of organic bodies.

364. We recently alluded (360) to the fact of the binary compounds of nitrogen entering into a state of decomposition without the aid, apparently, of any disturbing influence. If these substances, so simple in composition, decompose easily, we need not be much surprised to find that all those complex organic bodies containing nitrogen, which are formed under the influence of life, should commence to decompose as soon as they cease to be governed by it. They commence to putrefy immediately they are removed from the vital influence, and placed in a suitable

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* Liebig has suggested, in place of the ambiguous term decay, the term eremacausis, which signifies, burning by degrees.

condition; the conditions necessary for this change are very simple,—a certain temperature, moisture, and exposure to air, or oxygen; and when once the putrefaction has commenced, the air, or oxygen, may be excluded without interrupting the process; it appears to act merely as an exciter in the first instance. Without stopping to notice the different substances which may be formed in the different stages of the putrefaction of nitrogeneous substances, as we possess little knowledge upon the subject, we will pass on to consider the peculiar and interesting changes which non-nitrogenized organic bodies, and which are non-putrescent, suffer, when placed in contact with the nitrogenized, in the act of undergoing putrefaction. If yeast, which is a putrescing substance, be added to a sugar solution, it causes the sugar ($C_{12}\,H_9\,O_9, 2\,H\,O$) to change first into grape sugar ($C_{12}\,H_{11}\,O_{11}, 3\,H\,O$) by the addition of 3 eq. of water; and the grape sugar into carbonic acid, alcohol, and water, thus—

$$C_{12}\,H_{11}\,O_{11}, 3\,HO = 2\,(C_4\,H_5\,O, HO) + 4\,CO_2 + 2\,HO.$$

365. The yeast, as shown by the equation, shares none of its elements with the sugar, or its decomposition products,—it simply causes, by its own decomposition, the sugar to do the same. This kind of decomposition is called fermentation,—the sugar is the fermentescible substance, and the yeast is the putrescent one. All non-putrescible bodies are called *fermentescible*, when they possess the property of being decomposed by contact with putrescent matters; and the latter class, in such cases, are called *ferments*. The distinction between putrescible and fermentescible bodies is this,—the former undergo chemical change after a transient exposure to air, if kept at a proper temperature, and moisture be present; fermentescible bodies, of themselves, undergo no change under these circumstances.

366. As soon as the ferment has been completely converted into the substances which result from its putrefaction, the act of decomposing, of course, ceases, and therefore *the power* of inducing fermentescible substances to decompose. From this, it follows that there must be a certain relation as to quantity between the ferment and the fermentescible body, if the two complete their decomposition at the same time,—if the latter be in excess, the

excess remains undecomposed; if the former be in excess, its decomposition proceeds after the other is complete. The alcohol being one of the final products of the fermentation, is of course a non-fermentescible body. Although the fermentescible bodies yield in fermenting no element to the ferment, or its decomposition products, yet the putrescent body is resolved, when placed in contact with fermentescible bodies, into different substances to those which would be produced if it putrefied by itself. "When a solution of sugar is added to putrescent cheese or blood, the beginning of the fermentation is attended by the diminution of the formation of those products which give their offensive smell to putrid animal matters; so that, in the course of the process, these striking products entirely disappear."

367. We have seen that a certain temperature is requisite as well for decompositions as for combinations, and that each increase of temperature is attended with a different decomposition or combination; the same holds good with regard to putrefaction and fermentation. Thus, if a solution of sugar be exposed along with a ferment, like yeast, to a temperature of from 40° to 86° F., or if the juice of the beet-root, carrot, onion, or other fruits, which contain sugar and substances capable of putrescence, be exposed to a like temperature, the sugar in each case is converted into alcohol and carbonic acid; but if the juice of the carrot, &c., be subjected to a temperature of from (about) 97° to 104° F., the ferment in these juices undergoes a different decomposition to that which it experiences at a lower temperature, and as a consequence, it causes the sugar, also, to undergo a different change; instead of this last substance being decomposed, as before, into alcohol and carbonic acid, it is converted, at this higher temperature, into lactic acid, mannite, and a gum-like substance, gases at the same time being evolved. Milk turns sour after a longer or shorter exposure to the air, the time depending on the temperature. The sourness is due to the conversion of the sugar of milk fermenting (the caseine being the ferment), and becoming converted into lactic acid, this being the only substance formed, thus—

$$C_{24}H_{19}O_{19}, 5\,HO = 2\,(C_{12}H_{10}O_{10}, 2\,HO).$$

Cane sugar is converted into the same substance (lactic acid), if a solution of it be placed in contact with caseine which has been exposed to the air, and the mixture be kept at a temperature from about 75° to 90°. When a certain amount of acid has been formed, it stops the fermentation both in the sugar solution and the milk, but if it be neutralized, say with carbonate of lime, the fermentation recommences, and by neutralizing the acid as it is formed, the whole of the cane and milk sugar becomes at last converted into lactic acid. If the milk, instead of being exposed to the ordinary temperature, is exposed to a temperature of from about 76° to 90°, the products of the fermentation are altered, the sugar of milk being converted into alcohol. Again, after the cane sugar has become converted into lactate of lime, if the mixture still containing the caseine be kept for some time, at a temperature from about 90° to 105° F., the lactic acid becomes decomposed into butyric acid, carbonic acid, and hydrogen, thus—

$$C_{12}H_{10}O_{10}, 2HO = C_8H_8O_4 + 4CO_2 + 4H.$$

It need scarcely be observed, after what has been said, that there are different kinds of fermentation, as the vinous (when alcohol is formed), the lactic, butyric, and viscous (gummy).

368. A celebrated French philosopher (Gay-Lussac) has shown in a beautiful way, that substances cannot putrefy or ferment, unless they have been exposed to oxygen. He kept the juice of grapes some days over mercury, but no fermentation ensued; he then introduced a bubble of oxygen, and in a few hours fermentation commenced. We witness this experiment in other forms almost daily; we see that so long as the skin of the grape, apple, &c., remains impermeable to air, the juice, or the interior of the fruit, remains unchanged, but as soon as the air penetrates, fermentation or putrefaction commences. Advantage has been taken of this fact in the preservation of meat and vegetables. The food to be preserved is placed in vessels which are exhausted of air, generally by ebullition, and then hermetically sealed. The putrefaction and fermentation of organic substances is annihilated (for a time) in all cases, without exception, by heating to the boiling point. We need only consider the coagulation of albumen by heat, to understand the manner in which heat acts in

producing this effect. Most ferments have a constitution analogous to that of albumen, and, at a high temperature (like it), pass into a new state. If fresh milk be heated daily to the boiling point, it may be preserved for an indefinite period. Grape-juice, so readily mutable, and every fluid susceptible of fermentation, is affected in the same manner; when heated to the boiling point, all fermentation in them ceases. Beer-wort, after boiling, requires the addition of yeast, that is, an extraneous substance, already itself in a state of decomposition, in order to ferment in the shortest possible time. It is obvious that if that particular state into which an organic substance is brought by contact with the atmosphere,—although this contact may have been but for an instant,—be destroyed by a high temperature, and oxygen (the only cause of its re-appearance) from the time of its boiling be excluded, these substances must, for an unlimited period, retain all the properties they possessed at the moment of boiling. To the list of bodies which check putrefaction and fermentation (antiseptics, as they are called) belong all substances which exert a chemical action on ferments, —such as alkalies, mineral acids, concentrated vegetable acids (hence, when lactic acid is set free, it stops fermentation), volatile oils, alcohol, sea-salt. The most effective are sulphurous acid, metallic salts, especially those of mercury, which combine chemically with the ferments, or putrescent bodies. "Arsenious acid does not prevent the putrefaction of blood, nor the ordinary alcoholic fermentation of sugar; but the putrefaction of the skin, and of the gelatinous tissues, is entirely suppressed by the presence of arsenious acid; the cause of this is, that it combines with the skin, forming a compound with this substance similar to that which tannic acid forms with it, viz., leather."—(*Liebig.*) Alcohol and common salt act as antiseptics, by depriving the putrefying body of water, which is one of the chief conditions for its putrefaction.

369. Fermentation has long been employed in the domestic operations of bread-making, and in the production of beer and wine. If wheat flour be mixed with water sufficient to form a paste, and this be kept for some time in a warm place, the albumen in the flour begins to decompose, causing thereby the starch in the flour to decompose,—first into sugar, and this, again, into

alcohol and carbonic acid; the disengagement of the gas (carbonic acid) causes the upheaving of the paste: if the fermentation be not checked at this stage, acetic and lactic acids begin to be formed, and it is almost impossible, on account of the slowness of the fermentation, to prevent the formation of these acid substances. Bread made in this way is therefore unpalatable, and not fit to be eaten. The dough or paste, which has been allowed to ferment in this way, is called leaven, and if a small quantity of this leaven be mixed with new-made dough, and the mixture laid aside for a few hours, fermentation commences throughout the whole mass, and goes on rapidly, the mass swelling on account of the disengagement of the gas to twice its original bulk. If at this stage it be placed in the oven, the fermentation is checked before any acid is formed, and the bread is full of holes, light, spongy, and sweet. This plan is adopted by emigrants, and persons living in thinly inhabited districts.

370. "The ancient Gauls and Spaniards, as we are informed by Pliny, contrived another method for bringing on a fermentation in dough. Instead of *leaven* they added to the dough a quantity of *yeast* or barm, which collects on the surface of fermenting beer. This addition occasions fully as speedy a fermentation as leaven, and it is not nearly so apt to give the bread a sour flavour. About the end of the seventeenth century, the bakers of Paris began to substitute yeast for leaven. The practice was discovered, and exclaimed against. The faculty of medicine, in 1688, declared it prejudicial to the health; and many years elapsed before the bakers were able to convince the public that bread raised by means of yeast is better than that fermented by leaven. Barm is now employed in preference to leaven in every civilized country." —*Dr. T. Thomson's Organic Chemistry.*

371. In the production of fermented bread a certain quantity of flour, water, and yeast, are added together,—the yeast decomposes a part of the starch into sugar, and this again into alcohol and carbonic acid. The dough, after being sufficiently distended by the gas, is placed in the oven: the elevated temperature stops the fermentation, expands the gas, and volatilizes the alcohol, and all the water capable of being removed by the heat employed. The yeast or leaven is added for the purpose of producing

a certain quantity of carbonic acid, the disengagement of this gaseous body causing the bread to *rise;* the object to be effected by the disengagement of the gas, is the separation of the particles of which the loaf is composed, so that the particles may be thoroughly mixed with the saliva during the mastication of the bread, which, according to Liebig, is a condition essential to the rapid digestion of the starch.

372. It need scarcely be observed, that the gaseous substance which raises bread, is produced at the expense of a certain portion of the flour; to avoid this, carbonate of soda, and hydrochloric, or tartaric acid, have been employed in the place of the yeast: by this plan the loss of starch is avoided, as the carbonic acid is produced at the expense of the carbonate of soda. It is therefore more economical; for a quantity of flour, which would produce 100 loaves by the old or fermented plan, would produce, according to Dr. R. D. Thomson, 107 loaves of the same weight by the new or unfermented method. By the old plan, each little molecule of flour gives off its quota of gas, causing, therefore, the most complete separation; by the unfermented plan, however thoroughly the carbonate of soda may be mixed with the flour, there cannot be such a complete diffusion of gas throughout the mass. This, perhaps, may render the bread made by the unfermented plan less digestible than that made by the fermented method. Again, the evolution of gas by the unfermented plan is sudden, and not continuous, as it is by the older method, so that the bread sinks immediately; this requires the dough to be placed in the oven the moment the water and acid are added to the flour and soda.

373. We shall conclude this part of the subject by noticing briefly the chemical changes which take place in baking the bread. The crumb undergoes no change, as it is never exposed to a temperature higher than 212° F. The chemical changes which take place are confined to the surface or crust. The heat converts the starch of the crust into a substance called dextrine, or British gum, which is soluble in water, and therefore easier of digestion than starch. That this change takes place, may be proved by wetting with a sponge the crust of a loaf, and then re-

turning it to the oven ; after a few minutes, the crust will be quite shining, as if covered with gum.

374. "New baked bread possesses a peculiar softness and tenacity which is familiar to most people, and though generally considered less digestible, is a favourite with many. After two or three days it loses this softness, becomes free and crumbly, and apparently drier. In common language, the bread becomes stale, or it is stale bread. It is generally supposed that this change arises from the bread becoming actually drier by the gradual loss of water, but this is not the case. Stale bread contains almost exactly the same proportion of water as new bread, after it has become completely cold. The change is merely in the internal arrangement of the molecules of the bread. A proof of this is, that if we put a stale loaf into a closely-covered tin, expose it for half an hour, or an hour, to a heat not exceeding that of boiling water, and then remove the tin, and allow it to cool, the loaf, when taken out, will be restored in appearance and properties to the state of new bread."*—*Johnston.*

375. Attempts have been made to collect the alcohol which is volatilized from the bread in the oven. "The enormous amount of bread that is baked in large towns—in London, for instance, 88 millions of cwts. yearly,—would render the small amount of alcohol contained in it of sufficient importance to be worth collecting, providing this could be done cheaply. All the experiments which have been tried, with this object in view, have failed ; in the military bakehouse, at Chelsea, £20,000 have been expended in vain, upon a collecting and condensing apparatus. It is estimated that there is evolved from the bread annually baked in London, 300,000 gallons of spirit." —*Knapp.*

376. In the same way, yeast converts the sugar in *worts* (an infusion of malt) into alcohol and carbonic acid gas : a large portion of the latter is evolved, but a sufficient quantity to give what is termed sharpness or briskness to the beer, remains dissolved. After the fermentation is complete, the quantity of yeast is found to be thirty times greater than the quantity added in the first

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* If stale bread be dipped in cold water, rubbed dry with a towel, and then placed in the oven until it becomes warm, it will taste like new baked bread.—R. G.

instance;—this is owing to the albuminous matters present in the wort becoming converted into yeast.

377. This mode of inducing changes in substances not prone of themselves to decompose, is frequently made use of in the great laboratory of Nature. For instance, there is always stored up in the seeds an amount of food sufficient, when they germinate, for the young plants, until their roots and leaves are sufficiently developed to collect the required nutriment. But the food thus destined for the young plant is laid up in the form of starch, and this cannot, on account of its insolubility, nourish the embryo, as plants, in every stage of their growth, require their food to be in a state of solution. As soon as the seed begins to sprout, the albumen changes into a ferment, which converts the insoluble starch into dextrine and sugar, which are soluble. During the time these changes are going forward, oxygen is absorbed from the air surrounding the seed, and carbonic acid is evolved. This fact teaches us why seeds refuse to germinate if excluded from the air, and that if buried deep in the soil, so as to exclude air, they will remain unchanged, and when brought near the surface they spring into life. We have learned in a former lesson, that plants, when exposed to the light, absorb carbonic acid, and decompose it, giving back the oxygen to the atmosphere; the very opposite takes place during germination,—the seed absorbs oxygen, and gives out carbonic acid; but it can only do this in the absence of light: hence the necessity of covering seeds with a thin layer of soil, in order to protect them from this agent.

378. It is in this way that the nearly tasteless barley is changed into sweet malt. The barley is made to germinate, and as soon as the starch becomes converted into sugar, the germination is destroyed by a high temperature.

379. So far our attention has been confined to the effect of putrefying matter on putrescent and fermentescible bodies, *which have been removed from the influence of life;*—has putrefying matter the same, or a somewhat similar effect, on these substances, when they form a part of the living frame, or does the vital influence prevent the chemical transformations? Do we not all know that dangerous and even fatal diseases are produced in this way?—who has not heard of the fearful disease hydro-

phobia, or the anatomist dying, from merely puncturing his skin with the instrument with which he was dissecting a decomposing body? these and numerous other diseases are produced by introducing or inhaling putrefying matter into the living body. How careful, then, ought we to be, in removing all waste animal and vegetable matter from the neighbourhood of our dwellings; for if the putrefying exhalations are not sufficient in quantity, or are not in that stage of decomposition to produce actual disease, they nevertheless are present, if present at all, in sufficient quantity to prevent us from enjoying sound health.

380. When the *oxidation* of substances is attended with evolution of light as well as heat, it is usually called *combustion;* when the *oxidation of organic substances* takes place at common temperatures, and is not attended with an evolution of light, and the heat which is evolved being imperceptible from the slowness of the combination, it is called *decay.* The necessary conditions for the decay of organic substances are a certain temperature, moisture, and continued exposure to air or oxygen; the degree of temperature required varies with the substance, but no substance undergoes this change at or below a temperature of 32° F. Decay is retarded, or entirely prevented, by all those substances which obstruct putrefaction or fermentation.

381. By fermentation and putrefaction complex organic substances are resolved into more simple ones,—sugar, for instance, is resolved into alcohol, carbonic acid, and water; but decay converts even the most complex organic bodies into substances belonging to the inorganic kingdom, for the decay of any organic substance ceases not until its carbon is converted into carbonic acid, its hydrogen into water; and if it contains nitrogen, part of the hydrogen is expended in combining with this element to form ammonia, so that by decay, organic bodies are converted back into the same substances out of which they were originally formed.

382. All putrefying bodies pass into a state of decay when freely exposed to the air, but all decaying substances cannot putrefy. Many bodies do not decay, except they are in contact with an alkali; in the presence of alkalies, or alkaline earths, nitrogen, if a constituent of the decay-

ing body, is converted into nitric acid. Contact with decaying matter not only induces those substances to decay, which would, if placed in the proper condition, do so of themselves, but it induces substances to decay, which are not prone of themselves to enter into oxidation at ordinary temperatures. Thus alcohol, which is a very inflammable substance,—that is, its carbon and hydrogen readily enter into combination with oxygen at high temperatures,—does not oxidize (decay) at ordinary temperatures, unless placed in contact with decaying matter; by this means, it is converted into acetic acid.

383. "It is upon this power of substances undergoing decay, to increase the attraction of all organic substances for oxygen, and especially the affinity of alcohol for this element, that a speedy process for acidifying alcohol was based.

384. "The transformation of fermented liquors into vinegar formerly required weeks, and even months, to accomplish, in consequence of the imperfect access of the air: alcohol can now be converted into vinegar in less than twenty-four hours, and this is effected mainly by making brandy, diluted with water, or any other weak spirituous liquor, trickle slowly through casks filled with wood shavings, and at the same time causing a slight stream of air to circulate through these shavings. This method exposes to the air a surface of alcohol capable of absorbing oxygen, by many thousand times more extensive than the old method; and consequently, the time which alcohol, under ordinary circumstances, requires for its acidification, is abridged in the same proportion. At the commencement of this process it is usual to add to the dilute spirit a small quantity of some substance containing matter capable of undergoing the process of decay, such as beer-wort, honey, vinegar, &c.; but after the lapse of a very short time, the surface of the wood shavings passes into a state of oxidation, and from that moment effects the transformation of the spirit into vinegar, without the further co-operation of extraneous decaying matter."

385. We have said (366) that there must be a certain relation as to quantity between the ferment and the fermentescible body, if the two complete their decomposition at the same time. Now the juice of grapes, grown in hot climates, is proportionably richer in the fermentescible

body (sugar) than it is in the ferments, consequently, during the fermentation of the juice, the complete decomposition and separation of the latter class of substances from the juice is effected before all the sugar has been converted into alcohol and carbonic acid; a quantity of sugar therefore remains undecomposed; wine made from such juice never turns sour. But the juice of grapes grown in temperate regions, and also the wort from barley, &c., are richer proportionally in the ferments than they are in the fermentescible body, therefore all the ferment is not decomposed and separated by the time all the sugar has been converted into alcohol; the consequence is, that the undecomposed portion causes the wine, beer, &c., if access of air is not prevented, to be converted into vinegar, —because these ferments begin to decay, and thus cause the alcohol to be converted into acetic acid. By placing the wine and beer in casks this acetification is prevented, because all the oxygen in the small quantity of air which passes through the pores of the wood is appropriated by the ferments, for it is only when there is a larger quantity of oxygen than is sufficient to combine with these bodies, that the alcohol can oxidize. If the beer or wine were to remain in the cask until all the ferments were oxidized, it would not, of course, on free exposure to air be converted into vinegar. We have remarked that substances require a certain temperature for their decay, as well as for their combustion, and that the temperature varies with the substance. Thus, alcohol will not decay, even in the presence of decaying matter, under a temperature of 50° F.; this fact has been taken advantage of in Germany, in the manufacture of beer. Beer made by this plan, which is called the Bavarian process, never turns sour, because all the ferments are decomposed, which is effected in the following manner:—A large surface of wort is exposed to the air, by placing it in shallow vessels, and which at the same time is kept at a temperature under 50° F., consequently the ferments decompose, and the sugar becomes converted into alcohol; but this latter, although in the presence of substances undergoing decay, does not become converted into acetic acid, because there is not heat sufficient to effect the conversion,—in this way all the ferments become decomposed without acetification taking place.

CHAPTER XIII.

ISOMERIC COMPOUNDS.

The same chemical compound always contains the same elements in the same proportions; but the same elements in the same proportions do not of necessity generate the same substances. Examples. Explanation of terms. Isomeric substances converted and reconverted into each other. Doctrine of substitution. Important applications. Bleaching. Chloroform. Artificial oil of almonds. One of the colouring matters in madder, from a substance in coal tar. Exercises.

386. The class of facts contained in this chapter may appear to the student to contradict all that has been stated in the previous part of the work; it will, on this account, be as well to relate the proposition which they apparently contradict, viz., that the same chemical compound invariably contains the same elements in the same proportions. The facts we are about to notice prove that "the converse, however, is very far from being true; the same elements combining in the same proportions do not of necessity generate the same substances. Organic chemistry furnishes numerous instances of this very remarkable fact, in which the greatest diversity of properties is associated with identity of chemical composition. These cases seem to be nearly confined to organic chemistry; only a few well established and undoubted examples being known in the inorganic or mineral division of the science." Ex.—Oil of turpentine, essence of lemons, oil of rosemary, oil of juniper, and many others, differing widely from each other in their properties, are composed of the same elements, carbon and hydrogen, and in the same proportions. Again, the solid part of otto of roses, a substance well known on account of its delicious fragrance, and olefiant gas, the most valuable of the gases composing ordinary coal gas, and paraffine, are composed of the same elements, carbon and hydrogen, and in the same proportions. Albumen and fibrine we have seen have the same composition, and also starch, and woody fibre. To such substances—that is, substances composed of the same

elements in the same relative proportions, yet perfectly distinct in their physical and chemical properties—the term *Isomeric* (from ισος, *equal*, and μερος, *parts*) is applied.

387. To what cause is the difference in properties of Isomeric compounds to be ascribed? The difference is due either in the *absolute number*, or in the arrangement of the atoms. The first (that is, difference in absolute numbers) has been likened to words which, as compared with each other, contain the same letters arranged in the same way, but a different number of these letters. Thus, in the words *ma, mama; tar, tartar; do, dodo:* we have in each couple the same syllable, but the second contains it twice as often as the first. The second (that is, the arrangement of atoms) has been compared to words, as *ape* and *pea*, or *ate, eat, tea*, which have the same alphabetical elements, but the difference in the arrangement of the letters totally alters their verbal value.

388. The first class differs from one another by the atom of one compound containing a larger number of elementary atoms than another; such substances are distinguished from those composing the second class by the term Polymeric. We will now give a few illustrations of Polymeric substances. Turpentine and oil of lemons have the same composition in every 100 parts, but the following is their rational formula:—

Oil of turpentine . . .	$C_{10}H_8$
Oil of lemons	C_5H_4

Olefiant gas, gas from oil, napthene, cetene, have the same per-centage composition, but the following are their rational formulæ:—

Olefiant gas	C_4H_4
Gas from oil	C_8H_8
Napthene	$C_{16}H_{16}$
Cetene	$C_{32}H_{32}$

389. The members of the other class are ternary compounds, that is, they are made up of two other compounds, which are called their proximate elements. The members of this class, which have the same elementary constitution, differ from one another in their proximate elements; such substances are distinguished from the members of the

preceding class by the term Metameric. Ex.—Formiate of ether, and acetate of methyl, are metameric.

Proximate elements	Formic acid . .	$C_2 H O_3$
	Ether	$C_4 H_5 O$
	Formic ether . .	$C_6 H_6 O_4$

Proximate elements	Acetic acid . . .	$C_4 H_3 O_3$
	Methyl	$C_2 H_3 O$
	Acetate of methyl	$C_6 H_6 O_4$

390. The existence of isomeric compounds, "so highly important in their applications, was not received and admitted as sufficiently established, without sufficient proofs. Many examples have long been known where the analysis of two different bodies gave the same composition; but such cases were isolated observations, homeless in the realms of science; until at length, examples were discovered of two or more bodies, whose absolute identity of composition, with totally distinct properties, could be demonstrated in a more obvious and conclusive manner than by mere analysis; that is, they can be converted and reconverted into each other without addition and without subtraction.

391. "In cyanuric acid, hydrated cyanic acid, and cyamelide, we have three such isomeric compounds.

392. "Cyanuric acid ($C_6 N_3 H_3 O_6 = \overset{*}{C}y_3 O_3, 3 HO$) is crystalline, soluble in water, and capable of forming salts with metallic oxides.

393. "Hydrated cyanic acid $\{ C_6 N_3 H_3 O_6 = 3 (CyO, HO) \}$ is a volatile and highly corrosive fluid, which cannot be brought into contact with water without being instantaneously decomposed.

394. "Cyamelide $\{ C_6 N_3 H_3 O_6 = 3 (C_2 O_2, N H) \}$ is a white substance, very like porcelain, absolutely insoluble in water.

395. "Now, if we place the first—cyanuric acid—in a vessel hermetically sealed, and apply a high degree of heat, it is converted by that influence into hydrated cyanic acid; and then, if this is kept for some time at the

common temperature, it passes into cyamelide, no constituent being separated, nor any body taken up from without. And again, inversely, cyamelide can be converted into cyanuric acid, and hydrated cyanic acid.

396. "We have three other bodies which pass through similar changes, in aldehyde, metaldehyde, and elaldehyde; and again, two, in urea and cyanate of ammonia. Further, 100 parts of aldehyde, hydrated butyric acid, and acetic ether, contain the same elements in the same proportion. Thus, one substance may be converted into another without the separation of any of its elements, and without the introduction of any foreign body."—*Liebig.*

397. The discovery of isomeric compounds opened out a new field of research to chemists; till then, a difference, either in the elementary constitution, or in the proportion of the elements, distinguished the different compounds; the discovery of this class showed that the same elements united in the same proportions, but *arranged differently,* would cause the formation of a variety of compounds. The study of the arrangement of the elementary atoms in a compound has given rise to what is termed the *doctrine of substitution,* or the removal and replacement of one or more atoms of some element in a compound by another. As an example, we can substitute chlorine for the oxygen and hydrogen in ether, thus:—

Ether (oxide of ethyle) . .	$C_4\,H_5\,O$
Chloride of ethyle	$C_4\,H_5\,Cl$
Then, successively	$C_4\left\{\begin{matrix}H_4\\Cl\end{matrix}\right.Cl$
	$C_4\left\{\begin{matrix}H_3\\Cl_2\end{matrix}\right.Cl$
	$C_4\left\{\begin{matrix}H_2\\Cl_3\end{matrix}\right.Cl$
	$C_4\left\{\begin{matrix}H\\Cl_4\end{matrix}\right.Cl$
And lastly	$C_4\,Cl_5\,Cl$

398. It would have been impossible for England, at the present time, to have competed successfully in the bleaching of cotton goods, and therefore I think we may add their manufacture, had the bleaching effects of moist chlorine, which depends upon the removal and replacement of the hydrogen in the coloured compound by this

element, not been discovered and applied. "But for this new bleaching process, it would scarcely have been possible for the cotton manufacture of Great Britain to have attained its present enormous extent—it could not have competed in price with that of France and Germany. In the old process of bleaching, every piece had to be exposed to the air and light during several weeks in the summer, and kept continually moist by manual labour. For this purpose meadow land, eligibly situated, was essential. Now a single establishment, near Glasgow, of only moderate extent, bleaches 1,400 pieces of cotton daily, throughout the year. What an enormous capital would be required to purchase land for this purpose! How greatly would it increase the cost of bleaching to pay interest upon this capital, or to hire so much land in England! This expense would scarcely have been felt in Germany. Besides the diminished expense, the cotton stuffs bleached with chlorine suffer less in the hands of skilful workmen than those bleached in the sun; and already the peasantry in some parts of Germany have adopted it, and find it advantageous."—*Liebig.*

399. Ladies are indebted to this action of chlorine for the white patterns upon coloured grounds on their dresses. This is effected by stamping on the coloured cloth the pattern, in a mixture of paste or gum, to which a little acid, generally tartaric, has been added. The cloth is then dried, and afterwards immersed in a hot solution of bleaching powder, a compound of chlorine and lime. The result of this immersion is to develop the devices in *white* upon a coloured ground, in consequence of the acid of the paste with which they were executed decomposing the chloride of lime and liberating its chlorine, which destroys the colour of the cloth at all the points impregnated with acid, but does not sensibly affect its tint elsewhere. Science, at the present day, so ministers to our every wish and desire, that ladies cannot even substitute the material alpaca for that of cotton or mousseline-de-laine, without greatly disturbing the world of commercial chemistry; for in the former material the colour is never discharged, consequently no bleaching powder or tartaric acid is required; and as the chief consumption of the latter article depends on its use in this way, the manufacture of it was completely suspended a few years

back, when alpacas reigned paramount in the realms of fashion.

400. "The French calico printers employ mousseline-de-laines consisting altogether of wool, while in England we use a much cheaper fabric, consisting of wool and cotton. The colours on this mixture are, however, extremely meagre when compared with the former; but Mercer has shown that the mixed fabric acquires the properties of the other when it is treated with a bath of chloride of lime. This, one of the most important discoveries ever made in calico printing, has been of great value to this country."—*Playfair.*

401. We can substitute chlorine for the oxygen and hydrogen in oxide of methyl (a substance obtained in the destructive distillation of wood), thus :—

Oxyde of methyl . . . . $C_2\,H_3\,O$
Chloride of methyl . . . $C_2\,H_3\,Cl$
Then, successively . . $C_2 \left\{\begin{matrix}H_2\\Cl\end{matrix}\right. Cl$
$C_2 \left\{\begin{matrix}H\\Cl_2\end{matrix}\right. Cl$
And lastly . . . . $C_2\,Cl_3\,Cl$

402. The fourth compound in the series, $C_2\,H\,Cl_3$, or $C_2\,H\,Cl_2\,Cl$, has been known throughout the civilized world by name for some time; this compound is called chloroform; it is the best substance which has yet been discovered for producing insensibility to pain.

403. By acting upon benzole ($C_{12}\,H_6$), one of the substances in gas tar, with nitric acid, we remove one atom of the hydrogen and replace it by nitrous acid ($N\,O_4$); the compound thus formed is called nitrobenzole ($C_{12}\,H_5\,N\,O_4$), it possesses the smell and taste of oil of bitter almonds, and is now employed largely, instead of the veritable oil, in perfuming soap, and flavouring confectionary; it is much to be preferred to the true oil for the latter purpose, as it is free from the deadly poison, hydrocyanic acid, which the oil of almonds contains.

404. Ere long, it is expected that we shall be able, by substitution, to convert the waste substance, napthaline, formed during the manufacture of coal gas, at the present time valueless, into one of the most beautiful and valuable of the colouring matters of madder. This colouring

matter of madder is called alizarine, and has the following composition, $C_{20} H_6 O_6$; the following is the formula for napthaline, $C_{20} H_8$; by acting upon this latter substance with chlorine and other agents, we obtain a compound called chloronapthalic acid, which has the same composition as alizarine, with the exception that it contains one equivalent of chlorine in place of one equivalent of hydrogen, thus—$C_{20} H_5 Cl O_6$. At present we are unable to remove this atom of chlorine and replace it by an atom of hydrogen. Cotton ($C_{12} H_{10} O_{10}$) is converted into a substance called gun-cotton, from its explosive nature, by substituting for some of its hydrogen atoms an equivalent number of atoms of $N O_4$.

EXERCISES.

279. Pour into vessels containing infusion of blue cabbage, of litmus, in fact of any vegetable colour, a little chlorine water, the colour will instantly be destroyed.

280. Stain a little linen or cotton with port wine or fruit juice; when dry immerse it in water containing a little free chlorine, the stain will be quickly removed.

281. Take a piece of dyed cloth, and paint upon it some figure, with a paste consisting of ordinary flour paste, to which a little tartaric acid has been added; dry the cloth, and afterwards immerse it in a hot solution of bleaching powder (chloride of lime ($Ca O Cl$).*

405. The student must write out answers to the following questions:—

282. What substances are termed fermentescible?

283. What is the difference between putrescible and fermentescible bodies?

284. State what is meant by the terms Decay, Fermentation and Putrefaction.

285. Does a *ferment* undergo the same decomposition in the presence of a fermentescible body as it does alone?

286. Has heat any influence upon putrefaction and fermentation?

287. What is meant by the terms Metameric and Polymeric?

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* The next and concluding course of lessons is on the special properties of the metalloids; before entering upon them the teacher ought to instruct the pupils in the fitting up of apparatus.

CHAPTER XIV.

METALLIC OXIDES.

All the metals unite with oxygen, either directly or indirectly. Metals combine with oxygen in more than one proportion. List of the more important basic oxides. This class divided into four groups. Exercises.

406. All the metals unite with oxygen, the combination being sometimes attended, as we have witnessed, with an evolution of both light and heat. The affinity of the various metals for oxygen is very different; thus, some metals, such as potassium and sodium, combine *directly* with oxygen, even at ordinary temperatures, whilst others, such as gold and platinum, possess such a feeble affinity for this metalloid, that they do not combine with it *directly* under any circumstances, their oxides can only be obtained by indirect means; hence this latter class of metals are called *noble metals*, because they do not oxidize (rust) when exposed to the air or water. The first class retain their oxygen at the highest possible temperature, whilst the other class readily abandon it when their oxides are heated. There are other metals whose affinity for oxygen is intermediate between the two classes we have described.

407. The oxides of the metals have no metallic lustre; hey have, rather, what might be termed an earthy aspect; owing to this appearance, an oxide was called by the ancient chemists, who were ignorant of the chemical composition of this class of bodies, *a calx*, the process of forming it being expressed by the term *calcination*, a term which is still employed in chemistry.

408. The metallic oxides may be divided into the three following classes, viz., bases, acids, and indifferent bodies; the present chapter is devoted to the first of these classes only. It may, however, be observed, in passing, that many of the metals combine with oxygen in more than one proportion, and that the characters of the different oxides of the same metal are found to be regulated in a great measure by the quantity of oxygen they contain. The different oxides of manganese afford good examples;

the protoxide of that metal ($Mn\,O$) is a powerful base, the sesquioxide ($Mn_2\,O_3$) is feebly basic, and the binoxide, or, as it is sometimes termed, the peroxide ($Mn\,O_2$), is an indifferent body, whilst manganic acid ($Mn\,O_3$) and permanganic acid ($Mn_2\,O_7$) are, as the latter word of their name implies, acid bodies. The oxides of iron and chromium present similar, but less numerous, gradations. In these, and all other instances, the acid oxides always contain a larger quantity of oxygen than the basic oxides of the same metal. Without a single exception, the protoxide is the strongest basic oxide, the basic properties gradually decreasing as the oxygen increases from this point, until it disappears ; and the oxide displays negative properties, if the metal be still capable of combining with more oxygen ; the next highest oxide after the indifferent oxide uniformly possesses acid properties. The basic oxides are the largest class, the indifferent oxides the smallest. Many metals, so far as we know at present, are incapable of forming acid oxides, although they form basic oxides, whilst *only one metal*, arsenic, is capable of forming acid oxides and not a basic oxide. All the other metals which form acid oxides, likewise form one or more basic oxides. Not one metal forms an indifferent oxide without being capable of forming at least one basic oxide.

409. The following is a list of the more important metallic oxides possessing basic properties. The learner, be he young or old, must on no account omit committing the names and symbols of these compounds to memory before proceeding further.

LIST OF BASIC SUBSTANCES.

Names.	Colour.	Symbols.
Potash	White	$K\,O$
Soda	Ditto	$Na\,O$
Ammonia*		$N\,H_4\,O$
Baryta	Ditto	$Ba\,O$
Strontia	Ditto	$Sr\,O$
Lime	Ditto	$Ca\,O$

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* The oxide of an hypothetical compound metal ammonium ($N\,H_4$).

LIST OF BASIC SUBSTANCES (*continued*).

Names.	Colour.	Symbols.
Magnesia	White	MgO
Alumina	Ditto	Al_2O_3
Sesquioxide of Chromium	Green	Cr_2O_3
Protoxide of Iron . . .	Black	FeO
Sesquioxide of Iron . .	Brownish-Red	Fe_2O_3
Oxide of Zinc	White	ZnO
Protoxide of Manganese	Greenish-Grey	MnO
Protoxide of Nickel . .	Grey	NiO
Protoxide of Cobalt . .	Ditto	CoO
Oxide of Silver	Brown	AgO
Suboxide of Mercury .	Black	Hg_2O
Protoxide of Mercury .	Red	HgO
Oxide of Lead	Yellow or Reddish-Yellow	PbO
Oxide of Cadmium . .	Brown or Yellowish-Brown	CdO
Oxide of Copper . . .	Black	CuO
Teroxide of Bismuth . .	Yellow	BiO_3
Protoxide of Tin . . .	Black	SnO
Binoxide of Tin . . .	Light straw colour	SnO_2
Teroxide of Antimony .	Greyish-White	SbO_3
Teroxide of Gold . . .	Brown	AuO_3
Binoxide of Platinum .	Brown	PtO_2

410. Most of the basic metallic oxides are insoluble in water; but all those that are soluble have the property of giving a brown stain to yellow turmeric paper, and of restoring the blue colour of reddened litmus paper. This class of oxides is usually divided into the four following orders, viz.—alkalies, alkaline earths, earths, and salifiable metallic oxides.

411. "From the old name of potash, *kali*, with the Arabic prefix, *al*, potash and soda, at one time confounded together, were termed *alkalies*,* and ammonia resembling

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* "In the ninth century the Arabians were the most distinguished chemists, and several of the names they introduced still survive. Many of them may be recognized by commencing with the Arabic definite article Al. Thus we have alcohol, alkali, alembic."—*Dr. Wilson's Chemistry.*

them very much, when dissolved in water or combined with acids, was also called an alkali; it was the volatile alkali, potash and soda being fixed alkalies; it was also termed the animal alkali, being derived from animal matter, whilst soda was the mineral alkali, being derived from rock salt, or from the ocean; and potash received the name of the vegetable alkali, from its only known source at that time being the ashes of plants growing upon land. The alkalies are characterized by being very soluble in water, and by neutralizing the strongest acids. They hence restore the blue colour of reddened litmus paper, and change the vegetable colours in general; the yellows to brown, the reds and blues to green."*

412. Baryta, strontia, lime, and magnesia are termed alkaline earths; with the exception of magnesia they are all soluble in water, but much less so than the alkalies; they are distinguished from this order of bodies by their carbonates being insoluble in water, whilst the alkaline carbonates are very soluble. The solutions of the alkaline earths turn turmeric paper brown, and neutralize acids.

413. The only oxide we have given in the list belonging to the order of earths is alumina; the other oxides belonging to this order are the oxides of some of the rare metals; they do not, therefore, come within the scope of the work. Alumina is insoluble in water, and has therefore no action on turmeric paper.

414. Before proceeding to the next class, we will answer a question which is likely to occur to the observant learner. It is this,—Why does the naming of the oxides forming the three orders mentioned follow a different rule to that of the other metallic oxides? Why are they not called oxide of potassium, oxide of sodium, oxide of barium, oxide of strontium, oxide of calcium, oxide of magnesium, sesquioxide of aluminum, instead of potash, soda, baryta, strontia, lime, magnesia, alumina? At the time these names were given to these oxides, they were considered simple bodies, as the metals of these oxides had not been then obtained; and thus the old names, and their separation into alkalies, alkaline earths, and earths, still continue to be employed, although their exact chemical constitution

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* Sir Robert Kane's "Elements of Chemistry."

has been for some time determined. It is more correct to call them oxide of potassium, &c., instead of potash, &c. And the combinations of the other metalloids with these metals are named in the ordinary way; thus, sesquichloride of aluminum, iodide of potassium, &c.

415. "Salifiable heavy metallic oxides. Many of these compounds are coloured, and easily fusible or volatile; some of them exhibit a certain degree of solubility in water, alkaline reaction, and metallic taste. Their affinity for acids is in some cases greater, in others less, than that of earths. Some of them even possess slightly acid properties, as binoxide of tin, teroxide of gold, &c.; this class includes the oxides of iron, copper, zinc, mercury, &c."*

416. If the learner has accurately committed to memory the list of basic oxides, he will have no difficulty in writing out either the names or symbols of similar combinations of the other metalloids with the metals, as the symbols of these compounds resemble the symbols of the metallic oxides, with the exception that the place of the O in oxides is occupied by the symbol of the metalloid named. Ex.—The symbol for binoxide of platinum is $Pt\ O_2$, and the symbol for the biniodide of platinum is $Pt\ I_2$. The names are formed by taking away the first syllable in the word oxide and substituting for it the first few letters of the name of the particular metalloid which occupies the place of the oxygen in the compound under consideration. Ex.—The symbol $Au\ Cl_3$ only differs from the symbol $Au\ O_3$ by its containing chlorine in the place of oxygen; as the latter is called teroxide of gold, the former, of course, is called terchloride of gold.

417. The combinations of the metalloids with each other are symbolized and named in a similar way. But the learner had better consult paragraphs 163 and 164 before he commences to write the exercises.

418. In *writing out the symbols* of the compounds produced by a combination of the metalloids with the metals, the symbols of the metals are always placed before those of the metalloids. But in *naming* this class of compounds, or in writing out their names, the reverse order takes place, the names of the metalloids coming before the

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* Gmelin's "Hand-book of Chemistry."

names of the metals. The preceding lesson and examples illustrate these two points.

419. In combinations of the metalloids with each other, the symbol for hydrogen is always placed before that of the other metalloid, with the exception of carbon and phosphorus; the names of the two constituents are arranged in the name of the compound in reverse order to the symbolized expressions, with the exception of the hydrogen compounds of carbon and phosphorus.

420. The learner will now experience no difficulty whatever in writing out the following exercises :—

EXERCISES.

421. Write out the names of the following compounds :—

(288) $K\,Cl$. (289) $N\,H_4\,S$. (290) $H\,F$. (291) $F_2\,S_3$. (292) $Na\,I$. (293) $Ba\,F$. (294) $Au\,Br_3$. (295) $B\,F_3$. (296) $Zn\,Br$. (297) $Sn\,Cl_2$. (298) $I\,Cl$. (299) $I\,Cl_3$. (300) $Pb\,I_2$. (301) $Mn\,S$. (302) $Pb\,S$. (303) $H\,S$. (304) $H\,Cl$. (305) $H\,I$. (306) $H\,Br$.

422. Write out the symbols of the following compounds :—

307. Iodide of potassium. 308. Bisulphide of ammonium. 309. Fluoride of calcium. 310. Sesquibromide of iron. 311. Terhydride* of arsenic. 312. Iodide of silver. 313. Chloride of ammonium. 314. Subchloride of sulphur. 315. Terbromide of gold. 316. Quadrosulphide of potassium. 317. Dinoxide of copper. 318. Sesquioxide of manganese.

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* Hydr*ides* and Hydr*ates* are two different classes of compounds—the first are compounds of hydrogen with other substances, the latter are compounds of water with other substances.

CHAPTER XV.

ACID SUBSTANCES.

Characteristics of an acid. This class of substances divided into two groups. Acids either monobasic or polybasic. A list of acid bodies. Their nomenclature.

423. In the earlier period of chemistry an acid was considered to be an oxidized body, which had a sour taste, reddened litmus, and neutralized alkalies. This definition is now too limited, as we are acquainted at the present time with a numerous class of bodies possessing all the properties of acids, which do not contain oxygen. We likewise know of some bodies which, from their insolubility, have no sour taste or action upon vegetable colours, yet from their behaviour with bases are regarded as acids; and some bodies admitted to be acids, such as carbonic and boracic acids, are even unable to neutralize completely the alkaline reaction of potash and soda. "Facts of this kind have induced chemists to consider as acids all those compounds which unite with potash or soda, and give rise to bodies similar in their constitution and general character to the salts which the sulphuric or some admitted acid forms with those alkalies."*

424. The different oxygen combinations of each of the metalloids are, with few exceptions, acids, and also several of the higher metallic oxides, as has been before noticed. The hydrogen compounds of many of the other metalloids are likewise acid bodies. This class of compounds are therefore divided into two orders, viz., oxygen acids and hydrogen acids. When the oxygen acids contain water ($\bar{H}O$), they are called hydrated acids. When they are deprived of this body, or do not naturally contain it, they are called an-hydrous.

425. Acids are either monobasic or polybasic, according as they are capable of combining with one or more atoms of base. All the acids given in the following list are monobasic, with the exception of phosphoric, arsenic, and arsenious acids. The two first are called tribasic

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* Turner's "Chemistry," 8th Edition.

acids, from their capacity of uniting with three atoms of base. The last named acid is bibasic, as it combines with only two atoms.

426. The names and symbols of the following acids must be committed to memory.

OXYGEN ACIDS.

Sulphurous acid	a gas	SO_2
Sulphuric acid (oil of vitriol)	a liquid, freezes at 31° F., boils at 640° F	HO, SO_3
Nitric acid (aqua fortis)	a liquid, freezes about 40° F., boils at 184° F.	HO, NO_5
Chloric acid	an oily fluid, decomposed at 100 F.	HO, ClO_5
Oxalic acid	a solid, decomposed above 320° F.	$HO, C_2O_3 = HO, \bar{O}$[*]
Phosphoric acid	a solid; it volatilizes at very high temperatures	$3HO, PO_5$
Carbonic acid (choke damp)	a gas	CO_2
Arsenious acid	a solid; it volatilizes at 380° F.	AsO_3
Arsenic acid	a solid, decomposed at a high temperature into AsO_3 and O	AsO_5
Chromic acid	a solid, above 400° F. decomposed into Cr_2O_3 and O	CrO_3
Boracic acid	a solid, volatilizes very slowly by intense ignition	BO_3
Silicic acid (silica, quartz, sand)	a non-volatile solid	SiO_3

HYDROGEN ACIDS.

Hydrochloric acid (muriatic acid, spirit of salts)	a gas	HCl
Hydrosulphuric acid (sulphuretted hydrogen)	a gas	HS
Hydrofluoric acid	a very volatile acid, which boils about 60° F.	HF
Hydriodic acid	a gas	HI
Hydrobromic acid	a gas	HBr
Hydrocyanic acid (prussic acid)	a very volatile liquid, which boils at 80° F.	$H, C_2N = HCy$[†]

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[*] The O with a dash over is a contracted symbol, it stands for C_2O_3.

[†] Cy stands for C_2N, which is the symbol for cyanogen.

427. The nomenclature of acids is very defective; the names of these substances do not in the least express the proportional quantities of their constituents. The names of oxygen acids are formed by affixing the termination *ic* to the substance in combination with oxygen. Thus, the acid compound of phosphorus is called phosphor*ic* acid. If the same element forms with oxygen two acid compounds, the termination *ic* is applied to the compound containing the largest quantity, and the termination *ous* to the one containing the least quantity of oxygen, as sulphur*ic* acid ($H O, S O_3$), sulphurous acid ($S O_2$).

428. When, as in the case of sulphur, the metalloid forms more than two acid combinations, the two prefixes *hypo* (ὑπο, under) and *hyper* (υπερ, above) have to be employed. Thus, $S_2 O_2$ is called hyposulphurous, because it contains a less quantity of oxygen than sulphurous acid; $S_2 O_5$ is called hyposulphuric acid, because it contains a less quantity of oxygen than sulphuric acid; it might also, with propriety, be called hypersulphurous acid, as it contains more oxygen than sulphurous acid.

429. The names of the hydrogen acids which have been given in the list of acids, are those most generally used. Two new classes of names have recently been proposed for these acids. The one class of names are constructed in a manner similar to oxides, as chloride of hydrogen, sulphide of hydrogen, bromide of hydrogen, iodide of hydrogen, fluoride of hydrogen, cyanide of hydrogen. The other class are, chlorhydric acid, sulphydric acid, bromhydric acid, iodhydric acid, fluorhydric acid, cyanhydric acid.

430. The names placed within brackets are either older chemical names, or the popular names of the substances; in either case it is well for the student to know them.

CHAPTER XVI.

SALTS.

Divided into two groups. General formulæ for neutral salts. Nomenclature of salts. Exercises. Salts either neutral, acid, or basic. Exercises. Characteristics of an acid salt. Exercises. Characteristics of a basic salt. Exercises. Polybasic salts. Double salts. Exercises.

431. Salts are divided into two orders. To the first order belong all salts made up of an oxygen acid and an oxygen base—they are, therefore, called oxygen salts. The salts in the second order are called haloid (from αλς, sea salt, and ειδος, form), because in constitution they are analogous to sea salt, being composed of the radical of some hydrogen acid united with some metal.

432. "Nearly all salts are solid at common temperatures, and most of them are capable of crystallizing. The colour of salts is very variable, having no necessary connection with the colour of their elements. Salts composed of a colourless acid and base are colourless; but a salt, though formed of a coloured oxide or acid, may be colourless; or, if coloured, the tint may differ from that of both its constituents."

433. "All soluble salts are more or less sapid, while those that are insoluble in water are insipid. Few salts are possessed of odour; the most remarkable one for this property is carbonate of ammonia."

434. Salts differ remarkably in their affinity for water. Thus, some salts, such as the nitrates of lime and magnesia, are *deliquescent*, that is, attract moisture from the air, and become liquid. Others, which have a less powerful attraction for water, undergo no change when the air is dry, but become moist in a humid atmosphere; and others may be exposed, without change, to an atmosphere loaded with watery vapour.

435. "Salts differ likewise in their degree of solubility in water. Some dissolve in less than their weight of water, while others require several hundred times their

weight of this liquid for solution, and others are quite insoluble.

436. "Salts, which are soluble in water, crystallize more or less regularly when their solutions are evaporated. If the evaporation is rendered rapid by heat, the salt is usually deposited in a confused crystalline mass; but if it take place slowly, regular crystals are formed. The best mode of conducting the process is to dissolve a salt in hot water, and when it has become quite cold, to pour the saturated solution into an evaporating basin, which is to be set aside for several days or weeks without being moved. As the water evaporates, the salt assumes the solid form; and the slower the evaporation, the more regular are the crystals. Some salts, which are much more soluble in hot than in cold water, crystallize with considerable regularity when a boiling saturated solution is slowly cooled. The form which salts assume in crystallizing is constant under the same circumstances, and constitutes an excellent character by which they may be distinguished from one another.

437. "Many salts during the act of crystallizing unite chemically with a definite portion of water, which forms an essential part of the crystal, but not of the salt, and is termed *water of crystallization*. The quantity of combined water is very variable in different saline bodies, but is uniform in the same salt. A salt may contain more than half its weight of water, and yet be quite dry. On exposing a salt of this kind to heat, it is dissolved, if soluble, in its own water of crystallization, undergoing what is termed *watery fusion*. By a strong heat the whole of the water is expelled; for no salt can retain its water of crystallization when heated to redness. Some salts, such as sulphate and phosphate of soda, lose a portion of their water, and crumble down into a white powder, by mere exposure to the air; a change which is called *efflorescence*. The tendency of salts to undergo this change depends on the dryness and coldness of the air; for a salt which effloresces rapidly in a moderately dry and warm atmosphere, may often be kept without change in one which is damp and cold.

438. "This water of crystallization is retained by a very feeble affinity, as is proved by the phenomena of efflorescence, and by the facility with which such water

is separated from the saline matter by a moderate heat, or by exposure to the vacuum of an air-pump at common temperatures. It is frequently observed, however, that a portion of the water is retained with such obstinacy that it cannot be expelled by a temperature short of that at which the salt is totally decomposed;* in such a state it is called essential water, and is expressed by the symbol $H\,O$. Water of crystallization is called non-essential water, because it can be removed without destroying the compound. The first two letters of the Latin word *aqua*, which means water, are frequently used as the symbol for non-essential water."

439. The following general formulæ of the most important salts must be committed to memory. The letter M stands for any metal.

Oxygen Salts.		*Haloid Salts.*	
Sulphites	$M\,O, S\,O_2$	Chlorides (muriates)	$M\,Cl$
Sulphates	$M\,O, S\,O_3$	Sulphides (sulphurets)	$M\,S$
Nitrates	$M\,O, N\,O_5$	Fluorides	$M\,F$
Chlorates	$M\,O, Cl\,O_5$	Iodides	$M\,I$
Oxalates	$M\,O, \overline{O}$	Bromides	$M\,Br$
Phosphates	$3\,M\,O, P\,O_5$	Cyanides	$M\,Cy$
Carbonates	$M\,O, C\,O_2$		
Arsenites	$2\,M\,O, As\,O_3$		
Arseniates	$3\,M\,O, As\,O_5$		
Chromates	$M\,O, Cr\,O_3$		
Borates	$M\,O, B\,O_3$		
Silicates	$M\,O, Si\,O_3$		

440. It will be seen by the above formulæ, that when oxygen acids unite with bases and form salts, the terminations *ic* and *ous* of the acids are changed into *ate* and *ite*. When there is more than one basic oxide of the same metal (the two oxides, protoxide and sesquioxide, of iron, for example), it is necessary to use the same prefixes to distinguish the different classes of salts as are employed to distinguish the different oxides. Thus, we call the combination of protoxide of iron with sulphuric acid, sulph*ate* of the *prot*oxide of iron; in the same way, we call the combination of sesquioxide of iron with sulphuric

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* Turner's "Chemistry," 8th Edition.

acid, sulph*ate* of the *sesqui*oxide of iron; sometimes the prefixes are placed before the acid in the following manner,—protosulphate of iron, persulphate of iron; sesquioxide of iron being frequently called peroxide;—this was alluded to in the chapter on chemical nomenclature and notation. Very frequently the prefix *proto* is dispensed with, and we simply say sulphate of iron. The word oxide, in oxygen salt, is generally suppressed, if there is only one basic oxide of the particular metal,—thus, in place of saying, sulphate of the oxide of zinc, it is usual to say, sulphate of zinc. The student will never experience any difficulty as to the composition of an oxygen salt from this circumstance, if he will only remember the following simple but important rule,—"Oxygen acids unite with *metallic oxides*, and not with *metals;* an oxygen salt is therefore always made up of an oxygen acid and an oxygen base."

441. A chemical formula is an expression by symbols and figures of the composition of a chemical compound. The symbols denote the elementary substances composing the compound, and the figures annexed to the symbols denote the number of atoms of the different elements; a symbol with no number attached to it signifies that only one atom of the element exists in the compound. The symbols of electro-positive* substances, such as metals, hydrogen, oxides, &c., are always placed before electro-negative substances, such as oxygen, chlorine, and acids, in chemical formulæ; whereas, in naming a chemical compound, the electro-negative ingredient is always first announced, as oxide of silver ($Ag\,O$), chloride of sodium ($Na\,Cl$), sulphate of potash ($K\,O,\ S\,O_3$), &c.

442. The general formulæ for oxygen and haloid salts having been committed to memory, the student will experience little difficulty in writing out the formula for any particular salt. But in order to render it as easy as possible, two examples are given. Suppose the formula of an oxygen salt to be required, he will simply substitute for the general oxide, $M\,O$, the symbol of the particular oxide. Ex.—The general formulæ for sulphates being $M\,O,\ S\,O_3$, the formula for sulphate of strontia will be $Sr\,O,\ S\,O_3$. The haloid salts he has already learned to

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* Consult paragraphs 337 and 338.

write out, but we have thought it advantageous to reintroduce them here. In writing these salts out, he has simply to substitute for the general letter M, the symbol for the particular metal. Thus, the general formulæ for chlorides being M Cl, the formula for chloride of sodium becomes Na Cl.

443. The formulæ for the following salts must be written out, along with the combining proportions of acid, base, and salt.

Example.—Sulphate of potash

$$KO,\ SO_3 \left\{ \begin{array}{l} \left.\begin{array}{r} K=39 \\ O=\ 8 \end{array}\right\} 47 \\ \left.\begin{array}{r} S=16 \\ 3O=24 \end{array}\right\} \underline{40} \end{array}\right. \\ \hspace{7em} \underline{87}$$

EXERCISES.

319. Sulphate of soda (glaubers salt).
320. Sulphate of ammonia.
321. Sulphate of baryta (heavy spar).
322. Sulphate of lime (gypsum).
323. Sulphate of magnesia (Epsom salts).
324. Sulphate of zinc (white vitriol).
325. Sulphate of protoxide of iron (green vitriol).
326. Sulphate of copper (blue vitriol).

327. Sulphite of potash.
328. Sulphite of soda.
329. Sulphite of ammonia.
330. Sulphite of lime.
331. Sulphite of lead.

332. Subsulphide of mercury.
333. Sulphide of mercury (cinnabar, vermilion).
334. Sulphide of lead (galena).
335. Sulphide of zinc (zinc blende).
336. Sulphide of barium.
337. Sulphide of ammonium.

338. Nitrate of potash (saltpetre).
339. Nitrate of soda.
340. Nitrate of ammonia.
341. Nitrate of lead.
342. Nitrate of strontia.
343. Nitrate of silver (caustic).

344. Nitrate of suboxide of mercury.

345. Chlorate of potash.
346. Chlorate of baryta.
347. Chlorate of soda.
348. Chlorate of lime.

349. Chloride of sodium (kitchen salt).
350. Chloride of ammonium (sal ammoniac).
351. Protochloride of iron,
352. Sesquichloride of iron.
353. Protochloride of tin.
354. Bichloride of tin.
355. Subchloride of mercury (calomel).
356. Chloride of mercury (corrosive sublimate).
357. Chromate of potash.
358. Chromate of baryta.
359. Chromate of lead.

360. Carbonate of soda.
361. Carbonate of ammonia.
362. Carbonate of potash (salt of tartar).
363. Carbonate of lime (chalk, limestone, marble).
364. Carbonate of baryta (witherite).
365. Carbonate of strontia (strontianite).
366. Carbonate of zinc (calamine).
367. Carbonate of manganese.

368. Oxalate of potash.
369. Oxalate of soda.
370. Oxalate of ammonia.
371. Oxalate of baryta.
372. Oxalate of lime.
373. Oxalate of silver.

374. Iodide of potassium.
375. Subiodide of mercury.
376. Iodide of mercury.
377. Iodide of lead.

378. Cyanide of potassium.
379. Cyanide of silver.
380. Tercyanide of gold.
381. Protocyanide of iron.
382. Cyanide of mercury.
383. Cyanide of copper.

444. Write out the names of the following salts :—

(384) $Mn\,O, S\,O_3$. (385) $Hg\,O, Cr\,O_3$. (386) $Sb\,Cl_5$. (387) $Zn\,O, S\,O_2$. (388) $Ag\,O, C\,O_2$ (389) $Ba\,O, N\,O$. (390) $Sn\,S_2$. (391) $Pb\,O, \bar{O}$. (392) $Sr\,O, Cl\,O_5$ (393) $Hg\,I$. (394) $Hg\,Cy$. (395) $Cd\,O, S\,O_3$ (396) $Fe_2\,Cy_3$. (397) $Ca\,O, N\,O_5$. (398) $Ni\,O, S\,O_3$.

445. Salts may be either *neutral*, *acid*, or *basic*. The term neutral was formerly restricted to such salts as did not alter vegetable colours, but all salts are now classed as neutral when they contain as many atoms of acid as there are atoms of oxygen in the base; thus,—

$$M\,O, S\,O_3;\ M_2\,O_3, 3\,S\,O_3;\ M\,O_2, 2\,S\,O_3;\ M\,O_3, 3\,S\,O_3,$$

would all be classed as neutral salts, without respect to their action upon vegetable colours. The student must therefore remember, in writing out the formula of a *neutral* salt, to add as many atoms of acid as there are atoms of oxygen in the base. But the student will naturally ask, how he is to ascertain from the name of the salt whether it is *neutral*, *acid*, or *basic*. We answer, if no prefix is employed to indicate the quantity of acid or base, he may conclude with certainty that it is the neutral salt which is meant.

EXAMPLES.

446. Sulphate of potash is the neutral sulphate of that oxide, and as the formula of potash is $K\,O$, the formula of the neutral sulphate must, according to the rule that all neutral salts contain as many atoms of acid as there are atoms of oxygen in the base, be $K\,O, S\,O_3$. Sulphate of alumina is the neutral sulphate of that oxide, and as the formula of alumina is $Al_2\,O_3$, the formula of the neutral sulphate must, according to the rule that all neutral salts contain as many atoms of acid as there are atoms of oxygen in the base, be $Al_2O_3, 3\,S\,O_3$ When there is more than one basic oxide of the same metal (the two oxides, protoxide and sesquioxide, of iron, for example) it is necessary to use prefixes to distinguish the different oxides; these prefixes, the student must remember, relate to the kind of oxide, not to the quantity of *acid* or *base*. Ex.—The sulphate of the protoxide of iron, or as it is sometimes called, protosulphate of iron, is the neutral

sulphate of that oxide of iron; and as the formula of protoxide of iron is $Fe\,O$, the formula of the neutral sulphate must, according to the rule that all neutral salts contain as many atoms of acid as there are atoms of oxygen in the base, be $Fe\,O, S\,O_3$; again, the sulphate of the sesquioxide of iron, or as it is sometimes called, the persulphate of iron, is the neutral sulphate of that oxide, and as the formula for the oxide is $Fe_2\,O_3$, the formula of the sulphate must, according to the preceding rule, be $Fe_2\,O_3, 3\,S\,O_3$. The student must now write out the formulæ of the following neutral salts:—

EXERCISES.

399. Sulphate of alumina. 400. Sulphate of binoxide of tin. 401. Nitrate of the sesquioxide of iron. 402. Chlorate of the protoxide of mercury. 403. Silicate of alumina. 404. Sulphate of the teroxide of antimony. 405. Sulphate of the sesquioxide of chromium.

447. An acid salt is a salt which contains two or more equivalents of acid for each equivalent of oxygen in the base. There are two kinds of acid salts,—1st. Those in which the excess of acid is present in the hydrated state. 2nd. Those in which the excess of acid is in the anhydrous state. Bisulphate of potash, $K\,O, S\,O_3 + H\,O, S\,O_3$, and bicarbonate of potash, $K\,O, C\,O_2, + H\,O, C\,O_2$, are examples of the first class. Bichromate of potash, $K\,O, 2\,Cr\,O_3$, and biborate of soda (borax), $Na\,O, 2\,B\,O_3$, are examples of the second class. Although those in the first class are now viewed, not as acid salts, but as double salts, of which one base is water, the same prefixes are used in both classes to indicate the amount of acid. The prefixes employed are *bis*, *sesqui*, *ter*, *quadro*, &c.; the prefix *bis* is employed when the salt contains *two* atoms of acid to *each* atom of basic oxide; the prefix *sesqui* is employed when the basic oxide and acid are in the proportion of *two* of base to *three* of acid; the prefix *ter* is used when the basic oxide and acid are in the proportion of *one* of base to *three* of acid; the prefix *quadro* when the basic oxide and acid are in the proportion of *one* of base to *four* of acid, &c. The student must now write out the formulæ of the following acid salts, the excess of acid in each example being considered present in the anhydrous state:—

EXERCISES.

406. Sesquicarbonate of ammonia. 407. Quadroborate of soda. 408. Bisulphate of soda. 409. Terborate of magnesia. 410. Sexborate of magnesia. 411. Sesquisulphate of potash. 412. Bicarbonate of soda.

448. Basic or subsalts are salts which contain *more than one* equivalent of oxygen in the base for each equivalent of acid. The prefixes employed to indicate the excess of base are *di* and *tri*, &c.; or the excess is indicated thus: —bibasic subsulphate, tribasic subsulphate, &c. When there are two equivalents of oxygen in the base, and only one equivalent of acid, the prefix *di* is used, or the words bibasic sub., &c., as $2\ Pb\ O,\ Cr\ O_3$, which may be either called dichromate of lead, or bibasic subchromate of lead. When there are three equivalents of oxygen in the base, and only one equivalent of acid, the prefix *tri*, or terbasic sub., &c., is employed, as $3\ Hg\ O,\ S\ O_3$, which may be either called trisulphate of mercury, or terbasic subsulphate of mercury. The formulæ for the following basic salts must now be written out.

EXERCISES.

413. Dicarbonate of copper. 414. Triborate of magnesia. 415. Dicarbonate of lime. 416. Terbasic subsilicate of magnesia. 417. Bibasic subsulphate of copper. 418. Disilicate of lime.

449. All salts are not basic, however, which contain more than one atom of base for each atom of acid, as there are certain acids (arsenious, arsenic, and phosphoric acids) which always combine with two or three atoms of base, and form neutral polybasic salts. In addition, therefore, to ordinary neutral salts, which are *monobasic*, or contain an equivalent of base, and one of acid, there are bibasic and tribasic salts, containing, respectively, two and three equivalents of base to one of acid. Ex.—Arsenite of lime ($2\ Ca\ O,\ As\ O_3$), arseniate of soda ($2\ Na\ O,\ H\ O,\ As\ O_5$), phosphate of soda and ammonia ($Na\ O,\ N\ H_4\ O,\ H\ O,\ P\ O_5$).

450. A simple distinction between polybasic and basic salts is, that in the former the different atoms of base

may be of different kinds, whilst in the latter the metallic oxide is always of the same sort.

451. There are double haloid salts, and there are double oxygen salts; in other words, two salts sometimes unite together, and form a *double salt.* In naming double salts *it is usual* only once to express the acid or electro-negative ingredient, if it is the same in both salts: for example, sulphate of soda and lime ($Na\,O,\ S\,O_3 + Ca\,O,\ S\,O_3$); sulphate of alumina and potash ($Al_2\,O_3,\ 3\,S\,O_3 + K\,O,\ S\,O_3$).

452. There exists a class of compounds, formed by the combination of a metallic oxide with some haloid salt. These compounds are called oxychlorides, oxyiodides, oxyfluorides, &c. Prefixes have not as yet been employed to describe the composition of this unimportant class of compounds. The oxychlorides were formerly called submuriates.

453. The names of the following compounds must be written out by the student, in order that he may become thoroughly conversant with *all* the rules which have been given.

MISCELLANEOUS EXERCISES.

(419) $Hg\,O$. (420) $Cr_2\,Cl_3$. (421) $Fe\,S$. (422) $Fe\,O,\ C\,O_2$. (423) $Fe_2\,O_3$. (424) $Au\,Br_3$. (425) $Zn\,O,\ S\,O_3 + K\,O,\ S\,O_3$. (426) $Ca\,O,\ Si\,O_3$. (427) $Ca\,O,\ 2\,Si\,O_3$. (428) $2\,Ca\,O,\ Si\,O_3$. (429) $Ca\,O,\ 3\,Si\,O_3$. (430) $3\,Ca\,O,\ Si\,O_3$. (431) $K\,S_3$. (432) $K\,O,\ S\,O_2 + H\,O,\ S\,O_2$. (433) $Cr_2\,O_3,\ 3\,S\,O_3$. (434) $K\,O,\ 3\,Cr\,O_3$. (435) $2\,Na\,O,\ 3\,C\,O_2$. (436) $2\,Zn\,O,\ C\,O_2$. (437) $B\,F_3$. (438) $Sn\,O_2,\ 2\,S\,O_2$. (439) $Mg\,O,\ S\,O_3 + K\,O,\ S\,O_3$. (440) $Cu_2\,O$. (441) $2\,Pb\,O,\ Pb\,Cl$. (442) $Fe_2\,O_3,\ 3\,S\,O_3 + N\,H_4\,O,\ S\,O_3$. (443) $Na\,O,\ S_2\,O_2$. (444) $K\,O,\ \overline{O} + 3\,(H\,O,\ \overline{O})$. (445) $Mn\,O,\ S\,O_3 + Na\,O,\ S\,O_3$. (446) $Cr\,F_3$. (447) $3\,Pb\,O,\ N\,O_5$. (448) $Pt\,I_2,\ K\,I$. (449) $Mn_2\,O_3,\ 3\,S\,O_3$. (450) $Ba\,O,\ C\,O_2 + Ca\,O,\ C\,O_2$.

CHAPTER XVII.

CONSTRUCTION OF CHEMICAL FORMULÆ.

Use of the comma and plus sign. Bracketting. Exercises.

454. Compounds consisting of two elements are called *binary compounds.* Ex.—Oxides and haloid salts.

455. When two binary compounds combine together, a *ternary compound* is formed. Ex.—Oxygen salts.

456. A quaternary compound is produced when two ternary ones combine together. Ex.—Double oxygen salts.

457. The sign (+) and the comma are frequently employed in the construction of formulæ to show the arrangement of the elements and their degrees of affinity in the combination. The comma is employed to separate a ternary compound into the two binary ones, which are called its proximate elements. Thus, in the formula $K\,O, N\,O_5$, the comma points out the binary compounds which compose the salt, and it shows further, that the affinity which unites the potassium with the oxygen, and the nitrogen with the five equivalents of oxygen, is more intense than that which unites the base with the acid, since it is easier to break up this salt into potash and nitric acid than into potassium, oxygen, and nitrogen. The plus sign denotes a less intimate combination than the comma. It is therefore employed in quaternary compounds to separate the ternary compounds composing them. The use of the comma and plus sign is shown in the following formula, $Al_2\,O_3, 3\,S\,O_3 + K\,O, S\,O_3$.

458. It has been remarked before, that a small figure above or below the line, relates only to the element on the *left hand* of it; and that when a *large* figure is placed upon the line, it multiplies all the elements on the *right hand* of it as far as the first comma, or the first plus sign; if placed before a bracket, it multiplies all within that bracket. Ex.—$2\,H\,O$ signifies 2 atoms of water; these two compound atoms are composed of 2 atoms of hydrogen, and 2 of oxygen. $3\,C\,O_2$ signifies 3 atoms of carbonic acid, composed of 3 atoms of carbon, and 6 of oxygen.

$4\ Fe_2\ O_3$ signifies 4 atoms of sesquioxide of iron, composed of 8 atoms of iron, and 12 atoms of oxygen. $3\ Fe\ O,\ C\ O_2$, or $3\ Fe\ O + C\ O_2$, signifies 3 atoms of oxide of iron, and 1 atom of carbonic acid; whereas $3\ (Fe\ O,\ C\ O_2)$, or $3\ (Fe\ O + C\ O_2)$, signifies 3 atoms of oxide of iron, and 3 atoms of carbonic acid; in other words, 3 atoms of the ternary compound, carbonate of protoxide of iron. Whenever more than one equivalent of any ternary compound has to be expressed, it is always necessary, in order to express it correctly, to place it in a bracket, as $3\ (K\ O,\ S\ O_3)$.

459. The formulæ of the salts in the exercises below must be written out.

Ex. 1.—Required the formula for two equivalents of terchloride of gold.

$$2\ Au\ Cl_3.$$

Ex. 2.—Required the formula for three equivalents of nitrate of ammonia.

$$3\ (N\ H_4\ O,\ N\ O_5).$$

Ex. 3.—Required the formula for two equivalents of chloride of platinum and ammonium.

$$2\ (Pt\ Cl_2,\ N\ H_4\ Cl).$$

Ex. 4.—Required the formula for two eq. of sulphate of alumina and potash, one eq. of which is composed of an eq. of sulphate of alumina, and an eq. of sulphate of potash, and 24 eq. of non-essential water.

$$2\ (Al_2\ O_3,\ 3\ S\ O_3 + K\ O,\ S\ O_3 + 24\ aq.).$$

Ex. 5.—Required the formula for three eq. of basic carbonate of magnesia. One eq. of which is composed of three eq. of carbonate of magnesia, three eq. of non-essential water, and one eq. of hydrate of magnesia.

$$3\left\{3\ (Mg\ O,\ C\ O_2 + aq.) + (Mg\ O,\ H\ O)\right\}$$

EXERCISES.

460. Required the formulæ for the following substances:—

451. Two eq. of sesquichloride of chromium.
452. Three eq. of sulphate of ammonia.

453. Two eq. of chloride of platinum and potassium.

454. Two eq. of carbonate of lime and magnesia.

455. One eq. of phosphate of soda, composed of two eq. of soda, one eq. of essential water, and one of anhydrous phosphoric acid.

456. Two eq. of silicate of lime.

457. Three eq. of felspar, which is a double silicate of alumina and potash.

458. Three eq. of the oxalate of the sesquioxide of iron.

459. Two eq. of protoiodide of iron.

460. Two eq. of binoxalate of potash.

461. Three eq. of phosphate of silver; one eq. of which is composed of three eq. of oxide of silver, and one of anhydrous phosphoric acid.

462. Dolomite (magnesian limestone), composed of one eq. of neutral carbonate of lime, and three eq. of neutral carbonate of magnesia.

463. One eq. of the sulphate of the sesquioxide of iron and potash (iron alum), which contains, in addition to the sulphuric acid, potash, and sesquioxide of iron, twenty-four atoms of non-essential water.

464. Two eq. of sulphate of copper, one eq. of which is composed of an eq. of anhydrous sulphuric acid, one of oxide of copper, one of essential water, and six of non-essential water.

465. One eq. of the oxalate of the sesquioxide of iron and potash, which contains, in addition to the bases and acid, six eq. of non-essential water.

466. One eq. of oxychloride of antimony (powder of Algarotti), composed of one eq. of terchloride of antimony, three eq. of teroxide of antimony, and three eq. of non-essential water.

467. Three eq. of perphosphate of iron, one eq. of which is composed of two eq. of sesquioxide of iron, three eq. of essential water, and three of anhydrous phosphoric acid.

468. The topaz, composed of one eq. of alumina, two eq. of fluoride of aluminum, and six eq. of a silicate of alumina; one eq. of which is composed of an eq. of alumina, and one eq. of silicic acid.

469. Serpentine, composed of three eq. of hydrate of magnesia (one eq. of which contains one eq. of magnesia and two eq. of water), and two eq. of a subsilicate

of magnesia (one eq. of which contains three eq. of magnesia, and two eq. of silicic acid).

470. Meerschaum, composed of an eq. of sesquisilicate of magnesia, and two eq. of water.

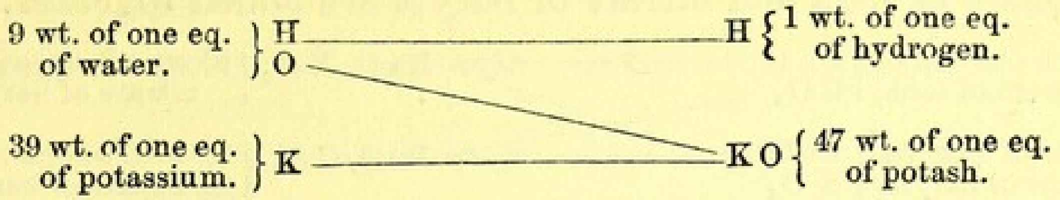
CHAPTER XVIII.

ON THE MODE OF EXPRESSING CHEMICAL CHANGES.

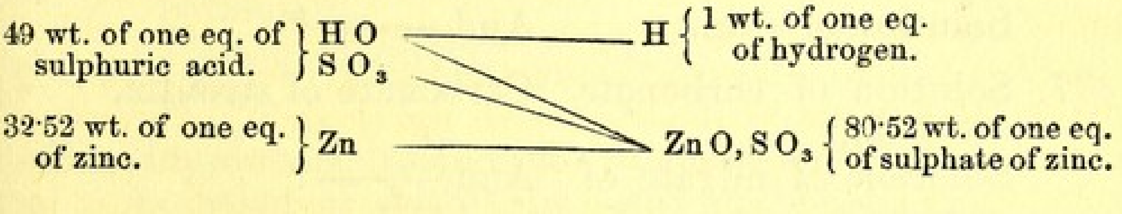
EXERCISES.

461. The separation of a chemical compound into its proximate or remote elements, is called decomposition, and the compound is said to be decomposed. The substances which result from the decomposition are called either *educts* or *products*. They are called educts when they exist in the compound before decomposition, and form part of it; products, when they are generated during decomposition. Carbonic acid, which is generated by the action of hydrochloric acid upon carbonate of lime, is an educt; but the same acid, when evolved by heating charcoal with oxide of lead, is a product. Products are always compound bodies; educts may be either simple or compound. Diagrams are employed to render intelligible the different chemical changes which take place where two or more elementary or compound substances are added together. The following exercises are given, in order to make the student acquainted with the mode of expressing chemical decompositions by diagrams. The weight of the substances added, and those which are produced, must be stated, as shown in the following examples :—

Ex. 1.—If potassium be added to water, potash will be formed. What element must be set free? To find the correct answer to this question, the student must first write down the symbols of the substances added together, viz., the symbol for potassium, and the symbol for water; he has then to withdraw, as shown in the following diagram, from the water that constituent which is necessary to convert the potassium into potash; this being done, of course the other constituent of water, as this compound is composed of two elements only, is set free, and when we have discovered this, we have answered the question. The best way for answering questions of this kind, is to draw them out in the following manner:—



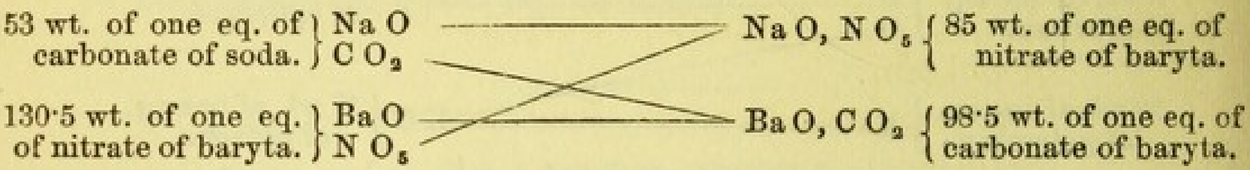
Ex. 2.—If sulphuric acid be added to zinc, hydrogen will be set free. What compound must be formed? The first step in answering this question, as in the last, is to mark down, in the form of a diagram, the symbols of the substances directed to be added together; having done this, the student will see that the hydrogen must come from the water of the sulphuric acid, as no other substance named contains it. Let him draw a straight line from it, as in the diagram; this being done, he sees that the oxygen is liberated in the presence of the zinc; he also knows that metals unite with oxygen, and form with it basic oxides, and that these basic oxides unite with acids in their anhydrous state, and form with them salts; if, in this instance, he unites the zinc and oxygen together, and the anhydrous sulphuric acid with this oxide, the remaining compound thus produced will be sulphate of zinc, which is correct, as shown in the diagram:—



Ex. 3.—If carbonate of soda be added to nitrate of baryta, what other substances besides carbonate of baryta will be formed?

462. To find the answer to this question, we proceed, as in the two former instances, to mark down the symbols of the substances to be added together; having done this, we have next to consider what is the composition of carbonate of baryta. Knowing this, we unite its constituents together, in the way shown in the diagram, viz., baryta and carbonic acid; and, having done this, we find we have left, the basic body soda, and nitric acid in its anhydrous state: as these two bodies are set free in the presence of

each other, they of course unite, and form the salt nitrate of soda, which is the other compound formed, when carbonate of soda and nitrate of baryta are added together.



EXERCISES.

471. If hydrosulphuric acid be added to iodine, hydriodic acid will be formed. What element must be set free?

472. If hydrochloric acid be added to zinc, hydrogen will be set free. What compound must be formed?

473. If sulphuric acid be added to iron, sulphate of the protoxide of iron will be formed. What element must be set free?

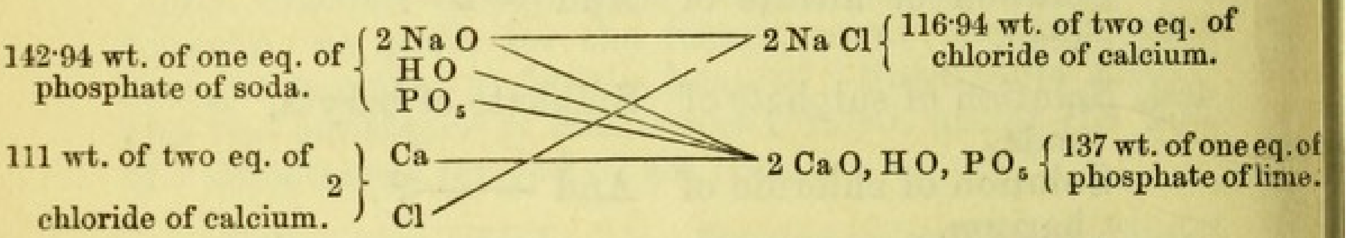
463. Instead of repeating the above in full on each occasion, we shall, for the future, name the substances brought together under the head of "Substances added," and the substance or substances formed, under the head of "Substances formed or set free."

	Substances added.	*Substances set free or formed.*
476.	Hydrochloric acid. Solution of soda.	Chloride of sodium, And ——?
477.	Solution of carbonate of soda. Solution of nitrate of strontia.	Carbonate of strontia, And ——?
478.	Sulphuric acid. Chloride of sodium.	Sulphate of soda, And ——?
479.	Solution of chloride of sodium. Solution of nitrate of silver.	Chloride of silver, And ——?
480.	Sulphuric acid. Nitrate of potash.	Sulphate of potash, And ——?
481.	Sulphide of ammonium.	Sulphide of zinc,

	Substances added.	*Substances set free or formed.*
	Solution of sulphate of zinc.	And ——?
482.	Solution of chromate of potash.	Chromate of baryta,
	Solution of chloride of barium.	And ——?
483.	Solution of hydrate of soda (NaO, HO).	Hydrate of manganese (MnO, HO),
	Solution of chlorine of manganese.	And ——?
484.	Solution of carbonate of ammonia.	Carbonate of lime,
	Solution of sulphate of lime.	And ——?
485.	Hydrosulphuric acid.	Sulphide of lead,
	Solution of nitrate of lead.	And ——?
486.	Solution of sulphate of soda.	Sulphate of baryta,
	Solution of chloride of barium.	And ——?
487.	Solution of iodide of potassium.	Iodide of silver,
	Solution of nitrate of silver.	And ——?
488.	Solution of oxalic acid.	Oxalate of baryta,
	Solution of nitrate of baryta.	And——?
489.	Sulphide of ammonium.	Sulphide of cobalt,
	Solution of nitrate of cobalt.	And ——?
490.	Hydrochloric acid.	Subchloride of mercury,
	Solution of nitrate of suboxide of mercury.	And ——?
491.	Hydrosulphuric acid.	Sulphide of mercury,
	Solution of chloride of mercury.	And ——?

464. In the preceding exercises, only single equivalents of each of the substances, which were directed to be added together, had to be employed, and never more than two were produced. In those which follow, the number of equivalents of the different substances employed will vary, and two or three products may be produced. Two examples are given, and a new mode of expressing chemical changes, which it will be well for the student to practise, as it is the one generally adopted by chemists at the present time.

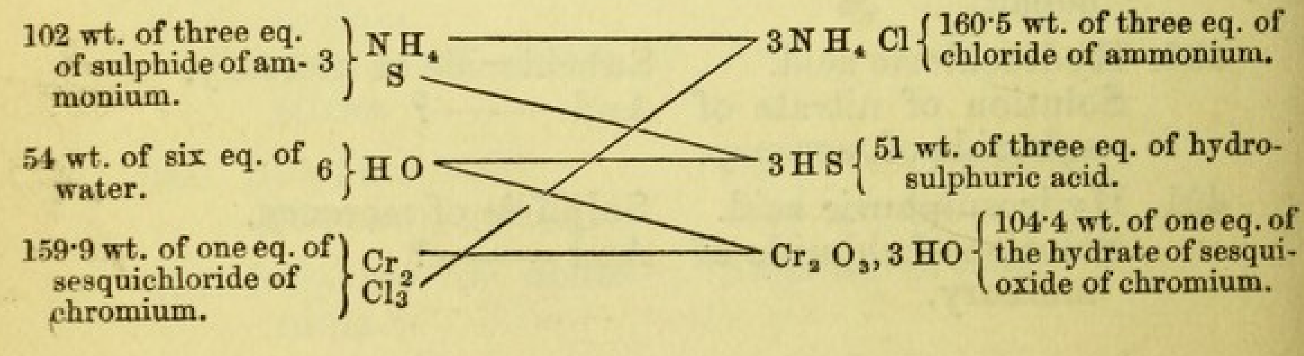
Substances added.	*Substances set free or formed.*
Ex. 4.—Solution of phosphate of soda ($2 Na O, H O, P O_5$). Solution of chloride of calcium.	Phosphate of lime ($2 Ca O, H O, P O_5$). And ———?



465. This decomposition would be expressed by the new mode thus :—

$$2 Na O, H O, P O_5 + 2 Ca Cl = 2 Ca O, H O, P O_5 + 2 NaCl.$$

Substances added.	*Substances set free or formed.*
Ex. 5.—Sulphide of ammonium. Sol. of sesquichloride of chromium.	Hydrate of sesquioxide of chromium ($Cr_2O_3, 3 H O$), And ———?



466. This decomposition, by the new mode, would be expressed in the following manner:—

$$3NH_4S + 6HO + Cr_2Cl_3 = Cr_2O_3, 3HO + 3NH_4Cl + HS.$$

EXERCISES.

493. When solid chlorate of potash is ignited, it is decomposed into oxygen and chloride of potassium. How many equivalents of oxygen will be liberated from one atom of chlorate of potash?

494. When solid nitrate of ammonia is heated, it is decomposed into nitrous oxide (laughing gas, NO) and some other substance. What will the other substance be, and how many atoms of each will be formed from one atom of nitrate of ammonia?

	Substances added.	*Substances set free or formed.*
495.	Hydrochloric acid.	Sesquichloride of iron,
	Sesquioxide of iron.	And——?
496.	Sol. protochloride of copper.	Subiodide of copper (Cu_2I),
	Sol. iodide of potassium.	And——?
497.	Sol. hydrate of potash (KO, HO).	Oxychloride of copper ($CuCl, 3CuO + aq.$),
	Sol. protochloride of copper.	And——?
498.	Sol. of arsenious acid.	Arsenite of copper ($2CuO, AsO_3$),
	Sol. of sulphate of copper.	And——?
499.	Protoxide of tin.	Oxysulphide of tin ($5SnO_2, SnS_2$),
	Sulphurous acid.	And——?
500.	Sol. hydrate of soda (NaO, HO).	Hydrate of the sesquioxide of chromium ($Cr_2O_3, 3HO$),
	Sol. of sesquichloride of chromium.	And——?

	Substances added.	*Substances set free or formed.*
501.	Terchloride of antimony. Water.	Oxychloride of antimony ($SbCl_3, 5 SbO_3$), And——?
502.	Carbonate of lead. Chromate of potash.	Dichromate of lead, And——?
503.	Terchloride of bismuth. Water.	Oxychloride of bismuth ($BiCl_3, 2 BiO_3$), And——?
504.	Sol. of the sulphate of the sesquioxide of iron. Sulphurous acid.	Sulphate of the protoxide of iron, And——?
505.	Sol. of hydrate of soda. Sol. of sulphate of alumina.	Hydrate of alumina ($Al_2O_3, 3 HO$), And——?
506.	Sol. of phosphate of soda ($2 NaO, HO, PO_5$). Sol. of nitrate of baryta.	Phosphate of baryta ($2 BaO, HO, PO_5$), And——?
507.	Sol. of phosphate of soda. Sol. of nitrate of silver.	Phosphate of silver ($3 AgO, PO_5$), And——?
508.	Sol. of phosphate of soda. Sol. of sulphate of copper.	Phosphate of copper ($2 CuO, HO, PO_5$), And——?
509.	Sol. of phosphate of soda. Sol. of chloride of calcium.	Phosphate of lime ($3 CaO, PO_5$), And——?
510.	Sol. of the sulphate of the sesquioxide of iron. Hydrosulphuric acid.	Sulphate of the protoxide of iron, And——?
511.	Sol. of phosphate of soda. Sol. of ammonia. Sol. of sulphate of magnesia.	Phosphate of magnesia and ammonia ($2 MgO, NH_4O, PO_5$), And——?

	Substances added.	*Substances set free or formed.*
512.	Ammonia.	Hydrate of the sesquioxide of iron ($Fe_2 O_3, H O$),
	Sesquichloride of iron.	And——?
513.	Arsenious acid.	Terhydride of arsenic (AsH_3),
	Sulphuric acid.	And——?
	Zinc.	
514.	Hydrochloric acid.	Protochloride of manganese,
	Peroxide of manganese ($Mn O_2$).	And——?
515.	Sol. nitrate of the protoxide of copper.	Subiodide of copper ($Cu_2 I$),
	Sol. sulphate of the protoxide of iron.	Sulphate of the sesquioxide of iron,
	Sol. iodide of potassium	And——?
516.	Sol. carbonate of ammonia.	Hydrate of alumina ($Al_2 O_3$, $3 H O$),
	Sol. sulphate of alumina.	And——?
517.	Sulphide of ammonium.	Hydrate of sesquioxide of chromium ($Cr_2 O_3, 3 H O$),
	Sesquichloride of chromium.	And——?
518.	Sol. of carbonate of ammonia.	Hydrate of sesquioxide of iron,
	Sol. of sesquichloride of iron.	And——?
519.	Sol. of phosphate of soda.	Perphosphate of iron ($2 Fe_2 O_3, 3 H O, 3 P O_5$),
	Sol. of sesquichloride of iron.	And——?
520.	Sol. of carbonate of potash.	Basic carbonate of magnesia $3 (Mg O, C O_2 + aq.) + (Mg O, H O)$,
	Sol. of sulphate of magnesia.	And——?
521.	Sol. of carbonate of soda.	Basic carbonate of zinc $(3 Zn O, H O) + 2 (Zn O, C O_2)$,
	Sol. of sulphate of zinc.	And——?

	Substances added.	*Substances set free or formed.*
522.	Sulphuric acid. Chloride of sodium. Peroxide of manganese ($Mn\ O_2$).	Sulphate of the protoxide of manganese, And——?

CHAPTER XIX.

THE METHOD FOR DETERMINING THE AMOUNT OF THE SEVERAL CONSTITUENTS CONTAINED IN A GIVEN QUANTITY OF ANY COMPOUND. EXERCISES.

467. The atomic weight of a compound is obtained by adding together the atomic weights of its constituents. It is plain, that whatever ratio the atomic weight of the constituent has to the atomic weight of the compound, the quantity of constituent present, in a given quantity of the compound, will have the same ratio to the quantity of the compound. Thus, if we wish to ascertain the quantity of potassium in a given quantity (say 100 grains) of sulphate of potash ($K\ O, S\ O_3$), we add together the atomic weights of its constituents, which gives us the weight of the compound atom. Thus—

$$\begin{array}{rcr} K & = & 39 \\ O & = & 8 \\ S & = & 16 \\ 3\ O & = & 24 \\ & & \overline{87} \end{array}$$

468. The atomic weight of potassium being 39, and that of the compound 87, we take $\frac{39}{87}$ as the quantity of potassium in the given quantity of compound (here 100 grs.), or $\frac{39}{87}$ of 100 grs. = 44·827. A simple rule, readily applicable to all cases, may be deduced from the above statement.

469. *As the atomic weight of the compound is to the atomic weight of the constituent, the quantity of which in the compound we wish to ascertain, so is the whole quantity of the compound to the quantity of constituent.*

$$\text{As } 87 : 39 :: \overset{\text{Grs.}}{100} : \overset{\text{Grs.}}{44{\cdot}827}.$$

EXERCISES.

523. Find the amount of lead in 100 tons of the sulphide.

524. Find the amount of chlorine by weight in 50 lbs. of chloride of sodium.

525. Find the amount of silver in 1,000 lbs. of sulphide of silver and antimony ($3\,Ag\,S, Sb\,S_3$).

526. Find the amount of platinum in 100 parts of chloride of platinum and ammonium.

527. Find the amount of iron in 360 grs. of sesquichloride.

528. What amount of oxygen, by weight, would one ton of sulphur require to be converted into sulphuric acid?

529. Find the amount of anhydrous nitric acid in 10 lbs. of nitrate of soda, and likewise in the same amount of nitrate of potash.

530. How much water must 200 lbs. of quicklime absorb to become converted into hydrate?

531. A chemical manufacturer delivers to his workmen 50 lbs. of metallic silver to be converted into nitrate (caustic). What amount by weight ought to be obtained?

532. If 100 grain measures of dilute sulphuric acid neutralize 47 grs. of potash, what amount of carbonate of potash, and what amount of ammonia, lime, soda, and their carbonates, will it neutralize?

533. How much ammonia would 300 tons of coal furnish which contains 1·5 per cent. of nitrogen?

534. If nitrate of potash and nitrate of soda were the same price per ton, which would be the most economical source for nitric acid? Prove the answer by equivalents.

535. If it requires 100 gr. measures of dilute sulphuric acid to neutralize 60 grs. of potash, what amount of real sulphuric acid does it contain?

536. An average crop of turnips removes from an acre of land 54·5 lbs. of phosphoric acid. If the farmer desires to restore his field to its original fertility, what amount of bone earth ($3\,Ca\,O, P\,O_5$) would he have to employ to give back the phosphoric acid?

537. If I borrowed 300 lbs. of nitrate of soda of a nitric acid manufacturer, what amount of nitrate of potash must I return to replace it?

538. What amount of ammonia would be required to precipitate the sesquioxide of iron from 20 lbs. of sesquichloride?

539. An average crop of oats removes from an acre of land 198·9 lbs. of inorganic matter; a crop of barley removes from the same extent of land 213·3 lbs. of inorganic matter. In the 198·9 lbs. of mineral matter removed by the oats, there are 23·3 lbs of phosphoric acid, 36·5 lbs. of potash, and 3·8 lbs. of chloride of potassium; in the 213·3 lbs. removed by the barley, there are 24·3 lbs. of phosphoric acid, and 38·3 lbs. of potash. If the farmer desired to restore his field to its original fertility, what weight of nitrate of potash, chloride of potassium, or sulphate of potash, and what amount of bone earth (phosphate of lime, $3\,CaO, PO_5$) would he have to employ in order to give back the potash and phosphoric acid which had been removed by the oats, and what amount would he likewise have to employ in order to restore fertility after the barley crop?

540. If mercury be added to a solution of nitrate of silver, the silver will be precipitated and replaced by an equivalent of mercury: the solution will now contain nitrate of mercury, from which the mercury may be precipitated by copper; the solution will now contain nitrate of copper, from which the copper may be precipitated by lead; the solution will now contain nitrate of lead, from which the lead may be precipitated by zinc. Suppose we had a solution of nitrate of silver containing 200 grs. of nitrate of silver, how much metallic silver would it contain, and how much mercury would it require to precipitate it; how much copper would it require to precipitate this mercury, how much lead to precipitate the copper, and how much zinc to precipitate the lead?

541. If, in some chemical process, baryta were employed, and an equivalent of strontia, magnesia, or lime could be substituted for it, what would be their relative cost, baryta costing one shilling per pound, strontia two shillings, magnesia sixpence, and lime one penny?

470. When a sulphide and an oxide of copper are roasted together, if the oxide is in such a proportion to the sulphide that the oxygen it contains is just sufficient to form with the sulphur, sulphurous acid; this gaseous acid will be formed, and escape, and all the copper will be left in the metallic state.

542. How much disulphide of copper would be required to effect the complete reduction of 40 parts of suboxide of copper, 20 parts of protoxide, and 30 parts of green carbonate of copper (malachite, $2\,Cu\,O, C\,O_2 + H\,O$), and how much metallic copper would be obtained?

471. If galena (sulphide of lead) and sulphate of lead be roasted together, in equivalent proportions, the oxygen in the sulphuric acid and oxide of lead is converted, along with the sulphur in the sulphide and sulphate, into sulphurous acid gas, and metallic lead is left. So, also, if galena is roasted with oxide of lead in proper proportions, all the lead is obtained pure, and the sulphur passes off in the form of sulphurous acid.

543. How much galena would be required to reduce a mixture of 20 parts of protoxide of lead, 10 parts of red lead (minium, $Pb_3\,O_4$), and 15 parts of sulphate of lead; and how much metallic lead would be obtained?

CHAPTER XX.

THE MODE OF DETERMINING THE RELATIVE PROPORTION OF THE ELEMENTARY ATOMS IN A CHEMICAL COMPOUND. EXERCISES. THE METHOD FOR DEDUCING NOT ONLY THEIR RELATIVE, BUT LIKEWISE THEIR ABSOLUTE NUMBERS. EXERCISES.

472. The atomic proportions of the constituents of a chemical compound are obtained by dividing their relative quantities by their atomic weights.

473. By quantitative analysis it has been found that 100 parts of carbonic acid are made up of 27·27 of carbon, and 73·73 of oxygen; the atomic weight of these elements being known, we have simply to divide their relative quantities in the acid by their atomic weights, to arrive at the relative number of atoms, thus:—

$$\underset{\text{(Eq. of carbon.)}}{\frac{27{\cdot}27}{6} = 4{\cdot}545} \qquad \underset{\text{(Eq. of oxygen.)}}{\frac{72{\cdot}73}{8} = 9{\cdot}091}$$

474. According to this, 4545 atoms of carbon are united with 9091 atoms of oxygen. This complicated ratio may however (as in most other cases), be reduced, by assuming the atomic number of the element which gives the smallest quotient in the calculation, to equal 1, and dividing the other quotient by this. In the present example, 4545 : 9091 = 1 : 2, consequently 1 atom of carbon is combined with 2 atoms of oxygen.

Ex. 2.—In 100 parts of sulphate of alumina and potash there are contained 9·95 per cent. of $K O$, 10·83 of $Al_2 O_3$, 33·71 of $S O_3$, and 45·51 of $H O$.

$$\frac{9{\cdot}95}{47} = {\cdot}211 \quad \frac{10{\cdot}83}{51{\cdot}4} = {\cdot}201 \quad \frac{33{\cdot}71}{40} = {\cdot}842 \quad \frac{45{\cdot}51}{9} = 5{\cdot}055$$

This gives the following atomic numbers, 211 of $K O$, 201 of $Al_2 O_3$, 842 of $S O_3$, and 5055 of $H O$ = 1 : 1 : 4 : 24, probably combined in the following manner :—

$$(Al_2 O_3, 3 S O_3 + K O, S O_3 + 24 \text{ aq.})$$

EXERCISES.

475. Deduce from the following per-centage numbers the *relative* number of atoms of the different substances, and give the chemical name of the compound.

544. 44·44 of C, 51·86 of N, 3·70 of H.
545. 70 of Fe, 30 of O.
546. 44·44 of S, 55·56 of O.
547. 52·14 of Cr, 48·0 of O.
548. 25·96 of $Na O$, 66·55 of $S O_3$, and 7·49 of $H O$.
549. 11·92 of $Na O$, 53·46 of $B O_3$, and 34·0 of $H O$.
550. 34·44 of $Sr O$, 35·76 of $N O_5$, and 29·8 of $H O$.
551. 9·82 of $N H_3$, 18·01 of $Na O$, 46·19 of $S O_3$, and 25·98 of $H O$.
552. 18·4 of $K O$, 15·6 of $Mg O$, 34·4 of $C O_2$, and 31·6 of $H O$.
553. 54·13 of $K O$, 25·23 of $C O_2$, and 20·64 of $H O$.
554. 68·5 of $Ba O$, and 33·0 of $C O_2$.
555. 28·81 $N H_3$, 55·93 $C O_2$, and 15·26 of $H O$.
556. 8·06 $N H_4$, 44·21 Pt, and 47·72 of Cl.
557. 23·88 $Cr_2 O_3$, 35·82 $S O_3$, and 40·30 $H O$.
558. 55·48 $Pb Cl$, and 44·51 $Pb O$.
559. 9·42 $K O$, 15·56 $Fe_2 O_3$, 31·92 $S O_3$, and 43·1 $H O$.

476. When the atomic weight of the compound is unknown, its true or *rational* formula cannot be obtained, and in such cases we can only arrive at the relative proportion of the atoms of its constituents, which may be called its *empirical* formula. The difference between a rational and empirical formula may be illustrated by the following example. Hyposulphurous acid contains in 100 parts, 66·66 sulphur, and 33·34 oxygen; these numbers, divided by their atomic weights, give their atomic proportions.

$$\frac{66{\cdot}66}{16} = 4{\cdot}16 \qquad \frac{33{\cdot}44}{8} = 4{\cdot}16$$

477. These quotients being equal, we conclude that hyposulphurous acid is composed of equal atoms of the two elements. The most simple formula would be $S\,O$, but it is evident that it might be S_2O_2, S_3O_3, or any multiple of $S\,O$; as they would all agree with the results of the analysis, this would be its empirical formula. To arrive at its rational formula, or in other words, to know not only the relative proportions of the atoms of its elements, but likewise their absolute number, we must find its atomic weight. This is obtained in the case of acids by uniting them with bases, and in the case of bases by uniting them with acids, whose atomic weights are known; the amount of acid and base in the salts is then determined by quantitative analysis. Thus, hyposulphite of baryta contains in 100 parts 61·6 of baryta, and 38·4 of hyposulphurous acid, and the atomic weight of the acid is arrived at, from these numbers, by a simple proportion sum.

$$\begin{array}{lllllll} \text{Amt. of Ba O in} & & \text{Amt. of acid in} & & \text{(Eq. of} & & \\ \text{100 pts. of salt.} & & \text{100 pts. of salt.} & & \text{Ba O).} & & \\ 61{\cdot}6 & : & 38{\cdot}4 & :: & 77 & : & x = 48 \text{ atomic weight} \\ & & & & & & \qquad \text{of the acid.} \end{array}$$

478. We find the number of atoms of oxygen and sulphur which make up this 48 (as the atomic weight of a compound is the sum of the atomic weight of its constituents) in the following manner:—

Pts. of acid.		Amount of S in 100 pts. of acid.		Atomic weight of acid.		Amount of S in an atom of acid.
100	:	66·66	::	48	:	$x = 32 = 2$ eq. of sulphur.
						Amount of O in an at. of acid.
100	:	34·34	::	48	:	$z = 16 = 2$ eq. of oxygen.

479. The rational formula for hyposulphurous acid is accordingly—$S_2 O_2$

EXERCISES.

560. Deduce the rational formula for hyposulphuric acid from the following numbers :—

Sulphur	44·44	Potash	39·554
Oxygen	55·56	Hyposulphuric acid	60·446
Hyposulphuric acid	100·00	Hyposulphate of potash	100·000

561. Deduce the rational formula for hyperchloric (perchloric) acid from the following numbers :—

Chlorine	38·7	Potash	34·05
Oxygen	61·3	Hyperchloric acid .	65·95
Hyperchloric acid	100·0	Hypochlorate of potash	100·00

480. When hydrogen acids combine with bases, their hydrogen is replaced by the metals, and when hydrated oxygen acids combine with bases, the metallic oxide displaces the oxide of hydrogen (water). These facts will have to be taken into consideration in the next exercises.

562. The rational formula for hydrocyanic acid.

Hydrogen . . .	3·70	Mercury	79·36
Carbon	44·44	Carbon	9·52
Nitrogen . . .	51·86	Nitrogen . . .	11·12
Hydrocyanic acid	100·00	Percyanide of mercury	100·00

563. The rational formula for oxalic acid.

Carbon	26·66	Carbon	8·6
Oxygen	53·33	Oxygen	17·19
Water	20·00	Oxide of lead . .	74·21
Oxalic acid . .	99·99	Oxalate of lead .	100·00*

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* Chapters xii. and xiii. must be studied next.

CHAPTER XXI.

CONSTRUCTION OF APPARATUS. CHEMICAL OPERATIONS. APPARATUS AND CHEMICALS REQUIRED. *Corks, their preparation. Glass tubing, its preparation. Indian rubber tubing. Apparatus used for the disengagement of gases, heat not being required,—heat being required. Apparatus for collecting gases. Solution. Exercises. Evaporation. Exercises. Precipitation. Filtration and decantation. Apparatus and chemicals required.*

481. We purpose, in this chapter, giving a few directions as to the fitting up of apparatus and its uses. Corks, glass tubing, caoutchouc are required in fitting up apparatus, we shall therefore begin by informing the student how these three articles are moulded, so as to render them equally serviceable in all cases.

482. Corks are constantly required in the laboratory, not only as stoppers for bottles, jars, &c., but for many other purposes, especially for connecting wide apertures with narrow ones. As they are used for rendering vessels air as well as water-tight, they must be free from pores. A good cork is inestimable in a laboratory, a bad cork is a constant source of trouble. In fitting them into the mouths and apertures of vessels, they should first be softened, either by pressure under the fingers, or by rolling them under the foot (in the latter case in a piece of paper, so as to preserve them from the dirt), taking care to preserve their conical form. If too large, they may be reduced to the proper size, either by the aid of the rasp or knife; but it is better to select them of the proper size in the first instance, rather than have recourse to these expedients. In fitting a cork into a glass vessel, the latter should be held firmly, close to the aperture, and, for the sake of security, covered with a piece of cloth. They require, for connecting wide apertures with narrow ones, to be perforated; this is done by piercing them in the proper place (the middle, if only one tube has to be fitted in) with a rat-tail file, taking care to make the bore *straight*, and, especially, *equal*. It is necessary, in order to make an equal bore, to introduce

the file alternately, at each end of the cork; the hole can, of course, be made of any size, by filing, and employing larger files as the size of the aperture increases.

483. Glass tubing.—After having selected a piece of tube of the proper bore and thickness, the next thing, if it does not require bending, will be to cut it into the required lengths. For this purpose, a mark is made round the tube, at the proper place, with the edge of a three-square file; the tube is then held in the hand, as you would a stick you were about to break; a slight and sudden pressure is then exerted at the mark, which causes the tube to break evenly in two. The depth of the mark made with the file must vary with the thickness and diameter of the tube, and in filing very small or thin tubes. the manipulator must not press too much on the file, otherwise the tube will be broken. When a tube has to be introduced into a cork, it is necessary to round its sharp edges before doing so, else the cork will be so cut and torn, that it will be rendered perfectly useless. To effect this, the tube must be heated in the flame of a gas or spirit lamp; it must be heated gradually, so as to prevent its cracking, by holding it near the flame at first, and by degrees introducing it. As soon as the edge becomes faintly red hot, the thing is accomplished, and the tube ought then to be removed from the flame, otherwise the opening at the extremity might contract, which, to say the least, is better avoided. If the heat of the lamp be not sufficient to round the edge, it must be rounded in the blow-pipe flame. A hot tube must not be laid on any cold surface, and it must be allowed to cool before inserting it into a cork. The perforation in the cork must, if anything, be a trifle smaller than the diameter of the tube which has to be inserted, in order that the connection may be perfectly air-tight. The best plan of fitting the tube into the cork, is to screw the tube, holding both it and the cork firmly, the first close to the extremity which has to be inserted; the tube may be greased very slightly at the part to be introduced.

484. Glass jets are sometimes required in the combustion of gases; they are made in the following way:—A hard glass tube of the proper diameter and thickness is heated in a spirit or gas lamp, at such a distance from one extremity, that there is sufficient left as a handle for

the manipulator, and also sufficiently remote from the part to be heated, that it does not become insupportably hot. "The part to be heated is to be brought, not into the flame, but into the current of hot air which passes off in the same direction from it, and the tube is to be turned so as to become heated all round, and also moved a little to the right and left, that the temperature of the neighbouring parts may be raised. After a few seconds, when the glass has become hot, it should be brought towards the point of the flame, and ultimately into it, being *turned round* all the time, and also moved laterally, though not to the same extent as before." When sufficiently soft, it is drawn out into a capillary, as shown in Fig. 19. The two ends are then separated at about the centre of the portion drawn out. The elongated extremity of the end to be used is filed down until the orifice is of sufficient size; it is then rounded at the edges in the flame of the spirit lamp.

Fig. 19.

485. The flame of a spirit or gas lamp is sufficient for bending ordinary glass tubing. The tube must be heated about an inch in length uniformly; it must be supported by the hands on each side of the part to be heated: it must be gradually introduced into the flame, in the way described in the preceding paragraph, and turned round continually during the process of heating, as there stated. Both ends must be turned alike, and in such a way that the heated part, when soft, shall retain its cylindrical shape, "being neither twisted, nor bent, nor elongated, nor thrust up." When the glass has become sufficiently soft, apply a gentle pressure with the hands, until it has assumed the proper form. The bend ought not to become flat at the convex portion, or in folds at the concave; to avoid these imperfections, the glass ought not to be made too soft, it ought to be heated uniformly to the length of about an inch, and the bend ought to be made very round.

486. Indian-rubber tubing.—Glass tubes are joined together by means of Indian-rubber tubes; these (vulcanized) can now be purchased of any size, but as they are easily made, any one studying Chemistry ought to be able

to make them himself. They are made in the following way:—A piece of sheet Indian-rubber of the required length is slightly warmed, so as to render it perfectly flexible; it is then bent round a moistened glass rod, which ought, if anything, to be rather smaller than the tubes to be connected. The superfluous portions are then pressed together, and subsequently cut off at one stroke with a pair of clean sharp scissors; the cut edges are then pressed closely together by means of the thumb-nails, and providing they have not been soiled, the joining becomes almost as perfect as any other part of the tube. In order to make the tube perfectly air-tight, another piece of Indian-rubber is then stretched round the first piece, and cut in the same manner, taking care to place the cut edges of the inner and outer tube on opposite sides. The tube is now carefully removed from the glass rod, and the two tubes may be joined at their extremities by cutting a piece off at each end, not at one cut, as that would close the end, but by moving the scissors round the tube. In connecting glass tubes by means of these joints, the ends of the glass tubes should not be brought close together inside the connector, but should be left a little distance apart, in order to allow of a certain degree of flexibility. If the Indian-rubber tubing does not fit the glass tube air-tight, it must be tied on with a bit of silk cord.

487. The manipulator having carefully attended to the preceding instructions, will experience very little difficulty in fitting up the different apparatus now to be described.

488. APPARATUS FOR GENERATING GASES, HEAT NOT BEING REQUIRED.—A bottle, with two or three separate openings, called a WOULFE'S BOTTLE, is a very convenient vessel for generating gases when heat is not required. It need only have two openings; one for the funnel tube, which serves for the introduction of the liquid, and which must pass down nearly to the bottom of the vessel, being covered by the liquid in the vessel, to the extent, at least, of half an inch; the other, for conveying off the gas to the receiver: this is called the delivery tube; it need only project into the bottle a trifle beyond the cork. The delivery tubes are of various shapes. If the bottle is provided with three openings, the middle one can be closed with a plain cork, and be used for introducing any solid substance into the bottle. Wide-mouthed bottles

may be used in the place of Woulfe's bottles; the only objection to them is the difficulty of making them air-tight, as large corks, free from pores, can seldom be obtained. If any of the corks be porous, it will be advisable, after the cork has been fitted into the apparatus, to paint the top of the cork with a solution of sealing-wax in spirit of wine. But if the tube does not fit the perforation in the cork perfectly air-tight, a paste, made with linseed meal and water, or, better still, with lime water, ought to be used for stopping the leakage. Gases should not be generated too rapidly; if an acid be employed for disengaging the gas, it ought to be added by degrees, commencing with a little, and when the gas begins to be *slowly* disengaged, to add a little more, &c. The delivery tubes are, as we have said, of various shapes. Fig. 20 represents a Woulfe's bottle fitted up in the way just described, the delivery tube being made of the shape required for collecting the gas at the pneumatic trough, or in the gas-holder. The other (Fig. 21) is fitted up for collecting the gas by displacement, or for passing it through a solution. Sometimes it is necessary to wash the gas, which is done in the following way:—A wide-mouthed bottle, capable of holding about half a pint, is fitted with two tubes, as shown in Fig. 22, one of which, *a*, should be about half an inch in diameter, straight, and of sufficient length to reach nearly to the bottom of the bottle, the water in which ought to cover the tube to the depth of half an inch; the other (the delivery tube) should only just pass through the cork, and be bent acccording to the mode of collecting the gas. The delivery tube of the

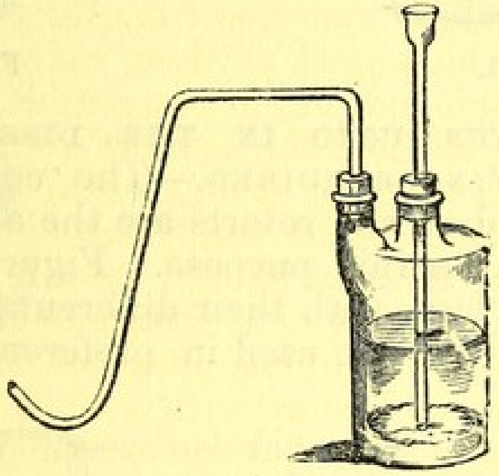

Fig. 20.

vessel in which the gas is generated, is made to pass down the tube *a*, and project a little beyond it in the bottle; the gas will then rise up through the liquid and pass off by the delivery tube *b* of the washing bottle.

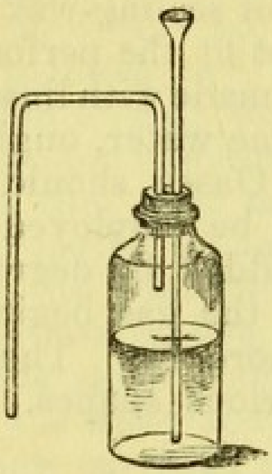

Fig. 21.

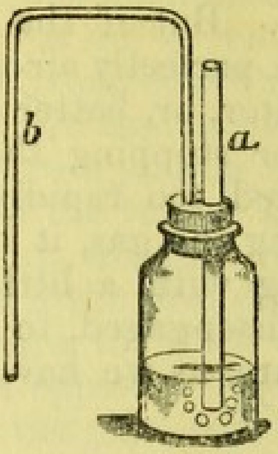

Fig. 22.

489. **Apparatus used in the disengagement of gases, heat being required.**—The common Florence oil flasks, test-tubes, and retorts are the ordinary kinds of apparatus used for this purpose. Figures 23 and 24 represent the two first, with their different fittings and connections. The first are used in preference to retorts on

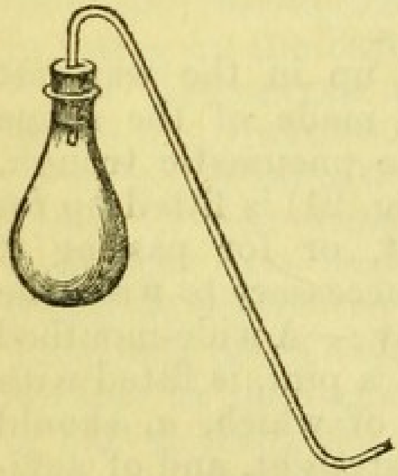

Fig. 23.

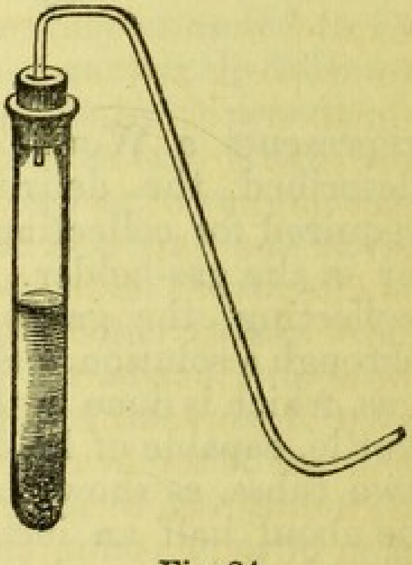

Fig. 24.

account of their cheapness, and the second are the most convenient when only a small quantity of gas is required. The materials used in the production of a gas ought only to occupy, at the most, one-third of the space in the generating vessel, whether heat be employed or not. When the materials for the production of the gas consist of a liquid and a powder, the liquid ought to be put into the vessel first, and after the powder has been added, they ought to be well mixed by shaking the vessel, before heat is applied. Heat is applied most conveniently by means of the spirit lamp (Fig. 25) or gas flame (Fig. 3). Wood naptha is the cheapest fuel for spirit lamps; it ought not to deposit any soot on the vessels. When the lamp is finished with, the cap ought to be placed over the wick, in order to prevent the loss of naptha by evaporation. The cap ought not to be used as an extinguisher, because the air in the cap becomes, if it is so used, so rarified that it is afterwards difficult to remove it, but the flame ought to be *blown out* before the cap is replaced. The heat ought to be applied gradually for two reasons;—1st, in order to prevent the breaking of the vessel, which is almost sure to be the case if the heat be applied suddenly; 2ndly, to prevent a tumultuous disengagement of the gas: when the evolution of the gas diminishes in rapidity, the heat ought then to be increased. A retort or flask is supported on one of the rings of a retort stand (Fig. 26), a test-tube is held over the lamp by means of a test-tube holder.

Fig. 25.

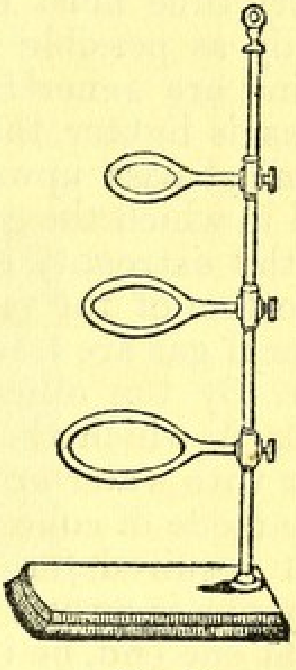

Fig. 26.

490. Apparatus for collecting gases.—Gases much heavier or lighter than air are collected by displacement,

but as all gases are collected by displacing some fluid or aëriform body, this mode of collecting gases ought to be called, by displacement of air. Wide-mouthed stoppered bottles are employed for collecting gases in this way. When the gas is heavier than air, the delivery tube must pass down to the bottom of the vessel, a piece of paper or glass plate partially covering the mouth of it during the time it is being filled with the gas; when it is filled, the delivery tube must be removed, and the bottle closed as speedily as possible with the stopper: carbonic acid and chlorine are generally collected in this manner. When the gas is lighter than air, the extremity of the delivery tube must pass upwards instead of downwards, and the vessel in which the gas has to be collected must be inverted over the extremity of the tube, the latter passing up to the bottom of the vessel; hydrochloric acid gas and ammoniacal gas are frequently collected in this manner.

491. By the other methods for collecting gases, the vessels in which they have to be received are first filled either with water or mercury; we confine our description to the mode of collecting over water, as the latter method is not required for any experiments given in this work. Every one is aware, that if a vessel, say a glass jar, open only at one end, be immersed in a vessel of water, with its open end upwards, yet covered with water, the air with which it was filled will escape, and it will become filled with water. If it be now inverted (open end downwards), it may be raised out of the water contained in the outer vessel (the one in which it is immersed) to such an extent that the water only just covers the open end, yet so long as this keeps covered, it will remain filled with water. If a delivery tube, from which gas is issuing, be placed underneath the open end of the jar, when in this position, the gas of course will ascend into the jar and displace an equal bulk of the water, and in this way it may become filled with gas. It is in this way that gases are collected over water; the vessel containing the water is called a pneumatic trough, which is a box made of wood or tin plate, generally about two feet long, a foot and a half in breadth, and a foot in depth; but it may be made of any size. It is provided with a shelf, fixed about three inches below the edge of the box. Holes are bored in this shelf at short distances, in order to allow gas to be passed into jars

standing on the shelf with their open ends over the apertures. When a jar has to be filled with gas, it is first

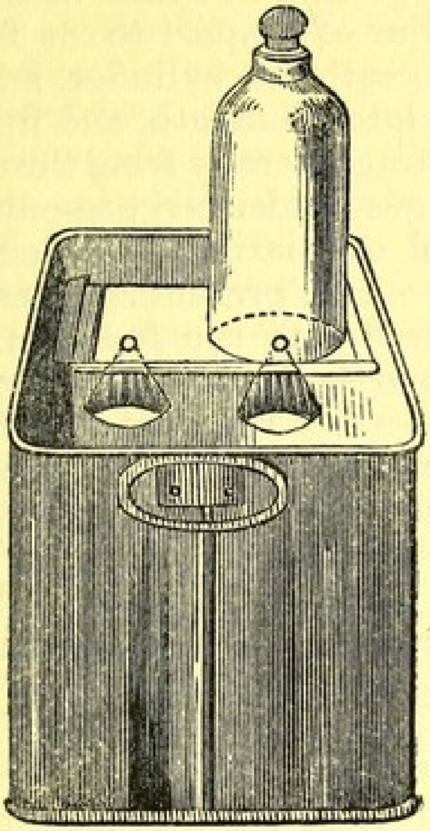

Fig. 27.

filled with water in that part of the trough not covered with the shelf; it is then placed on the shelf, in an inverted position, over one of the holes; the operator then directs the point of the delivery tube (which is bent a little upwards) whence the gas is to issue into or underneath the hole in the shelf. The water in the trough must always stand an inch or so above the shelf. A spout ought to project from one extremity of the trough, about two inches above the level of the shelf. It serves to carry off the water discharged from the jars when they are being filled with gas.

492. "Besides the pneumatic trough with its glass jars, it is desirable to have vessels of larger capacity, in which considerable quantities of gas can be collected, and from which it can be drawn off at pleasure. Such vessels are called gas-holders, or gasometers, and are constructed of tin plate, or better, of zinc or copper. The figure (28) represents one of the most convenient, distinguished by it inventor's name, as Pepys' gas-holder. A is a metallic

drum or cylinder; B a large funnel, communicating with A by a small tube C, which terminates in the roof of the cylinder, and a large one, D, which descends to nearly the bottom; E is a pillar of support to the funnel; F is a tube placed at an angle with the cylinder, and provided with a nut which screws into its mouth, and fits it air-tight; G is a stopcock, projecting laterally from the top of the cylinder. In the figure the gas-holder is represented in the condition in which it would ordinarily be called empty—in other words, full of air. As a preliminary step to filling it with gas, water is poured into the funnel B. It descends by the tube D, and partly by C, whilst the air escapes by C and G. When the water runs out at G, the cylinder is full, and all the stopcocks are shut. The nut of the oblique tube F is then unscrewed, and the beak of the retort, or exit tube of the flask, from which the gas is issuing, is inserted through F, and pushed in till its end is fairly within the cylinder. The gas rising vertically, accumulates in A, whilst the water it displaces flows out at F, past the neck of the retort or tube of the flask. When the water is all expelled, the retort or flask is withdrawn, and F

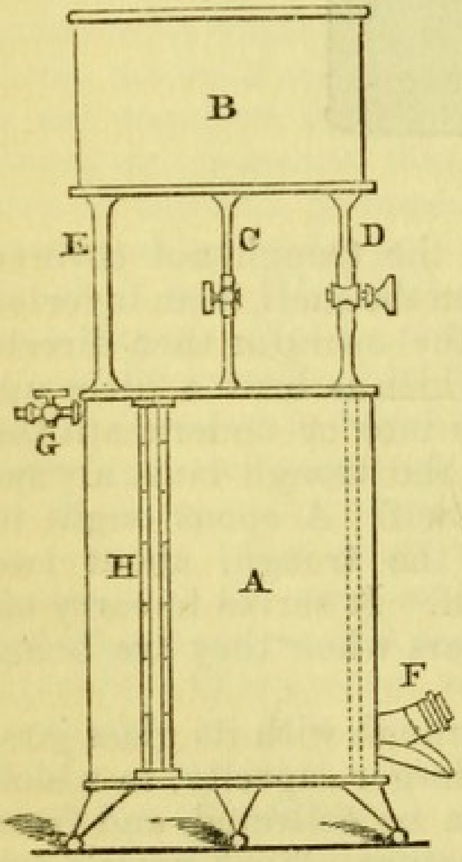

Fig. 28.

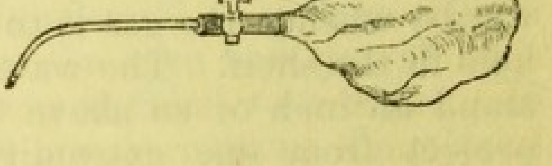

Fig. 29.

closed again with the nut. A glass tube or guage, H, communicating at each end with the cylinder, and in which the water stands at the same level as in A, allows the amount of gas in the latter to be readily observed. The gas is drawn off either by C or by G. If a jar is to be filled, water is poured into B, and the jar full of water is placed, mouth downwards, over C. C and D are then opened, and the water, which descends by D, expels the gas by C. If a bladder (Fig. 29) has to be filled, or a current of gas is wished, as for the lime-ball light, or the oxyhydrogen blow-pipe, the tube to convey it is attached to the end of G. B is kept full of water, and when D and G are opened, the gas rushes out by the latter. The stopcocks at D and G admit of the current being very nicely regulated."

493. In collecting gas over water, the extremity of the delivery tube ought not to be immersed in the liquid as soon as heat is applied to evolve the gas, because the atmosphere in the gas vessel becomes expanded by the heat, and therefore a portion of it escapes; if after this escape of air, and before the gas begins to be evolved, the intensity of the heat becomes in the least diminished, the atmosphere within the vessel contracts, the cold water rushes up the delivery tube (we are supposing that the delivery tube has been placed in water) into the gas generating vessel, causing it to crack and fall to pieces. The gas ought to have been freely issuing from the exit of the delivery tube for a few seconds before immersing it in water; and before collecting any of the gas, sufficient should be allowed to escape to insure the expulsion of all the common air. When the gas ceases to be evolved, the exit tube ought to be removed out of the water instantly, in order to prevent the water rushing up through the tube into the generating vessel.

494. Gas jars or receivers are of various kinds. *Plain jars* should be from twelve to sixteen inches in length, two and a half or three inches in diameter, and of such thickness as to withstand the general liabilities of use (about one-eighth or one-tenth of an inch), and ground at the edges, so as, when moistened or greased, to be closed accurately by a flat glass plate. *Stoppered jars* have an aperture above, fitted air-tight with a ground glass stopper, and resemble stoppered bottles without bottoms. They

are transferred from the pneumatic trough to the lecture table, upon a common plate or saucer containing water, in order to prevent the air having access to the gas contained in the jar. When substances have to be burned in gases, they are introduced through the mouth of the jar to the gaseous atmosphere within by means of a deflagrating spoon (Fig. 30), which consists of an iron cup about

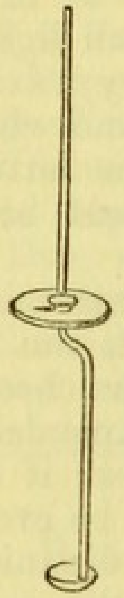
Fig. 30.

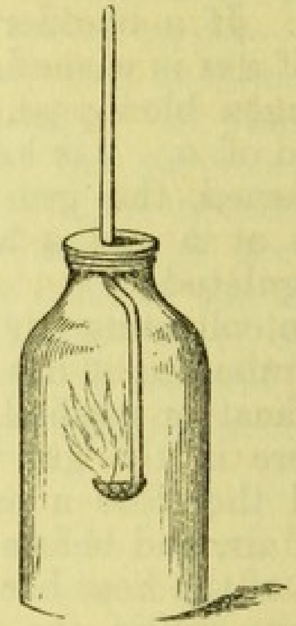
Fig. 31.

the size of a shilling, to which is attached a long handle of iron wire passing through a stuffing-box, which serves to cover the mouth of the jar. A cork or piece of flat metal may be substituted for the stuffing-box ; if a cork be employed, it must not be fixed firmly into the mouth of the jar, because gas, when heated, expands, and the cork must, therefore, be sufficiently loose to allow for the necessary quantity of the expanded gas to escape, otherwise the glass vessel will most probably be shattered.

495. Solution.—Many solid bodies, when placed in contact with a liquid, disappear by dissolving in the liquid. (Ex.—A lump of sugar placed in water dissolves.) The solid is said to be soluble in the liquid in which it dissolves, insoluble in that in which it does not dissolve. (Ex.—Sugar is soluble in water, but insoluble in alcohol.) The liquid in which the solid dissolves is called the *solvent* or *menstruum*. The more minutely any substance is powdered, the more its solution is facilitated. Solid substances are generally reduced to powder in mortars.

496. Solutions are of two kinds, simple and chemical. A simple or mechanical solution is the mere dissolving of a solid in a liquid, no chemical change occurring in either; on the removal, therefore, of the liquid by evaporation, the solid is obtained in its original condition. Common salt dissolved in water affords an illustration of a simple solution. In a chemical solution, the solid and fluid combine together, forming an entirely new substance, from which the original solid and fluid can no longer be extracted by mere mechanical operations. Chalk dissolved in hydrochloric acid affords an example of a chemical solution.

497. The solvent, in a simple solution, cannot dissolve unlimited quantities of the substance to be dissolved, it can only dissolve certain fixed quantities of the solid, the amount varying with the kind of solid, and the amount of any particular solid varying with the solvent. When the solution contains as great a quantity of the solid matter as it is capable of dissolving, it is said to be *saturated.* A solution is known to be saturated when fresh solid matter of the same sort, on being put into it, remains undissolved. "But as fluids dissolve generally larger quantities of a substance, the higher their temperature, the term *saturated,* as applied to simple solutions, is only relative, and refers invariably to a certain temperature." "From the tendency of heat to diminish the force of cohesion, it naturally results, that the solubility of most bodies is increased by heat; thus, 100 parts of water, at 60° F., dissolve 11 of sulphate of potash, and at 212° dissolve 25. At 60° F., 32 parts of dry sulphate of magnesia are dissolved by 100 of water, but 74 at 212°. This, however, is not always the case; some bodies, as common salt, are equally soluble in water at all temperatures, whilst in other cases, the solubility is greater at particular temperatures than either above or below them. Of this peculiarity, the sulphate and nitrate of soda are examples. Thus, 100 parts of water dissolve of dry sulphate of soda, at 32°, 5·02; at 52°, 10·22; at 76°, 28; at 93°, 53; at 122°, 47; and at 212°, 42; the solubility increasing up to 93, and from thence diminishing. 100 parts of water dissolve of nitrate of soda, at 21°, 63; at 32°, 80; at 50°, 23; 60°, 55; and at 246°, 218 parts. Here the peculiarity is of the opposite kind to what occurs with sulphate

of soda; the solubility diminishing up to 50°, and from thence progressively increasing." The liquids employed as solvents in simple solutions are water, alcohol, ether, oils, &c. The most important solvent is water; the others are only resorted to when the substance to be dissolved is insoluble in that liquid.

498. "A chemical solution may be *accelerated* by elevation of temperature, and this is indeed usually the case, since heat generally promotes the action of bodies upon each other. But the *quantity* of the dissolved body remains always the same in proportion to a given quantity of the solvent, whatever may be the difference of temperature — the combining proportions of substances being invariable, and altogether independent of the gradations of temperature." The liquids which produce chemical solutions are, in most cases, either acids or alkalies.

499. The process of solution is conducted either in evaporating dishes, Florence flasks, or test-tubes. The latter are generally employed when the quantity of the solid operated upon is small.

EXERCISES.

564. Make a saturated solution of nitrate of potash in cold water, by triturating (rubbing) in a mortar an excess, say 1,000 grains, of this powdered salt, with 2,000 grains of water; after the liquid has become saturated, pour 1,000 grains of the clear solution into a Florence flask; heat the solution in the flask until it boils, but in such a way that the temperature of the solution increases slowly; add from time to time (that is to say, as fast as the salt dissolves) weighed quantities (twenty grains at a time) of the nitrate of potash, until the solution is saturated at the boiling point.

565. Make a saturated solution of chlorate of potash in cold water, in the way previously described, employing 400 grains of the salt for 2,000 of the water. Take 1,000 grains of the clear saturated solution, and apply heat until it boils, in the way previously described, adding, during the time the solution is being heated, weighed quantities of the salt, twenty grains at a time, until the solution is saturated at the boiling point.

566. Make a saturated solution of common salt in cold water; employ 1,000 grains of salt for every 2,000 grains

of water. Take 1,000 grains of the clean saturated solution, and heat it until it boils, adding during the time the solution is being heated, ten grains of the salt; this ought not to dissolve, as common salt is equally soluble at all temperatures.

567. Make a saturated solution of lime in cold water; employ five grains of quick lime for 2,000 grains of water. Take 1,000 grains of the clear saturated solution and boil it, which will cause the liquid to become turbid, as lime is less soluble in hot than cold water.

500. Some substances are rendered more soluble in water, if the water contains in solution some particular substance; thus the alkaline earths are much more soluble in solutions of sugar than in pure water, and chloride of mercury is more soluble in solutions of the alkaline chlorides than in pure water, as the mercury salt forms with the latter double salts, which are very soluble.

568. Dissolve some chalk in dilute (one part of strong acid to two of water) hydrochloric acid.

569. Mix equal parts of common salt, carbonate of lime (chalk), and sand together. The first is soluble in water, the second is insoluble in water, but soluble in hydrochloric acid; the last is insoluble both in water and acids. Take a few grains of the mixture, and separate the three substances from each other by dissolving out the salt by means of water,—then the chalk, by means of dilute hydrochloric acid, so that finally no other substance but the sand remains undissolved.

501. When a saturated solution of a substance, which is more soluble in a hot than a cold liquid, is made at the boiling point, the proportion which has been dissolved by reason of the temperature, separates from the solution when it becomes cold. "Thus, if 151 parts of sulphate of magnesia be dissolved in 100 parts of boiling water, and allowed to cool to 60°, a quantity of the salt in a crystalline form will be obtained, weighing 86 parts, for at 60° the 100 of water can only dissolve 65 parts of the salt, and the difference between that and the 151, which had been dissolved by the boiling water, must separate from the solution in the solid state. If the body be, like common salt, equally soluble in water at all temperatures, the

above process cannot be applied, and a quantity of the liquid must be evaporated," an operation now to be explained.

502. EVAPORATION. This process is used for the purpose of separating volatile fluids from less volatile or from solid bodies, the former passing off in the form of vapour into the atmosphere, whilst the latter, that is, the less or non-volatile matter, remains behind.

503. The passage from the liquid condition to a state of vapour occurs at all temperatures, but of course the higher the temperature the quicker the evaporation. When a liquid evaporates at common temperatures, it is said to undergo spontaneous evaporation. If the evaporation be conducted slowly, the solid matter will frequently, on being deposited, assume a crystalline form. The operation is then termed crystallization.

504. Evaporation is frequently performed for the purpose of obtaining a more concentrated solution of the dissolved body; this is effected by volatilizing a portion of the *solvent*. Thus, if we had a weak solution of sulphate of magnesia, and we required it in a more concentrated state, we should evaporate so much of the water as would render the solution of the necessary degree of concentration.

505. Evaporation is also had recourse to for the purpose of obtaining a solid back from its solution; this is effected of course by vaporizing the solvent. Thus, if we desired to obtain chloride of sodium from a solution of this salt in water, we should evaporate the water, and thus obtain the salt in the solid state.

506. We can frequently separate two or more solid bodies from one another, by taking advantage of the different degrees of solubility which different substances possess. Ex.—Commercial nitrate of potash (saltpetre) always contains variable quantities of chloride of potassium and chloride of sodium, and from these substances it must be entirely free when used in the manufacture of gunpowder. Now 100 parts of water at 70° F. dissolves the same quantity (35 parts) of each of these salts; but 100 parts of water at 212° F. dissolves 240 parts of nitrate of potash, 35 parts of chloride of sodium, and 55 of chloride of potassium. Suppose we had some saltpetre containing, for every 240 parts of that salt, 30 parts of

chloride of sodium, and the like quantity of chloride of potassium; if we were to dissolve it in the proportion of 300 parts of the salt to 100 of boiling water, and let this solution become cold, about 200 parts of the nitrate of potash would crystallize out, whilst the whole amount of the other two salts would remain in solution. These 200 parts of nitrate of potash would be perfectly pure, with the exception of the small quantity of mother liquor,* with which they would be moistened; to free the crystals from this contamination they may be washed with a small quantity of cold water, or better, with a saturated solution of pure nitrate of potash.† If the mother liquor, which would contain nearly equal quantities of each of the three salts, were evaporated at 212°, 84 parts of water out of every 100 could be evaporated, without any of the nitrate of potash being deposited, whereas the expulsion of so much water would cause 25 parts of chloride of sodium, and 22 of chloride of potassium, to separate. If the clear solution (that is, free from the chlorides which have crystallized out), when it has reached this degree of concentration, were drawn off into another vessel and allowed to cool, a further crop of crystals of nitrate of potash, nearly pure, would be obtained; they might easily be rendered perfectly pure by washing them in the way just stated.

EXERCISES.

570. Allow the boiling saturated solutions obtained in Ex. 564, 565, to become cold; as these solutions cool, the salt they contain will begin to crystallize out, and when the solutions have become quite cold, all the salt dissolved by warming the solution will in both cases crystallize out.

571. Evaporate the solution of nitrate of copper obtained in Expt. 73 until the solution reaches the crystallizing point, then place it aside to cool; when it has ceased to deposit crystals, pour the liquor from them, and then dry them between blotting paper, and afterwards place them in a bottle. Evaporate the solution again, and so obtain a further crop of crystals. To ascertain when a solution has reached the crystallizing point, that is to say,

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* The liquor from which the crystals have separated.

† After water has been saturated with one substance, although it cannot dissolve a further quantity of that one, it can still dissolve other substances.

when a hot solution has reached such a degree of concentration that it will deposit crystals when cold, transfer a drop of it by a rod upon a cold glass plate, and observe whether it deposits crystals as it cools; if it does, then the evaporation must be discontinued, but if not, it must go on until such a result is obtained.

572. "Let equal parts of nitrate of potash and sulphate of soda be mixed and dissolved in five parts of water, and the solution divided between two similar dishes; on a crystal of nitrate of potash being laid in one dish, and a crystal of sulphate of soda being laid in the other, a crystallization of pure nitrate of potash will occur in the former, whilst nothing but sulphate of soda will crystallize in the latter dish." A little crystal of the same kind of salt which it is intended to crystallize, is often introduced into the solution about to crystallize, in order to serve as a nucleus round which the new crystals may gather; and in a solution containing many salts, the nature of the salt which shall crystallize may be determined by the nature of the little crystal introduced.

507. Precipitation.—It is frequently necessary to remove a constituent; it may be either the metal or metalloid of some binary compound, or the acid or base of some ternary one, from the liquid in which the compound is dissolved. This is effected by making it a constituent of some new compound which is insoluble in the liquid in which the original compound was dissolved. This operation, which is called precipitation, is owing, therefore, to the formation of a new substance, which is insoluble in the liquid in which its elements were dissolved, and which falls or is precipitated to the bottom in the solid state, owing to the solid being specifically heavier than the liquid. Occasionally, however, it is lighter, and floats upon the surface. In both cases the insoluble substance is called the *precipitate*, and the substance producing the precipitation is termed the *precipitant*.

508. Precipitates are classified, according to their appearances, into crystalline, pulverulent, flocculent, curdy, and gelatinous. The terms *turbid* and turbidity are applied when the precipitate is so small that it cannot be distinguished, except by impairing the transparency of the fluid.

509. Precipitation is an operation which is constantly practised in the preparation of substances in the manufactory as well as in the laboratory. We also resort to it in the laboratory, for the purpose of detecting and separating substances from one another. Thus, if we had a solution which might contain some compound of baryta and lime,—to ascertain whether baryta was present, and if it was, to separate it from the solution, before ascertaining whether lime was likewise present, we might add a soluble chromate,—if baryta was present, the chromic acid would combine with it, and as chromate of baryta is insoluble in water, it would precipitate, whilst chromate of lime, being soluble, would remain in solution. If we were now to add to the clear filtered solution some soluble oxalate—oxalate of lime, being insoluble in water, would precipitate. If the chromate produced no precipitate, there could be no baryta; if the oxalate produced no precipitate, after having separated the baryta, if present, lime must be absent.

510. The separation of precipitates from the liquid is, with a few exceptions, much assisted by the application of heat and agitation. The operation is conducted in test-tubes, if used as an analytical process: at the lecture table it must be performed in Florence flasks, if heat has to be applied; if not, in vessels of the description illustrated in Fig. 32.

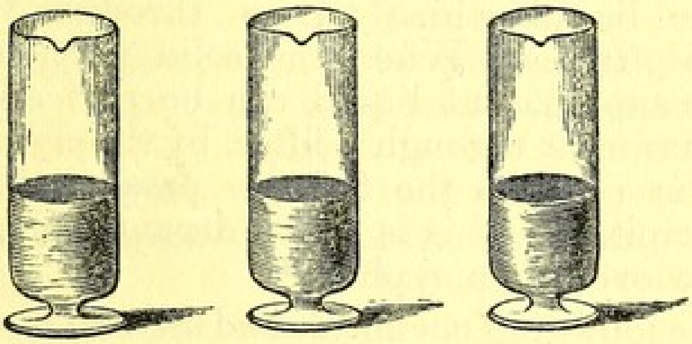

Fig 32.

511. Filtration and Decantation.—These terms are applied to a modification of the same operation, viz., the mechanical separation of fluids from solid matter mixed with them.

512. In filtration, the separation of the fluid from the solid matter is accomplished by passing it through filtering

paper (white blotting paper) of a proper size and shape, supported in a funnel. The pores of the paper permit the fluid to pass through, whilst the solid matter, being prevented, remains behind.

513. "To prepare a filter, take a small piece of filtering paper, and fold it twice from side to side, then round off with scissors the projecting corners, so that the paper may fall wholly within the funnel (Fig 33). Moisten the paper when placed within the funnel with water, and then carefully pour in the liquid to be filtered." The funnel is supported in one of the rings of the retort stand (Fig. 34).

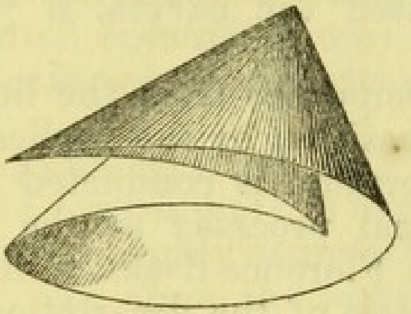

Fig. 33.

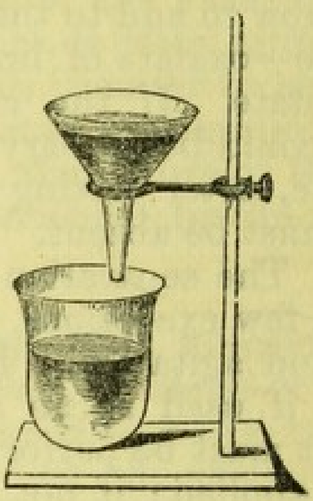

Fig. 34.

514. The liquid which passes through the filter is called the *filtrate.* When the solid particles are very heavy, the supernatant liquid can be perfectly separated without passing it through a filter, by simply inclining the vessel, so as to allow the fluid to pass away unattended by the precipitate,—this is called decantation; or the fluid may be removed by a syphon.*

515. The following chemicals and apparatus are required for the illustration of this work :—

CHEMICALS.

2 lbs. Common sulphuric acid
2 lbs. ,, hydrochloric acid
1 lb. ,, nitric acid
1 lb. Commercial ammonia
1 lb. Solution of caustic soda
4 oz. Nitrate of ammonia

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* Chapter vi. must be studied next.

4 oz. Carbonate of ammonia
2 oz. Chloride of ammonium
4 oz. Sulphide of ammonium
1 oz. Oxalate of ammonia
½ dram Potassium
½ oz. Iodide of potassium
½ lb. Chlorate of potash
2 oz. Carbonate of potash
½ oz. Permanganate of potash
2 oz. Nitrate potash
2 oz. Bichromate of potash
1 oz. Chromate of potash
½ dram Sodium
4 oz. Carbonate of soda
1 oz. Phosphate of soda
1 oz. Hyposulphite of soda
4 oz. Sulphate of soda
1 oz. Biborate of soda
2 oz. Chloride of barium
1 oz. Nitrate of baryta
1 oz. Carbonate of baryta
¼ oz. Peroxide of barium
1 lb. Marble
1 oz. Phosphuret of calcium
4 oz. Sulphate of magnesia
4 oz. Alum
1 oz. Sesquichloride of chromium
Iron wire
4 oz. Sulphide of iron
4 oz. Sulphate of iron
Zinc turnings
2 oz. Sulphate of zinc
Copper turnings
Copper leaf
Copper wire
4 oz. Sulphate of copper
1 lb. Peroxide of manganese
½ oz. Chloride of manganese
½ lb. Bleaching powder
Tin-foil
Metallic antimony
——— lead
4 oz. Red lead
4 oz. Nitrate of lead
1 oz. Vermillion
1 oz. Mercury
1 oz. Chloride of mercury
1 oz. Red oxide of mercury
1 oz. Nitrate of mercury
1 oz. Subnitrate of mercury
½ oz. Nitrate of silver
1 oz. Oxalic acid
4 oz. Acetic acid
2 oz. Absolute alcohol
¼ oz. Iodine
½ oz. Phosphorus
¼ oz. Camphor
Charcoal
1 oz. Bisulphide of carbon
Roll Sulphur
Flowers of sulphur
1 oz. Ultramarine (artificial)
1 oz. Solution of indigo
Litmus paper
4 oz. Ether

APPARATUS.

4 oz. Graduated measure
8 oz. Mortar and pestle
Glass spirit lamp and cotton wick
Gas lamp (Fig. 3)
Retort stand
Two pint glass funnels
Two 4 oz. ditto ditto
Filtering paper
Glass tubing and rod
One pint and half pint evaporating dish

- ½ doz. Precipitating vessels
- ½ doz. Florence flasks
- Pneumatic trough
- Gas-holder
- Bladder, with stop-cock, &c.
- Three gas-jars
- Deflagrating spoon
- Doberiner's lamp
- Corks (assorted)
- Two pint beakers
- Two 1-quart wide-mouthed stoppered bottles
- Three pint narrow-mouthed stoppered bottles
- One Woulfe's bottle
- Funnel tube
- Four hard glass test-tubes
- Vulcanized caoutchouc tube
- One pint glass retort
- Two 4 oz. hard glass retorts
- Wide glass tube for holding over a jet of hydrogen
- Balloon (goldbeater's skin)
- Ure's eudiometer
- Davy's safety lamp
- Piece of fine wire gauze
- Mouth blow-pipe
- Specific gravity bottle (1000 grs.)
- Common balance and weights for taking specific gravities
- Smee's battery, for decomposing water
- Faraday's *b* tube, for decomposing salts
- Apparatus for decomposing water, and collecting the gases separately
- Two round files
- One three-cornered ditto
- 1 doz. Test-tubes and stand
- Gas diffusion tube
- 2 Collodion balloons

CHAPTER XXII.

SPECIAL PROPERTIES OF THE METALLOIDS AND OF THEIR MOST IMPORTANT COMPOUNDS.

OXYGEN.

Symbol, O; *Equivalent,* 8; *Specific gravity,* 1·1057.

516. History.—Discovered by Priestly in 1774, and by Scheele a year or two after, without previous knowledge of Priestly's discovery; it was termed by Priestly *dephlogisticated air*, by others *vital air*, and *pure air*.

Physical Properties.—A non-condensible, colourless, inodorous and tasteless gas.

It forms a larger proportion of the material world than any other element; it is supposed to constitute at least a third of the total weight of the mineral crust of the globe; it forms 89 per cent. of all the water, and 23 per cent. of the atmosphere.

Chemical Properties.—It has a very wide range of affinity—it has been combined with every known element but fluorine, and from analogy, we may conclude that it would combine with this latter element if they were brought together under proper conditions. All substances which burn in common air, burn with increased splendour in an atmosphere of pure oxygen; but some substances which burn vividly in an atmosphere of pure oxygen, cannot burn in atmospheric air, because the nitrogen in the air absorbs so much of the heat generated as to reduce the temperature below that required for the combination.

The element which most frequently develops light and heat in combining with others, is oxygen; and the act of its combination with other bodies is pre-eminently denominated *combustion.* It is essential to the support of animal life. It is only slightly soluble in water, which takes up about $\frac{1}{20}$ of its bulk.

Preparation.—*First method.*—Oxygen is most conveniently prepared from chlorate of potash (KO, ClO_5). For this purpose, powdered chlorate of potash is intimately mixed with one-fifth its weight of peroxide of manganese (MnO_2), and then introduced into a Florence flask, or large test-tube, with a bent tube, as shown in Figs. 23 and 24. The flask, or test-tube, may be heated by a spirit lamp,—at first moderately, as the gas, on the first application of heat, comes off very abundantly and rapidly; it (the heat) is gradually increased as the evolution of gas decreases: the gas may be collected over water in the pneumatic trough. The peroxide of manganese undergoes no chemical change, but it causes the complete decomposition of the chlorate of potash to be effected at a much lower temperature than would be the case if the chlorate were heated by itself. The following is the decomposition expressed in symbols:—

$$KO, ClO_5, = KCl + 6O.$$

Second Method.—Decompose the black oxide (peroxide) of manganese (MnO_2) at a red heat; the following change takes place:—

$$3MnO_2 = Mn_3O_4 + 2O.$$

Third Method.—Decompose by heat the red oxide of mercury (HgO); the following decomposition takes place:

$$HgO = Hg + O.$$

OZONE.—Under the influence of electricity, oxygen acquires new properties, and bears then the name of ozone. In this new state "it possesses considerable bleaching powers, acts rapidly as a powerful oxidizing agent, and corrodes organic matters, such as the cork or caoutchouc used in connecting the different parts of the apparatus together. Fragments of iron, of copper, and even of silver, when moistened, rapidly absorb ozone and become converted on their surface into oxides; silver even becomes a peroxide, though this metal is wholly unchanged by ordinary oxygen."

A mixture of iodide of potassium and starch furnishes the readiest and most delicate method of detecting ozone. A slip of paper moistened with starch and iodide of potassium, and inserted into a vessel containing the smallest admixture of ozone, becomes blue from the action of the liberated iodine upon starch; blue iodide of starch, which is so characteristic of iodine, being formed.

"Ozone may be obtained without the aid of electricity. If a stick of clean phosphorus, moistened with a few drops of water, be placed in a bottle of atmospheric air, the slow oxidation of the phosphorus is attended with the production of ozone: in an hour or two this attains its maximum."

HYDROGEN.

Symbol, H; *Equivalent*, 1; *Specific gravity*, 0·0692.

517. HISTORY.—First correctly described in 1766 by Cavendish under the name of *inflammable air.*

PHYSICAL PROPERTIES.—A non-condensible, colourless, inodorous, and tasteless gas. It is the lightest body in nature.

It occurs in nature only in combination; it is one of the constituents of water.

CHEMICAL PROPERTIES.—It has a very great affinity for oxygen; the most intense heat which can be obtained by artificial means is produced by the combustion of these two gases; water is the compound produced by their union. Hydrogen does not combine directly with nitrogen. Tallow, wax, oil, coal-gas, and all compound substances which are burned either for heat or illumination, consist essentially of hydrogen and carbon. A mixture of hydrogen and oxygen or air is dangerously explosive on being inflamed.

PREPARATION.—*First method.*—Decompose water in the cold by zinc or iron, in the presence of sulphuric acid, thus:—

$$Zn + HO, SO_3 = ZnO, SO_3 + H.$$

The best apparatus for the purpose of preparing by this method is a Woulfe's bottle (Fig. 20). Clippings of the metal being introduced into the bottle, sufficient dilute acid is poured in through the funnel tube until the metal is covered to the depth of an inch or so with it; at all events, enough acid should be added to produce a brisk but not violent effervescence, and as the end of the funnel tube is covered with liquid, the gas evolved can only escape through the other tube. The gas must not be collected until the whole of the air in the different parts of the apparatus has been expelled, as a mixture of this gas and air or oxygen is dangerously explosive. To guard against this, as much of the newly-formed hydrogen ought to be allowed to escape uncollected, as would fill the gas apparatus two or three times; after this, it may be collected with perfect safety. When the gas begins to be slowly evolved, the addition of a little more acid through the funnel tube causes it to be evolved again as briskly as at the first.

Hydrochloric acid can be employed in place of the sulphuric acid; in this case the acid, and not the water, furnishes the hydrogen.

Second method.—Decompose a current of steam by iron heated to redness, thus:—

$$4\,HO + 3\,Fe = Fe_3O_4 + 4\,H.$$

WATER.

Symbol (HO); *Equivalent*, 9; *Specific gravity as vapour*, 0·622; *as liquid*, 1·000.

518. PHYSICAL PROPERTIES.—A liquid body at the ordinary temperature; solidifies at 32° F.; boils at 212° F. under the ordinary pressure. When free from admixture, water is a clear, colourless, transparent liquid, destitute of taste or smell.

Composition.—100 parts of water contain—

Hydrogen	11·11
Oxygen	88·89
	100·00

Or in volume—

1	volume of	oxygen	1·1056
2	,,	hydrogen	0·1384
2	,,	water	1·2440

Synthesis of Water.—*First method.*—Combustion of hydrogen in air or oxygen gas. *Second method.*—Explosion of a mixture of hydrogen and oxygen by electricity in the eudiometer. (Ex. 250.)

Analysis of Water.—*First method.*—Decomposition of water by voltaic electricity (par. 254, page 170). *Second method.*—Decomposition of the vapour of water by iron heated to redness.

NITROGEN, OR AZOTE.

Symbol, N; *Equivalent,* 14; *Specific gravity,* 0·9713.

519. History.—First noticed by Rutherford in 1772. Discovered to be a constituent of the atmosphere by Lavoisier in 1775, and by Scheele about the same time.

Physical Properties.—It is a non-condensible, colourless, inodorous, and tasteless gas.

Chemical Properties.—It is incapable of supporting the combustion of burning bodies, and the respiration of animals. It does not, in fact, possess any of the marked characters of the other elements, but is chiefly distinguished by the absence of all active properties. It cannot (except with very great difficulty) be made to unite directly with any element; but requires for its combination that one or both the elements should be in the *nascent state.* It occurs principally in the atmosphere, forming about 77 per cent. by weight of the whole mass. Water dissolves not more than $\frac{1}{40}$th of its bulk of this gas at ordinary temperatures.

Preparation.—*First method.*—By inverting a glass jar in water and burning phosphorus in the confined air contained in the jar. The phosphorus and oxygen combine together, and produce phosphoric acid (PO_5). which is dissolved by the water, whilst the nitrogen remains behind almost pure. *Second method.*—Make to pass a current of air over copper scales heated to redness; the oxygen combines with the copper, forming oxide of copper (CuO), and the nitrogen is collected.

ATMOSPHERIC AIR.

520. Physical Properties.—Its pressure is equal to 15 lbs. on the square inch; it is capable of supporting a column of water 34 feet high, and one of mercury 30 inches. 100 cubic inches of dry air weigh, at 60° F. and 30 inches barometer, 30·935 grs.

Chemical Properties.—The air is a mixture of oxygen and nitrogen; it also contains minute quantities of carbonic acid, watery vapour, nitric acid, and ammonia. That the nitrogen and oxygen in the air are not chemically united, but only mixed, is demonstrated—1st. The most convincing proof that the air is a mixture of these gases, is in the manner in which air behaves with water. If the air were a compound, the oxygen and nitrogen would be dissolved by the water in the same proportion as they exist in air—which is not the case. If on the contrary, air is only a simple mixture of these two gases, and as they are not equally soluble in water, the composition of the dissolved gases in the water will be different from that of the air—which is the case. 2nd. Nitric oxide (NO_2) cannot take oxygen if in a state of combination, but it can take oxygen from the air (par. 66, page 37). 3rd. If oxygen and nitrogen are mixed in the proportion constituting the air, we obtain a gaseous mixture absolutely identical with our atmosphere.

Analysis of Air.—Introduce into a eudiometer placed over mercury a certain volume of air, which is carefully measured; then introduce a ball of phosphorus attached to a platinum wire into the air. When the gas ceases to diminish in bulk, remove the phosphorus, and carefully read the volume. The diminution in bulk caused by the phosphorus is the quantity of oxygen, and the gas which remains is the nitrogen.

Atmospheric air contains, on an average,
In volume: 100 of air = 20·9 of oxygen and 79·1 of nitrogen.
In weight: 100 „ = 23·1 „ „ 76·9 „

It contains in 100 parts by volume 0·04 of carbonic acid; 1·4 of watery vapour, and traces of nitric acid and ammonia.

COMPOUNDS OF NITROGEN AND OXYGEN.

521. We are acquainted with five definite combinations of nitrogen and oxygen, to which the following formulæ have been assigned:—

		Composed by weight of
1. Protoxide of nitrogen	NO	14 N + 8 O
2. Deutoxide of nitrogen.........	NO_2	14 N + 16 O
3. Nitrous acid	NO_3	14 N + 24 O
4. Peroxide of nitrogen	NO_4	14 N + 32 O
5. Nitric acid.........................	NO_5	14 N + 40 O

522. NITRIC ACID; *Aqua Fortis* (HO, NO_5).—This, which is the highest oxide of nitrogen known to exist, is the most important. It occurs in small quantities in the atmosphere; but it is found most abundantly in combination with potash or soda in the form of an efflorescence on the soil, especially in tropical climates, as in some parts of India and Peru. The compound formed with potash constitutes the nitre or saltpetre of commerce.

PHYSICAL PROPERTIES.—The anhydride (NO_5) is a white crystalline solid, which melts at 86° F., and boils at 112. The hydrate (HO, NO_5) is a colourless fuming liquid, which acquires a yellow colour in time. It freezes about 40° F, and boils at 184° F. Its sp. gr. is 1·52.

CHEMICAL PROPERTIES.—It is very easily decomposed. If passed through a red-hot porcelain tube, it is resolved into oxygen and nitrogen. All oxidizable bodies deprive it of oxygen, reducing it to peroxide of nitrogen, nitrous acid, or deutoxide of nitrogen; and even, in some cases, removing all the oxygen and leaving only nitrogen. It is therefore a powerful oxidizing agent, and is much used for oxidizing and dissolving metals. It turns all animal matter, containing albumen, of a bright yellow colour.

Every 100 parts of NO_5 by weight contain 23·93 by weight of nitrogen, and 74·07 of oxygen; or in volume,—

1 volume of nitrogen, which weighs......	0·9713
2½ „ „ oxygen „ „	2·7640
	3·7353

The volume of gaseous acid produced is unknown, because this acid has not yet been obtained isolated.

PREPARATION of the liquid acid. Decompose by heat, nitrate of soda or nitrate of potash by sulphuric acid, thus :—

$$NaO, NO_5, + 2\,(HO, SO_3) = HO, NO_5 + (NaO, SO_3 + HO, SO_3)$$

523. PEROXIDE OF NITROGEN ; *Nitrous Acid ; Hyponitric Acid* (NO_4).

PHYSICAL PROPERTIES.—This body freezes at 40° F., and boils at 82° F. In the liquid state it is colourless at 0° F., becomes yellow at 14° F., and at ordinary temperatures is red. Its sp. gr. is 1·451.

CHEMICAL PROPERTIES.—In contact with water it is destroyed, giving rise to nitric acid and deutoxide of nitrogen, thus :—

$$3\,NO_4 = 2\,NO_5 + NO_2.$$

Every 100 parts by weight contain 30·43 parts by weight of nitrogen, and 69·57 of oxygen ; or in volume,—

½ volume of nitrogen	0·4856
1 „ „ oxygen............................	1·1056
1 „ „ peroxide of nitrogen	1·5912

The red fumes which appear in mixing the deutoxide with air consist mainly of this compound.

PREPARATION.—Obtained by distilling dry nitrate of lead, thus :—

$$PbO, NO_5 = PbO + O + NO_4.$$

524. NITROUS ACID ; *Hyponitrous Acid* (NO_3).—In its uncombined form it is decomposed very readily. At a temperature of 0° F. it condenses to a blue very volatile liquid ; it is immediately decomposed by water, like the peroxide, and into the same compounds. Every 100 parts

by weight contain 36·84 parts by weight of nitrogen, and 63·16 of oxygen; or in volume,—

1 volume of nitrogen	0·9713
$1\frac{1}{2}$,, ,, oxygen	1·6584
	2·6297

The volume of nitrous acid in the gaseous state is not known.

Preparation.—Best obtained by heating 1 part of starch in 8 parts of nitric acid. Sp. gr., 1·25.

525. Deutoxide of Nitrogen; *Binoxide of Nitrogen; Nitric Oxide; Nitrous Gas* ($N O_2$).

Physical Properties.—A transparent colourless gas. Its sp. gr. is 1·039.

Chemical Properties.—It is an indifferent body. It is insoluble in water. When brought in contact with oxygen, in its free state, it combines with it, forming red fumes ($N O_4$). Bodies will not burn in it, except at very high temperatures. Every 100 parts by weight contain 46·66 parts by weight of nitrogen, and 53·34 of oxygen; or in volume,—

$\frac{1}{2}$ volume of nitrogen	0·486
$\frac{1}{2}$,, ,, oxygen	0·552
1 ,, ,, deutoxide of nitrogen	1·038

526. Protoxide of Nitrogen; *Nitrous Oxide; Laughing Gas.*

Physical Properties.—A colourless, inodorous gas, of a slightly sweetish taste. Under a pressure of fifty atmospheres, at 45° F. it is reduced to a liquid, which may be frozen into a transparent solid about 150° F. Its density is 1·527.

Chemical Properties.—It is an indifferent body. Some combustible bodies, as phosphorus, if introduced into an atmosphere of this gas, decompose and combine with its oxygen. It is soluble in water. When breathed, it possesses intoxicating effects; but different individuals are affected in different degrees, and in various ways, according to the temperament of each. Every 100 parts by weight contain 63·77 parts by weight of nitrogen, and 36·23 of oxygen; or in volume,—

1 volume of nitrogen	0·972
½ ,, ,, oxygen	0·552
1 ,, ,, protoxide of nitrogen	1·524

Preparation.—Decompose by heat nitrate of ammonia (NH_4O, NO_5), thus:—

$$NH_4O, NO_5 = 2NO + 4HO.$$

COMBINATIONS OF NITROGEN WITH HYDROGEN.

527. *Ammonia. Volatile Alkali. Hartshorn* (NH_3). Equivalent, 17.

Physical Properties.—A colourless gas, of a very pungent and peculiar smell and taste. It is liquefied by a pressure of about 6½ atmospheres; it is also liquefied by exposure to a cold of 40° F., and by a cold of 103° F. it is frozen to a white translucent crystalline solid. Its density is 0·597.

Chemical Properties.—It is a strong base. It is very soluble in water; the aqueous solution is called aqua, or liquor, ammonia. A red heat decomposes it. It burns with difficulty in oxygen, and with great difficulty in air. It does not support respiration; it is even deleterious. If it is brought in contact with any volatile acid, as hydrochloric, dense white clouds are formed, which are the solid salt; by this property, and its smell, it is easily distinguished. Every 100 parts by weight contain 17·61 parts by weight of hydrogen, and 82·39 of nitrogen; or by volume,—

1½ volumes of hydrogen.....................	0·1038
½ ,, ,, nitrogen	0·4856
1 ,, ,, ammonia	0·5849

Preparation.—When organic substances, containing nitrogen, decay and putrefy, or when they are submitted to destructive distillation, carbonate of ammonia (NH_4O,

CO_2) is produced; this salt is converted into sulphate or muriate; and by heating these salts with lime, the ammonia is liberated and collected in water, which forms the liquid ammonia of commerce.

$$NH_4Cl + CaO = CaCl + HO + NH_3.$$

It is considered that there are two other compounds of nitrogen and hydrogen—amidogen (NH_2) and ammonium (NH_4)—but they have not yet been isolated.

CHLORINE.

Symbol, Cl; *Equivalent*, 35·5; *Specific gravity*, 2·47.

528. History.—Discovered by Scheele in 1774; he named it *dephlogisticated marine air*.

Physical Properties.—It is a gas of a transparent greenish-yellow colour, possessing a powerful suffocating odour; if respired pure, it causes instant death. It is liquefied under a pressure of 4 atmospheres at 60° F., which remains unfrozen even at 220° F. It is much heavier than the air, as shown by its sp. gr.

Chemical Properties.—It does not exist naturally uncombined, its principal natural compound is common kitchen salt (NaCl). It is soluble in half its weight of cold water,—it cannot, therefore, be collected over cold water; and as it readily acts upon mercury, it cannot be collected over that metal: it must either be collected over hot water, in which it is less soluble, or by displacement. It supports the combustion of many substances; some of them take fire spontaneously in it, as antimony, phosphorus, &c. The affinity of chlorine for the metals is very powerful, it is frequently stronger than that of oxygen. The distinguishing property of chlorine is its affinity for hydrogen. A mixture of chlorine and hydrogen detonate if exposed to the direct rays of the sun; they combine without detonation if exposed to diffuse daylight. Moist chlorine possesses the property of destroying or bleaching most vegetable colours; it also destroys fœtid or noxious effluvia, and is, on that account, much employed as a disinfectant, in checking the spread of contagious disease. The chlorine acts as a bleaching and disinfectant agent, by removing the hydrogen of the colouring or fœtid body.

Preparation.—From its great practical importance to the bleacher and dyer, it is prepared on an enormous scale by heating peroxide of manganese ($Mn\,O_2$) with hydrochloric acid ($H\,Cl$), thus:—

$$Mn\,O_2 + 2\,H\,Cl = Mn\,Cl + 2\,H\,O + Cl.$$

The operation is conducted in the laboratory in the following way:—One part of finely-powdered peroxide of manganese is placed in a capacious flask, and four parts of hydrochloric acid added; the flask is fitted with a tube, bent at right angles,—the shorter limb is fitted into the neck of the bottle by means of a perforated cork, and a longer one is conducted to the bottom of a dry wide-mouthed stoppered bottle. The flask is gently warmed, and as soon as the gas begins to be evolved, the heat is removed until it commences to be slowly evolved, when it is again applied. The gas, being much heavier than air, collects in the bottle by displacing the air; as soon as the bottle is filled, which is easily seen, it is removed, and another substituted; the full bottle is immediately stoppered, the stopper being first well greased.

COMBINATIONS OF CHLORINE WITH OXYGEN.

529. These combinations are very numerous, five of them being well ascertained, and others more complex exist, which may be regarded as resulting from the union of the former with each other.

The five most important compounds are—

1. Hypochlorous Acid	$Cl\,O$
2. Chlorous Acid	$Cl\,O_3$
3. Hypochloric Acid	$Cl\,O_4$
4. Chloric Acid	$Cl\,O_5$
5. Perchloric Acid	$Cl\,O_7$

530. Hypochlorous Acid ($Cl\,O$). Physical Properties.—Is a gas of a strong yellow colour, and a peculiar penetrating smell. Its density is 2·977.

Chemical Properties.—It is very easily decomposed by substances which have an affinity for chlorine or oxygen: it therefore bleaches powerfully; it is even decomposed by a gentle heat. Water absorbs 100 times its volume of this gas, and acquires a pale yellow colour. It contains in every 100 parts by weight, 81·61 of chlorine and 18·39 of oxygen; or in volume,—

1 volume of chlorine	2·440
½ ,, ,, oxygen	·552
1 ,, ,, hypochlorous acid	2·992

Preparation.—Passing perfectly dry chlorine over oxide of mercury.

$$HgO + 2\,Cl = Hg\,Cl + Cl\,O.$$

Bleaching Compounds.—If the base over which the chlorine is passed is a powerful one, like the alkalies or alkaline earths, the gas is absorbed, and peculiar compounds, possessed of bleaching properties, are produced. It is in this way that the bleaching compounds so extensively used in the arts under the names of chloride of lime, chloride of potash, &c., are produced; of these bleaching compounds the chloride of lime is most important. There are different views as regards the constitution of these bleaching compounds; some chemists regard them as simply a combination of chlorine with the base (Ex.—$Ca\,O\,Cl$); others regard them as a double compound of a chloride and hypochlorite (Ex.—$Ca\,Cl + Ca\,O,\,Cl\,O$). All the chlorine is set free from these compounds on the addition of an acid in excess, thus:—

$$Ca\,O\,Cl + H\,O\,S\,O_3 = Ca\,O\,S\,O_3 + H\,O + Cl.$$

531. Chlorous, Hypochloric, and Perchloric Acids are unimportant, we shall therefore pass them over without further notice.

532. Chloric Acid ($H\,O, Cl\,O_5$). Physical Properties.—It is a limpid liquid, having a faint chlorous smell, and a powerful acid taste. It has never been obtained in its anhydrous state.

Chemical Properties.—In diffused daylight, it gradually undergoes spontaneous decomposition. By a heat of a little above 100° F. it is decomposed into oxygen gas, chlorine and perchloric acid ($2\,Cl\,O_5 = Cl\,O_7 + O_3 + Cl$). It is instantly decomposed by contact with organic matter, and in its concentrated state it chars and even sets paper on fire.

Preparation.—If chlorine be passed through a solution of potash, it is absorbed, and the bleaching compound ($K\,O\,Cl$) is formed, which on the application of heat is decomposed into chloride of potassium (K Cl) and chlorate of potash, thus:—

$$6\,K\,O\,Cl = 5\,K\,Cl + K\,O,\,Cl\,O_5.$$

The chlorate, being more insoluble than the chloride, can be separated from it by crystallization. In order to obtain chloric acid, the chlorate of potash is decomposed by the addition of hydro-fluo-silicic acid ($3\,H\,F,\,2\,Si\,F_3$), which forms an insoluble compound with the potash, and the chloric acid is liberated.

COMBINATION OF CHLORINE WITH HYDROGEN.

533. Hydrochloric Acid; *Muriatic Acid* (H Cl). Equivalent, 36·5.—A concentrated solution of this acid has been long known, under the names of spirit of salt, and marine, or muriatic, acid.

Physical Properties.—A colourless gas, of a peculiar pungent odour and an intensely acid taste. Under a pressure of 40 atmospheres at 50° F. it condenses to a colourless liquid of sp. gr. 1·27, which has never been frozen. The sp. gr. of the acid in its gaseous state is 1·2474.

Chemical Properties.—It is very soluble in water; the ordinary liquid hydrochloric acid is merely a solution of the gas in water; its solution reddens, but does not bleach, vegetable blue colours. The acid forms with basic bodies a class of salts called chlorides.

Preparation of the Gaseous Acid.—Heat gently chloride sodium (Na Cl) with concentrated sulphuric acid, thus:—

$$Na\,Cl + H\,O,\,S\,O_3 = Na\,O,\,S\,O_3 + H\,Cl + H\,O.$$

534. Nitro-Muriatic Acid; *Aqua Regia.* — "The name of aqua regia was given by the alchemists to a mixture of nitric with hydrochloric acid, from the power that it possesses of dissolving gold, 'the king of metals.' Platinum and gold are insoluble in either acid separately; but when the two acids are mixed, they mutually decompose each other; free chlorine, and abundant ruddy fumes, long mistaken for peroxide of nitrogen, being liberated. The chlorine in the moment of its extraction acts upon the metals and dissolves them."—*Miller.*

BROMINE.

Symbol, Br ; *Equivalent,* 80; *Specific gravity of the vapour,* 5·34 ; *of the liquid at* 32° F., 3·187.

535. Physical Properties.—This element exists at ordinary temperatures as a deep brownish-red liquid. It possesses a very pungent and peculiar smell—hence its name, which is derived from a Greek word, *bromos*, signifying a disagreeable smell. It boils at 145·5° F., and when exposed to a cold of 9·5° F. it forms a red crystalline solid. It is very volatile; it even volatilizes at common temperatures, and has therefore to be kept under water in stoppered bottles.

It is found in very minute quantities in sea water and some saline springs, in combination with the metals potassium, sodium, and magnesium. Bromine and mercury are the only elements which are liquid at ordinary temperatures.

Chemical Properties.—It resembles chlorine very closely in all its chemical relations and properties; its affinities are, however, less powerful, so that chlorine always disengages bromine from its compounds. It bleaches many vegetable colours. A candle will not burn in its vapour. It is slightly soluble in water; it is very soluble in alcohol, and still more so in ether. Bromine combines directly with many of the metals, forming a class of salts called bromides.

Preparation.—Bromine is obtained by treating the mother liquor of salt springs, which are rich in bromides, with chlorine, after the sea salt has been crystallized out. The liquid is then agitated with ether, which dissolves out the bromine which has been set free. The etherial solution is treated with an excess of potash, which produces a mixture of bromate of potash (KO, BrO_5) and bromide of potassium, thus :—

$$6\,KO + 6\,Br = 5\,KBr + KO,\,BrO_5.$$

This mixture is then dried and ignited, when all the bromate is converted into bromide, on account of the expulsion of its oxygen by the heat. The bromide is then mixed with rather more than half its weight of peroxide of manganese (MnO_2), and then distilled along with its own weight of sulphuric acid; the bromine is volatilized, and is collected in a receiver containing water kept cool by ice. The following is the reaction:—

$$K\,Br + Mn\,O_2 + 2\,(H\,O,\,S\,O_3) = K\,O,\,S\,O_3 + Mn\,O,\,S\,O_3 + 2\,H\,O + Br.$$

COMBINATION OF BROMINE WITH OXYGEN.

536. Only one compound of bromine and oxygen is known, viz., bromic acid ($Br\,O_5$). Its properties are quite analogous to those of chloric acid.

COMBINATION OF BROMINE WITH HYDROGEN.

537. Hydrobromic Acid ($H\,Br$).—It is a gas, transparent and colourless, fuming strongly when mixed with air. Its sp. gr. is 2·73. It resembles hydrochloric acid so closely in all its properties, that it is hardly to be distinguished from it. Chlorine, however, decomposes it, setting bromine free. It combines with bases, bromides and water being formed.

Preparation.—It may be procured abundantly by decomposing bromide of potassium with a concentrated solution of phosphoric acid.

IODINE.

Symbol, I; *Equivalent*, 126·8; *Specific gravity of vapour*, 8·716.

538. Physical Properties.—This element, at ordinary temperatures, is a grayish black-coloured solid, possessing a metallic lustre. It generally occurs in scales; it melts at 220° F., and is converted into vapour at 347° F.; the colour of its vapour is a magnificent purple. Its sp. gr. in the solid state is 4·947.

It is found combined with potassium, sodium, and magnesium, in the ashes of most sea-plants; and it also exists, in combination with these substances, in sea water.

Chemical Properties.—It resembles chlorine and bromine in its chemical properties and relations; its affinities are, however, less powerful. It is slightly soluble in water; it is very soluble in alcohol, ether, and solutions of the iodides. Its bleaching properties are very slight. It combines directly with the metals, forming a class of salts called iodides. The most delicate test for iodine in its uncombined state is starch; the compound it produces with this substance possesses a most intense blue colour.

Preparation.—It is extracted from kelp (the ash of sea-weeds). The soluble salts of the ash are dissolved in water, the carbonate of soda and other salts are crystallized out; the mother liquor is then treated with one-eighth of its bulk of sulphuric acid, and allowed to stand twenty-four hours; it is then introduced into a leaden still, and heated to 140° F., a quantity of binoxide of manganese ($Mn\,O_2$) in powder is then added, and the temperature is gradually raised to 212° F., but not higher; the iodine distils over, and is condensed in the receiver. The following is the reaction:—

$$Na\,I + Mn\,O_2 + 2\,(H\,O, SO_3) = Na\,O,\,S\,O_3 + Mn\,O,\,S\,O_3 + 2\,H\,O + I.$$

COMBINATIONS OF IODINE WITH OXYGEN.

539. "Iodine has a more powerful affinity for oxygen than either chlorine or bromine, and forms with it two well defined acids, viz., the iodic acid ($I\,O_5$), and the periodic acid ($I\,O_7$), besides some other oxides but imperfectly known."

COMBINATION OF IODINE WITH HYDROGEN.

540. Hydriodic Acid ($H\,I$). Physical Properties.—It is a gas, transparent and colourless, with a suffocating smell. It fumes strongly in the air. Its sp. gr. is 4·385.

Chemical Properties.—It is exactly similar to hydrochloric and hydrobromic acids in its chemical relations and properties; it cannot easily be distinguished from them, except that chlorine or bromine decomposes it, disengaging the purple vapours of iodine. It is very soluble in water. With metallic oxides it forms water and a class of salts called iodides.

Preparation.—The gaseous acid is best obtained by gently heating a mixture of one part of phosphorus and sixteen of iodine, stratified with moistened sand or powdered glass, in a small tube. A solution of the acid is easily prepared by suspending iodine in water, and passing sulphuretted hydrogen through it until all the iodine is combined with hydrogen, which is accomplished when the brown colour has disappeared. The following is the reaction:—

$$H\,S + I = H\,I + S.$$

FLUORINE.

Symbol, F; *Equivalent*, 19; *Theoretical density*, 1·31.

541. This element, owing to its powerful affinities, has never yet been isolated, for as soon as it is separated from one substance, it instantly combines with another. Vessels of fluor spar ($Ca\,F$) are the only ones which have yet been found capable of withstanding its action. It is found in the mineral kingdom, principally combined with calcium, as fluor or Derbyshire spar. The bones of animals, especially the enamel of teeth, contain small quantities of fluoride of calcium.

Fluorine is the only element which has not been combined with oxygen.

COMBINATION OF FLUORINE WITH HYDROGEN.

542. HYDROFLUORIC ACID ($H\,F$). PHYSICAL PROPERTIES.—This acid is a colourless gas, strongly acid and corrosive; a drop on the skin burns it like red-hot iron, and causes a painful sore, not easily healed.

CHEMICAL PROPERTIES.—This acid is distinguished from all others by dissolving insoluble silicic acid, and the silicates, which are insoluble in other acids; on this account it cannot be prepared or kept in glass vessels. The silicic acid and the hydrofluoric acid are mutually decomposed, fluoride of silicon ($Si\,F_3$) and water being formed. With metallic oxides it forms water and a class of salts called fluorides. It is frequently employed to etch glass.

PREPARATION.—It is obtained by acting on fluoride of calcium with sulphuric acid; it must be prepared in metallic vessels.

SULPHUR.

Symbol, S; *Equivalent*, 16; *Specific gravity of vapour*, 6·6117.

543. PHYSICAL PROPERTIES.—It is a pale yellow-coloured solid, with a slight peculiar odour. It melts at 239° F.; in close vessels it may, by increasing the heat, be distilled. its boiling point being about 824° F.; when heated to between 450° and 500° F., in contact with the air it takes fire, burning with a blue flame. "It crystallizes into two distinct and irreconcileable forms; it is thus dimorphous; and it occurs besides in an altogether amorphous

state when heated to 500° F., and thrown into cold water. These three states of sulphur are called different allotropic modifications of that element." In its elementary state, it is met with in large quantities in volcanic districts. It exists in combination with silver, lead, antimony, zinc, iron, &c., in considerable quantities,—the principal ores of the first four being their sulphides, whilst iron forms with sulphur the well-known mineral, iron pyrites (bisulphide of iron, $Fe S_2$). As sulphuric acid, it is met with in combination with baryta, lime, magnesia, and other metallic oxides. It is also an important constituent of many animal and vegetable substances. It occurs in commerce in two states—roll sulphur, which has been melted and run into moulds, and flowers of sulphur, which is a crystalline powder, formed by the sudden condensation of sulphur vapour. There is also another form, called milk of sulphur, or precipitated sulphur, which is employed exclusively in medicine. It is a very light powder, nearly white, and is prepared by decomposing an alkaline sulphide by an acid.

Chemical Properties.—It is insoluble in water, soluble in alcohol, ether, oils, bisulphide of carbon, &c. The affinities of sulphur are powerful; it combines directly with carbon at a red heat, sulphide of carbon being produced. It combines indirectly with hydrogen. Its combustion in air is due to its combination with oxygen, sulphurous acid ($S O_2$) being produced. Most metals, when heated along with sulphur, combine with it, the combination being accompanied with a development of heat and light; sulphur, like oxygen, frequently forms several compounds with the same metal, so that we may have monosulphides, bisulphides, tersulphides, &c. Some of the metallic sulphides possess basic properties, others possess acid properties; the two combine together and form sulphur salts.

COMBINATIONS OF SULPHUR WITH OXYGEN.

544. Sulphur forms a great number of compounds with oxygen. Seven of these are now well ascertained, and they are all acid bodies, viz.:—

1. Hyposulphurous, or dithionous acid	$S_2 O_2$
2. Trisulpho-hyposulphuric, or pentathionic acid	$S_5 O_5$

3. Bisulpho-hyposulphuric, or tetrathionic acid… S_4O_5
4. Monosulpho-hyposulphuric, or trithionic acid S_3O_5
5. Sulphurous acid …………………………………… SO_2
6. Hyposulphuric or dithionic acid ……………… S_2O_5
7. Sulphuric acid (oil of vitriol) …………………HO, SO_3

545. SULPHUROUS ACID (SO_2). PHYSICAL PROPERTIES. —A colourless gas, which has a smell of burning sulphur. It is liquefied by surrounding the vessel containing it with a mixture of snow and salt; at 105° F. it freezes, forming a transparent, colourless, crystallized solid. Its sp. gr. is 2·247.

CHEMICAL PROPERTIES.—It is very soluble in water. It is not decomposed by heat. It will not combine with dry oxygen, therefore it will not burn in the air; it does not support respiration. Dissolved in water it becomes slowly converted into sulphuric acid; it is also converted into this body by chromic acid and other oxidizing bodies, and also in the presence of porous substances. It possesses weak acid properties. It combines with the bases, forming a class of salts called sulphites. It possesses considerable bleaching properties, and is much used for bleaching straw and wool.

PREPARATION.—*First method.*—Burn sulphur in the air or oxygen gas. *Second method.*—Heat copper or mercury with sulphuric acid in excess.

$$Cu + HO, SO_3 = CuO, SO_3 + HO + SO_2.$$

Charcoal can be substituted for the copper or mercury, but in this case the sulphurous acid is accompanied by one-half its volume of carbonic acid.

546. SULPHURIC ACID (HO, SO_3). PHYSICAL PROPERTIES.—The anhydride (SO_3) is a white crystalline solid; it melts at 65° F., and boils at about 110° F. The hydrate (HO, SO_3) is a colourless, oily, odourless liquid; it boils at 640° F., and freezes at about 30° F. The density of ordinary sulphuric acid of commerce is 1·842.

CHEMICAL PROPERTIES.—The anhydride possesses no acid properties; it fumes in the air, and is very deliquescent; when thrown into water it hisses as a hot iron would do from the heat emitted. The hydrate is a powerful acid; it chars almost all organic substances, from its powerful affinity for moisture. With water it mixes completely in all proportions: great heat is given out the moment the mixture is made, and the mixture, when col occupies less bulk than the two liquids did separately. It does not evaporate at the ordinary temperature of the air. The acid of commerce is often of a dark brown colour, occasioned by its charring action on fragments of organic matter, such as straw or wood, which have accidentally fallen into it. It combines with bases, forming a class of salts called sulphates.

Preparation of the ordinary acid.—Sulphurous acid ($S\,O_2$), deutoxide of nitrogen ($N\,O_2$), and air, are brought together in a proper chamber, the bottom of which is covered with water; peroxide of nitrogen ($N\,O_4$) is formed by the deutoxide combining with the oxygen of the air; a white crystalline substance is then formed, into the composition of which sulphurous acid, peroxide of nitrogen, and water enter. Water decomposes this crystalline substance into deutoxide of nitrogen and sulphuric acid; the liberated deutoxide of nitrogen passes into the atmosphere, and goes through the same round of combinations and decompositions, till the whole of the oxygen in the air has been consumed.

547. The hyposulphurous acid is the only other oxygen compound of sulphur which has any practical importance. In combination with soda, it has been largely employed in fixing photographic pictures, owing to the property it possesses of dissolving the insoluble salts of silver.

COMBINATIONS OF SULPHUR WITH HYDROGEN.

Sulphuretted hydrogen, or sulphide of hydrogen...	$H\,S$
Bisulphide of hydrogen..................................	$H\,S_2$

548. Sulphuretted Hydrogen; *Hydrosulphuric Acid* ($H\,S$). Physical Properties.—A colourless gas, of an intolerable odour, resembling that of rotten eggs. It liquefies under a pressure of 16 atmospheres, and the liquid freezes at a temperature of 122° F. The sp. gr. of the gas is 1·1912.

Chemical Properties.—Water dissolves two or three times its bulk of this gas. The solution is decomposed by keeping; the oxygen of the air combining with the hydrogen, the sulphur being set free. It is decomposed slowly in the air in the cold, but at a high temperature with combustion, water and sulphurous acid being formed.

Sulphurous acid and this gas mutually decompose one another. It is exceedingly poisonous. It is a feeble acid; with metallic oxides it forms water, and a class of salts called sulphurets or sulphides.

PREPARATION.—Decompose sulphide of iron ($Fe\,S$) with dilute sulphuric acid in the cold; the following is the reaction:—

$$Fe\,S + H\,O,\,S\,O_3 = H\,S + Fe\,O,\,S\,O_3.$$

PHOSPHORUS.

Symbol, P; *Equivalent*, 31; *Specific gravity of the vapour*, 4·355.

549. PHYSICAL PROPERTIES.—This element at ordinary temperatures is a solid substance resembling that of wax. It fuses at 111·5° F.; in close vessels it boils at 550° F., giving off a colourless gas. Its sp. gr. is 1·83.

It is found both in the animal, vegetable, and mineral kingdom, principally as phosphoric acid, and in union chiefly with lime and magnesia. It is always prepared from bones, which consist almost entirely of phosphate of lime; it is used in large quantities in the manufacture of lucifer matches.

CHEMICAL PROPERTIES.—It has a very great affinity for oxygen. When exposed to the air it undergoes a slow combustion, which is attended with a pale greenish light, and with the production of white fumes and a garlic odour; it is therefore always preserved under water, in which liquid it is insoluble. It takes fire in the open air at a temperature little above its fusing point. It is easily soluble in bisulphide of carbon.

PREPARATION.—Superphosphate of lime ($Ca\,O,\,2\,H\,O,\,P\,O_5$) is mixed with carbon and distilled; phosphate of lime ($3\,Ca\,O,\,P\,O_5$) is formed, which remains in the retort; the rest of the phosphorus is deprived of its oxygen by the carbon, and the phosphorus thus set free distils over, and is collected in appropriate receivers.

COMBINATIONS OF PHOSPHORUS WITH OXYGEN.

550. Phosphorus forms four compounds with oxygen, three of which are acids, viz.:—

1. Phosphoric acid	$P\,O_5$
2. Phosphorous acid	$P\,O_3$
3. Hypophosphorous acid......................	$P\,O$
4. Oxide of phosphorus	$P_2\,O$

551. Phosphoric Acid.—The anhydride (PO_5) does not possess acid properties; it is a snow-white solid; it has a very great affinity for water, and passes by degrees into the hydrated state. There are three different hydrates of phosphoric acid, each of which possesses the properties of a distinct acid, forming a distinct class of salts, viz.:—

Tribasic phosphoric acid	$3HO, PO_5$
Bibasic phosphoric acid	$2HO, PO_5$
Monobasic phosphoric acid	HO, PO_5

For a description of them, we must refer the student to the larger works on Chemistry.

552. Phosphides of Hydrogen.—The compounds of phosphorus with hydrogen are not possessed of acid characters; they are three in number, viz., H_3P; H_2P; and HP_2. The first is gaseous, the second liquid, and the third solid, at ordinary temperatures. The gaseous compound has been proved recently, by Hoffman, to be a base, allied to ammonia.

CARBON.

Symbol, C; *Equivalent,* 6; *Specific gravity as diamond,* 3·33 *to* 3·53.

553. Physical Properties.—An infusible non-volatile solid. It does not alter at common temperatures in contact with air. It is met with in nature both crystallized and uncrystallized. In its crystallized state it constitutes the diamond; and when uncrystallized, the black lead used in the manufacture of pencils. It is also obtained as an article of commerce from several of its compounds; and according to the source and mode of preparation, passes under the names of lamp black, bone or ivory black, soot, charcoal, &c. As diamond, it is quite infusible, and is the hardest body known.

Chemical Properties.—It is insoluble in water, and all other liquids. Its affinity for oxygen, at a red heat, exceeds that of almost all other bodies; hence, when heated in the open air, it takes fire by combining with the oxygen, carbonic acid (CO_2) being produced. It is one of the chief elementary constituents of all animal and vegetable substances. Prepared from animal substances, it possesses the property of rendering coloured liquids colourless; on this account large quantities of bone black are employed in sugar refining. Animal and wood charcoal possess the power of destroying offensive odours, they are therefore employed to purify tainted meat, water, &c.

COMBINATIONS OF CARBON WITH OXYGEN.

554. Carbon forms several compounds with oxygen, of which we shall notice only the three most important:—

1. Carbonic acid	CO_2
2. Carbonic oxide	CO
3. Oxalic acid	C_2O_3

The first two are gaseous at ordinary temperatures; and the third has not been isolated, being only known in combination with water or bases.

555. Carbonic Acid; *Fixed Air; Mephitic Acid* (CO_2). Physical Properties.—It is a non-permanent, colourless, inodorous gas. It is liquefied at 32° F., under a pressure of 36 atmospheres. The evaporation of the liquid acid produces so much cold as to freeze a part of the acid into a white solid like snow. Its density is 1·529.

Chemical Properties.—It is incombustible and irrespirable; it will not support combustion. It is produced in the combustion of fuel, and the respiration of animals. It is absorbed and decomposed by plants, under the influence of light. It is always produced when carbon is burnt in a sufficient quantity of air or oxygen. It is soluble in water at the ordinary temperature; water takes up about two-thirds of its bulk of the acid, and if the pressure be increased, its solubility increases (Ex.—Soda water). It is a feeble acid, so that it is expelled from its compounds by almost every other acid; it combines with bases, forming a class of salts called carbonates.

Preparation.—Decompose carbonate of lime (CaO, CO_2) by hydrochloric acid; the following reaction takes places:—

$$CaO, CO_2 + HCl = CO_2 + CaCl + HO.$$

556. Carbonic Oxide (CO). Physical Properties.—It is a permanent, colourless, inodorous, and insipid gas. Its density is 0·967.

CHEMICAL PROPERTIES.—It is very slightly soluble in water. It is neutral to test. It is very poisonous. It neither supports combustion nor respiration. It burns in the air or oxygen with a blue flame, carbonic acid being produced. It is formed whenever carbon is burnt in a deficiency of air or oxygen. It unites with chlorine on exposing a mixture of these two gases to sunlight, a compound chloro-carbonic acid ($CO\,Cl$) being formed.

PREPARATION.—Heat oxalic acid with sulphuric acid, the following is the reaction:—

$$HO, C_2 O_3 + HO, SO_3 = CO + CO_2 + 2\,HO, SO_3$$

557. OXALIC ACID ($HO, C_2 O_3$).—This acid exists in a great number of vegetables. It is prepared artificially by boiling sugar with slightly dilute nitric acid, which, by yielding a portion of its oxygen, evolves deutoxide of nitrogen and carbonic acid, while oxalic acid remains in the liquid, from which it crystallizes on cooling. The formula of the crystallized acid is $C_2 O_3, 3\,HO$.

COMBINATIONS OF CARBON WITH HYDROGEN.

558. The compounds of carbon and hydrogen are very numerous. We shall describe two.

559. LIGHT CARBURETTED HYDROGEN; *Marsh Gas; Fire Damp* (CH_2 or $C_2 H_4$). PHYSICAL PROPERTIES.—A permanent, colourless, inodorous gas. Its density is 0·556.

CHEMICAL PROPERTIES.—It neither supports combustion nor respiration. It burns in the air and oxygen, forming water and carbonic acid. It forms an explosive mixture with air and oxygen (see par. 41, page 20). It is disengaged in stagnant pools, and it is one of the principal constituents of coal-gas. It also occurs abundantly in many coal mines.

PREPARATION.—It may be formed artificially by heating an acetate ($MO, C_4 H_3 O_3$) with an excess of hydrate of baryta. The following is the reaction:—

$$MO, C_4 H_3 O_3 + Ba\,O, HO = 2\,CH_2 + Ba\,O, CO_2 + MO, CO_2.$$

560. OLEFIANT GAS ($C_2 H_2$ or $C_4 H_4$). PHYSICAL PROPERTIES.—It is a transparent, colourless gas, of an etherial odour. Its density is 0·978.

Chemical Properties.—It does not support combustion nor respiration. It burns in air and oxygen, forming water and carbonic acid. It forms, with air and oxygen, explosive mixtures. It is decomposed at high temperatures. It is insoluble in water, and it is a neutral body. It occurs in the gaseous mixture of coal mines, and is one of the principal gases in the common street gas.

Preparation.—It is prepared by heating 1 part of strong alcohol with 4 parts of oil of vitriol.

COMBINATION OF SULPHUR WITH CARBON.

561. Sulphide of Carbon, or Sulphocarbonic Acid ($C S_2$). Physical Properties.—It is a very mobile, colourless liquid, of a disagreeable odour. It does not solidify. It is exceedingly volatile. It boils at 118·5° F. Its density is 1·29.

Chemical Properties.—It is insoluble in water, but very soluble in alcohol and ether. It burns in air and oxygen, forming carbonic acid and sulphurous acid. It is neutral to vegetable colours. It has certain analogies with carbonic acid. It dissolves sulphur and phosphorus. These substances can be obtained crystallized, by allowing the solution to evaporate spontaneously. It is employed for vulcanizing caoutchouc and gutta percha.

COMBINATION OF CARBON WITH NITROGEN.

562. Cyanogen ($C_2 N = Cy$). Physical Properties.—A colourless gas, of a penetrating odour. It is liquefied by a pressure of about 4 atmospheres. It freezes at 30° F. Its density is 1·86.

Chemical Properties.—It dissolves in water, and still more freely in alcohol. It has no action upon vegetable colours. It burns in the air and oxygen with a characteristic purple flame. It is poisonous if respired. It plays the part of a simple body analogous to chlorine.

Preparation.—Prepared by decomposing cyanide of mercury ($Hg Cy$) by heat.

563. Hydrocyanic Acid; *Prussic Acid* ($H, C_2 N = H Cy$). Physical Properties.—It is a colourless, transparent, and very volatile liquid; it boils at 80° F., and

freezes at 5° F. It evaporates so rapidly, that if a drop be allowed to fall upon a glass plate, part of it becomes frozen by the cold produced by its own evaporation. It has the smell of peach blossoms, and is intensely poisonous. Its sp. gr., 0·9476.

Chemical Properties.—It speedily decomposes into formiate of ammonia ($N H_4 O, C_2 H O_3$) if exposed to diffuse daylight. It is a feeble acid; it combines with bases, forming a class of salts called cyanides.

564. The student is referred to the larger works on Chemistry for a description of boron and silicon, and their compounds.

CHAPTER XXIII.

GENERAL PROPERTIES OF THE METALS.*

It will be seen, by consulting the Table of Elements, that the metals are much more numerous than the non-metallic elements, from which class they are separated by being good conductors of heat and electricity, and possessing what is termed metallic lustre. In their other physical characters and chemical properties the metals exhibit great variety, by reason of which their applications are various. We may subdivide the metals, from their applications, into the following classes:—1. Metals which cannot be employed in the arts in the metallic state. 2. Metals which admit of being employed in the metallic state.

The metals in the first class possess a very great affinity for oxygen, speedily uniting with that element when exposed to the air; in consequence of this property they cannot be employed in the arts in the metallic state, but only in combination with the metalloids. The metals in this class are,—

Potassium	Barium	Calcium
Sodium	Strontium	Magnesium

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* The principal part of the general properties of the metals has been extracted from the "Cours Elémentaire de Chemie," par M. V. Regnault.

The metals in the second class do not alter by exposure to the air at ordinary temperatures. These are,—

Manganese
Iron
Cobalt
Nickel
Chromium
Zinc
Cadmium
Copper
Lead
Bismuth
Mercury
Arsenic
Tin
Antimony
Silver
Gold
Platinum
Palladium

The metals in the second class are numerous, but they cannot receive any extended application in the arts, unless they possess a certain degree of malleability and ductility, for without these properties it would be impossible to work them and give them the desired shapes. And it is likewise necessary that the natural material from which the metal is extracted is not too rare or too difficult to treat; otherwise the metal becomes costly, and is therefore not employed, excepting in those cases where it cannot be replaced by a cheaper metal. Thus, the metals iron, manganese, nickel, and cobalt, possess similar properties; but the ores of iron being much more abundant than the ores of the other metals, and the metal being likewise more easily extracted, the iron is naturally preferred to the other three, when it can be used for the same purposes. Manganese is likewise a more oxidizable metal than iron, and is therefore altered more rapidly in contact with air, which also renders it incapable of being substituted for that metal. But nickel is less oxidizable, and as it possesses a malleability nearly equal to that of iron, it would on these accounts replace that metal in a number of its applications if it could be extracted from its ores at less cost. At present, nickel is especially employed when a metal resembling silver in colour is required, as it rivals that metal in whiteness and brilliancy. Antimony and bismuth cannot be employed by themselves in their metallic state, for they are so brittle that they can be powdered in a mortar. But combined with the malleable metals they can be rendered useful, the mixed metals possessing particular physical properties.

The metals exist in nature in different states. Some are met with in their pure metallic state, which is called their *native state*. All those metals which have a feeble affinity for oxygen, and are not altered by atmospheric agents, are found in this state. Such are gold, platinum, palladium, silver, mercury, and bismuth. Many of the others, as well as silver, mercury, and bismuth, are found in combination with oxgen, sulphur, or arsenic. These are, manganese, iron, cobalt, nickel, chromium, zinc, cadmium, copper, lead, tin, and antimony. Some of these last are found in the state of insoluble salts, principally in the state of silicates and carbonates. The metals in the first class are never met with in their metallic state, but always in the form of salts, which are frequently insoluble.

PHYSICAL CHARACTERS OF THE METALS.

The physical characters of the metals we shall notice are, their colour, specific gravity, malleability, ductility, fusibility, and volatility.

COLOUR.—The metals exhibit great difference in colour; the majority are of various shades of bluish-white or grey, whilst gold is yellow and copper red.

SPECIFIC GRAVITY.—The metals vary much as regards density, platinum being 21 times heavier, and gold being 19 times heavier, than an equal bulk of water; whilst others, as potassium and sodium, are lighter than that liquid.

MALLEABILITY AND DUCTILITY.—Malleability is that property which renders metals capable of being rolled or beaten out into thin sheets, and ductility that by which they can be drawn out into fine wires. Gold is the most malleable of metals; one grain of it may be extended so as to cover about 52 square inches of surface, and to have a thickness not exceeding $\frac{1}{28202}$nd of an inch. Silver, copper, and tin rank next in malleability. A metal which is not malleable cannot be ductile, but the most malleable metals are not always the most ductile; platinum and even iron can be obtained in finer wire than gold. Wollaston obtained a platinum wire so small that in diameter it did not exceed $\frac{1}{3000}$th of an inch. The malleability and ductility of metals vary with the temperature. Thus zinc, which is malleable and ductile at 300°, loses this power but remains tough at 60°, whilst at 600° it becomes so brittle that it powders as easily as bismuth.

FUSIBILITY.—"All the metals, with the exception of mercury, are solid at common temperatures; but they may be all liquefied by heat. The degree at which they fuse, or their point of fusion, is very different for different metals, as appears from the following table:—

TABLE OF THE FUSIBILITY OF DIFFERENT METALS.

Fusible below a red heat.	Mercury		39° F.
	Potassium		136
	Sodium		190
	Tin		442
	Bismuth		497
	Lead		612
	Arsenic Cadmium	undetermined.	
	Zinc		773
	Antimony—a little below red heat.		
	Aluminum—above a red heat.		
Infusible below a red heat.	Silver		1873° F.
	Copper		1996
	Gold		2016
	Iron, cast		2786
	Iron, malleable Manganese	Requiring the highest heat of a smith's forge.	
	Cobalt—rather less fusible than iron.		
	Nickel—nearly same as cobalt.		
	Palladium Chromium	almost infusible, and not to be procured in buttons by the heat of smith's forge.	Fusible before the oxy-hydrogen blowpipe.
	Platinum—infusible in the heat of a smith's forge, but fusible before the oxy-hydrogen blowpipe.*		

Volatility. Many of the metals admit of being volatilized without difficulty. Even those metals which are generally considered fixed in the fire are likewise found to be volatilizable to a certain extent when exposed to the greatest heat of our furnaces.

CHEMICAL PROPERTIES OF THE METALS.

Action of Oxygen upon the Metals.—All the metals, without a single exception, combine with oxygen; but

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* Turner's "Chemistry," p. 347.

their affinities for that body are very different. Thus, potassium, sodium, and some other metals, combine directly with that metalloid at the lowest temperature; whilst gold, platinum, and some others, possess such a feeble affinity for it, that they do not combine directly with it under any circumstances. The oxides of these metals can only be obtained, therefore, by indirect processes. The first retain oxygen at the most elevated temperatures, whilst the second abandon it easily when their oxides are heated.

The affinity of metals for oxygen can be ascertained in several ways :—

1. By their behaviour with oxygen gas at different temperatures.

2. By the greater or less difficulty with which their oxides are reduced to the metallic state.

3. By the decomposing action which they exercise upon the same oxide under different circumstances. Water is the oxide upon which they are ordinarily made to act. Certain metals decompose water even at the temperature of 32° F.; others do not decompose it in appreciable quantity below 120°; some require even a temperature of 212°; others only decompose the vapour of water at a red heat, or at still more elevated temperatures; whilst others, again, do not decompose it at any temperature which can be obtained in laboratory furnaces.

4. By the decomposing action which the metals exercise upon water in the presence of powerful acids. A great number of metals decompose water in the cold in the presence of sulphuric acid; others, on the contrary, do not decompose it at all under these circumstances, even when the temperature is raised. This property does not depend solely upon the more or less powerful affinity which metals possess for oxygen; it depends especially upon the affinity which the metallic oxide has for the acid.

The metals can, in this point of view, be divided into six sections.

First Division.—Metals which possess the property of absorbing oxygen at all temperatures, even at the highest, and of decomposing water at the lowest, the decomposition being attended with an abundant disengagement of hydrogen gas. These are,—

Potassium, sodium, barium, strontium, calcium.

The first two are called alkaline metals; the last three, metals of the alkaline earths.

Second Division.—Metals which absorb oxygen at the highest temperatures, and whose oxides are not decomposed by heat alone, do not decompose water to any appreciable extent at very low temperatures, but easily above 122°. These are,—

Magnesium, manganese.

Third Division.—Metals which absorb oxygen at a red heat, whose oxides are not decomposed by heat alone, and which decompose water only at temperatures superior to 212°, but inferior to a red heat. These metals decompose water in the cold in the presence of strong acids. These are,—

Iron, nickel, cobalt, chromium, zinc, cadmium.

The temperature at which these metals combine with gaseous oxygen, and that at which they decompose water, depends much upon their state of division. Iron, even in the state of filings, does not oxidize in an atmosphere of dry oxygen unless it be heated to dull redness, whilst in the very finely divided state in which it is obtained in reducing the oxides of iron by hydrogen gas at the lowest possible temperature, it takes fire when brought in contact with the atmosphere, consequently oxidizing at the ordinary temperature. Iron in the mass does not decompose the vapour of water below a red heat, whilst in a finely divided state it decomposes it at about 392°.

Fourth Division.—Metals absorb oxygen at a red heat, and their oxides are not decomposed by heat alone. These metals decompose the vapour of water with facility at a red heat, but they do not decompose it in the presence of energetic acids. This is owing probably to their oxides possessing more an acid than a basic character. Thus they decompose water in the presence of potash with disengagement of hydrogen gas. This division contains,—

Arsenic, tin, antimony.

Fifth Division.—Metals absorb oxygen at a red heat, but their oxides are not decomposed by heat alone. They decompose water only at very elevated temperatures, and even then very feebly. These metals do not decompose water in the presence of strong acids or bases. These are,—

Copper, lead, bismuth.

Sixth Division.—Metals whose oxides are reduced by heat alone at a temperature more or less elevated, and which do not decompose water under any circumstances. These are,—

Mercury, silver, gold, platinum, palladium.

Action of Sulphur upon the Metals.—All the metals are capable of combining directly with sulphur when they are heated with this metalloid, or when the vapour of it is made to pass over the ignited metal. Copper and some other metals burn in the vapour of sulphur with vivid incandescence. Others combine with it even at ordinary temperatures, if water be present. If a mixture of iron filings and flowers of sulphur be moistened with a little water, they combine together, the combination being attended with a considerable evolution of heat. The sulphides of the metals of the alkalies and alkaline earths are frequently prepared by mixing powdered charcoal with their sulphates, and heating the mixture strongly. The charcoal, at the high temperature to which the mixed mass is subjected, removes the whole of the oxygen, leaving the sulphur of the sulphuric acid and the metal of the oxide in combination.

Action of Chlorine upon the Metals.—Chlorine acts upon the metals more energetically than oxygen, and transforms them easily and completely into chlorides. The greater number of the metals combine with this element, even in the cold. Many of the metals, if in a state of fine division, take fire when projected into an atmosphere of chlorine, a chloride of the metal being formed.

Combination of Metals with Metals.—The compounds of metals with metals are called alloys, but when mercury is a constituent they are called amalgams. The point of fusion of an alloy is frequently inferior to that of the most fusible metal which enters into its composition. Thus:—

Lead melts at	612° F.
Bismuth	509
Tin	442

An alloy formed of 5 parts of lead, 3 of tin, and 8 of bismuth, melts below 212°, which is far below the melting point of the most fusible metal. This alloy is called Newton's fusible metal.

ACTION OF ACIDS UPON THE METALS.

The following metals dissolve in hydrochloric acid and dilute sulphuric acid with evolution of hydrogen, a chloride being formed in the one case, and a sulphate in the other. They dissolve likewise in dilute nitric acid, a nitrate being formed and hydrogen evolved; but if concentrated acid be employed, the gas evolved is binoxide of nitrogen (NO_2):—

Manganese, iron, cobalt, nickel, chromium, zinc, cadmium.

The following metals dissolve in hydrochloric acid with evolution of hydrogen, a chloride of the metal being formed. Dilute sulphuric acid converts them slowly into sulphates, which is attended with a disengagement of hydrogen. Concentrated sulphuric acid dissolves them energetically, a sulphate being formed and sulphurous acid expelled. These are,—

Antimony, tin, arsenic.

Metals which are not attacked by dilute sulphuric acid, but the concentrated acid converts them into sulphates, sulphurous acid being formed. Nitric acid converts them into nitrates, binoxide of nitrogen being evolved. Boiling concentrated hydrochloric acid has little or no action upon them, with the exception of mercury:—

Copper, lead, bismuth, mercury, silver.

Sulphuric, nitric, and hydrochloric acids are without action upon the following metals; they are dissolved and converted into chlorides by a mixture of hydrochloric and nitric acids, which mixture is therefore frequently called aqua regia:—

Gold, platinum, palladium.

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