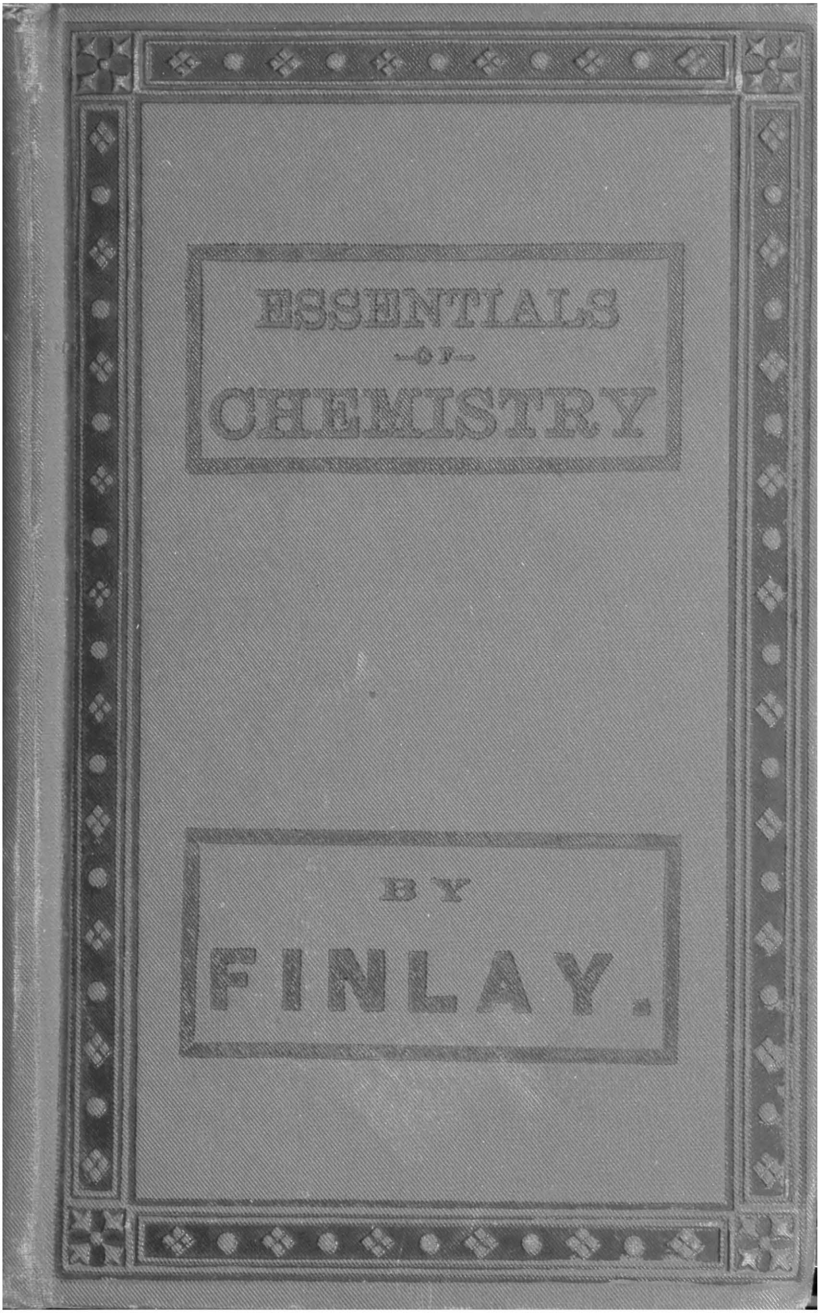

ESSENTIALS
OF
CHEMISTRY

BY

FINLAY.

THE ESSENTIALS

OF ELEMENTARY

Chemistry and Chemical Physics,

FOR THE ASSISTANCE OF

High School Students and Intermediate Candidates,

COMPILED AND COLLATED

BY

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OF

THE SCIENCE AND ART DEPARTMENT

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PREFACE.

THE *raison d'être* of this little book is as follows: The compiler has, during some years, been obliged, for lack of a suitable handbook, to give to his large classes in Chemistry copious explanatory notes and definitions. This practice has at length become such a serious task that, in self-defence, he has sought relief by resorting to publication.

Unless a compiler be the veriest literary mechanic his work can hardly fail to bear some impress of his own distinctive method of imparting instruction, and the experience of the writer, in the past, encourages him to hope that he is contributing a not unwelcome aid to a large and increasing class of students, in the Collegiate Institutes and High Schools of Ontario.

The matter of the work has been evolved in its present form from a great number of notes collected at various times from many sources, but in every case from good authorities on the subject treated of.

These notes have been so condensed and altered, for convenience sake, that they are to all intents original as to *shape*, but the essential *matter* of the authors consulted has been carefully retained. The following are the principal authorities whose works have been utilised, or collated: Ansted, Tyndall, Ganot, Gerhardt, Ure, Hoffmann, Frankland and Bloxam. Especially to the personal and invaluable tuition of his sometime teachers—Professors Tyndall and Frankland, and to the valuable treatises of Professor Bloxam—is the compiler indebted. In two important points the work will be found to differ from most elementary handbooks, viz :—the absence of illustrations, and the paucity of detailed experiments. As regards illustrations, the opinion of the writer is that, except in large and technical manuals, they are almost useless, and quite unnecessary, since a teacher who knows his business can either illustrate his lecture by dashing off a rough sketch on the black-board, or, better still, can rig up apparatus before the student, thereby obviating the necessity for superfluous encroachments upon the space which ought to be devoted to the letter-press, as well as materially reducing the cost of the work. The same objection applies, in a less degree perhaps, to lengthy details of experiments; such details are no doubt very proper and necessary in large manuals, but, for class work, the teacher ought to know the details thoroughly, and, in such a course of study as the present handbook is intended to cover, it is from him that the student has a right to expect them, illustrated at the same time, by the actual performance of all such experiments as the teacher's apparatus permits of.

This is the writer's own practice, with the addition that he insists on the performance of the experiments, under his direction, by the students themselves; as well as on verbal and written description of the experiments forming a portion of the ordinary class work.

It is difficult to understand what objection can be made to such a substitution of practical work for mere book-work, except by such teachers as those referred to by Professor Bloxam, "who have themselves never had the opportunity of learning how to conduct the simplest chemical operation." The following remark of the same author is so much to the point that it may be quoted entire: "To acquire a knowledge of the rudiments of Chemistry by personal observation, has, without doubt, a very beneficial effect; but to *get up* a number of formulæ and equations, with the sole object of gaining a certain number of marks at examination, altogether defeats the object with which Chemistry should be introduced into a system of liberal education." The introduction of tables of tests for the more important elements, acids and gases, and the addition of the Intermediate and other professional examination questions will, the compiler feels assured, be fully appreciated by students. With regard to these questions, it has not been the design to adopt a mechanical method of question and answer, but, except in special cases, simply to assist the student in finding the answers for himself, by directing him to the paragraphs where they will be found.

In conclusion, the following merits are claimed for this juvenile addition to the literature of technical education. First,—It represents the latest results of the labours of the highest authorities in chemical and physical science. Second,—It contains a larger amount of information on the subjects treated of than any other book of the same moderate compass and price; and, Third,—It has been compiled with a special view to meet the requirements of Ontario professional students. How far these requirements have been met, it is now left to the class interested to decide.

A. W. A. F.

Brantford, February, 1880.

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(The numbers refer to paragraphs).

Intermediate Exam. Papers. A selection of questions from the examination papers of First-class candidates.

Preliminary Definitions.

1. **Matter** is anything which possesses weight; whatever, therefore, is subject to the law of gravitation is material in its nature.

2. **The volume** of any body of matter is the space occupied by it.

3. **The density of a body** is the relative closeness of the particles of matter of which it is composed.

4. **The mass of a body** is the whole quantity of matter contained in it.

5. **Cohesion** is a force acting between the particles of the same kind of matter at inappreciable distances, serving to unite and retain them in contact with each other.

7. **Adhesion** is a force acting at inappreciable distances, which retains the particles of dissimilar bodies in contact with each other.

7. **Matter** exists in three different conditions—solid, liquid, and gaseous. Liquids and gases are included also under the name of fluids. Liquids may be practically defined as incompressible, and gases as compressible fluids. The solid state is characterised by such cohesion between the material particles, that they can only be separated by an effort, more or less considerable. In the liquid state, the cohesion of the particles is so weak that they can easily move over, and about one another. In the gaseous state the cohesion of the particles is entirely overcome, and, in its stead, there is a constant tendency to separation, which causes expansion to be a marked characteristic of this condition of matter.

8. **Every separated portion of matter** is found, on examination, to be either an elementary substance, or a compound substance.

9. **An element** is that form of matter which cannot be reduced to a simpler form.

10. **A compound** is that form of matter which can be resolved into two, or more, constituent elements.

11. **The ancients** recognized four elements, or, more correctly speaking, four types of elements: Earth, Air, Water, and Fire. With earth, were classed all solids. With air, were classed—smoke, steam, and everything of an aëriform nature; with water, all liquids; and with fire,—light, heat, flame, lightning and all similar phenomena.

12. There are, at present, 64 elements determined; and these for the sake of convenience, are classified as non-metals or metalloids, and metals, there being 15 non-metals and 49 metals. No strict line of demarcation is to be understood as existing between these two classes.

13. The following table exhibits the name, with its derivation; the symbol; combining weight; atomicity; discoverer, and date of discovery, when known; of each of the more important non-metals and metals. It is to be noted that the symbols of the elements are the inital letters of the *Latin* names, which are often different from the *vulgar* names; and when two, or more, elements have the same initial, a small letter is added to the initial, to distinguish between the elements symbolized.

NAME.	DERIVATION OF NAME.	SYMBOL.	COMB. WEIGHT.	ATOMICITY.	DISCOVERER.	DATE OF DISCOV'RY.
ALUMINIUM	L. alumen, alum	Al.	27·5	IV.	Wöhler	1828.
ANTIMONY	Gr. *anti*, against; *monos*, one	Sb.	122	V.	Basil Valentine	1500.
ARSENIC	Gr. *arsenikon*, potent	As.	75	V.	Brandt; Paracelsus	1733.
BARIUM	Gr *bărus*, heavy	Ba.	137	II.	Davy	1808.
BISMUTH	Ger. Weissmuth	Bi.	210	V.	Agricola	1529.
BORON	Arab. baraga, to shine	B.	11	III.	Guy-Lussac; Thénard,	1808.
BROMINE	Gr. *bromos*, a bad smell	Br.	80	I,	Balard	1826.
CADMIUM	Gr. *kadmeia*, calamine	Cd.	112	II.	Stromeyer	1817.
CALCIUM	L. calx, lime	Ca.	40	II.	Davy	1808.
CARBON	L. carbo, a coal	C.	12	IV.	Known to the ancients.	
CHLORINE	Gr. *chloros*, green	Cl.	35·5	I.	Scheele	1774.
CHROMIUM	Gr. *chroma*, colour	Cr.	52·5	VI.	Vauquelin	1797.
COBALT	Ger. Kobold, an evil spirit	Co.	59	VI.	Brandt	1733.
COPPER	L. Cyprium, Isle of Cyprus	Cu.	63·5	II.	Known to the ancients.	
FLUORINE	Fluor spar, name of mineral	F.	19	I.	Scheele	1771.
GOLD	Probably from Hebrew—to shine	Au.	196·5	III.	Known to the ancients,	
HYDROGEN	Gr. *hudor*, water; *gennao*, I produce	H.	1.	I.	Cavendish; Watt	1781.
IODINE	Gr. *ioeides*, violet coloured	I.	127.	I.	Courtois	1812.
IRON	Probably from Hebrew—to melt	Fe.	56	VI.	Known to the ancients.	
LEAD	Gr. *molubdos*, Galena, lead ore	Pb.	207.	IV.	Known to the ancients.	
MAGNESIUM	Magnesia, in Asia Minor	Mg.	24	II.	Davy	1808.
MANGANESE	Mangana, in East Indies	Mn.	55	VI.	Pott	1740.
MERCURY	Heathen god	Hg.	200	II.	Known to the ancients.	
NICKEL	Ger. Kuppernickel, false copper	Ni.	59	VI.	Cronstedt	1751.
NITROGEN	Gr. *nitron*, nitre; *gennao*, I produce	N.	14	III.	Rutherford	1772.
OXYGEN	Gr. *oxus*, acid; *gennao*, I produce	O.	16	II.	Priestley	1774.
PHOSPHORUS	Gr *phos*, light; *pherein*, to carry	P.	31	V.	Brandt	1669.
PLATINUM	Span. platina, little silver.	Pt.	197	IV.	Wood	1741.
POTASSIUM	Pot-ash, from its occurrence in plant—ash	K.	39·1	I.	Davy	1807.
SILICON	L. silex, flint	Si.	28	IV.	Berzelius	1823.
SILVER	Probably from Hebrew—money	Ag.	108	I.	Known to the ancients.	
SODIUM	Salsoda, name of a plant	Na.	23	I.	Davy	1807.
STRONTIUM	Strontian, place in Scotland	Sr.	87·5	II.	Davy	1808.
SULPHUR	L. sulphurium; Sanscrit, sulvari	S.	32	VI.	Known to tne ancients.	
TIN		Sn.	118	IV.	Known to the ancients.	
ZINC	Ger. Zinkin, nails.	Zn.	65·2	II.	Paracelsus	Doubtful.

14. **Chemistry** is the science by aid of which are investigated the inherent, or acquired properties of the elementary and compound substances, which make up the solid and liquid material of the globe, and its gaseous envelope; and by its means the chemist is enabled to resolve matter into its simplest constituents, and to combine the simple elements with each other so as to form compounds. Chemistry is likewise an art, since it enunciates certain rules and methods for effecting the objects above enumerated. It is divided into two branches—Organic, and Inorganic Chemistry.

15. **Organic Chemistry** treats of those substances which are formed by the operation of Animal, or Vegetable Life; as flesh, hair, wood, etc.

16. **Inorganic Chemistry** treats of those substances, which are formed without direct vital intervention; as limestone, salt, bleaching powder, etc.

17. The name Chemistry has been variously derived from—*Kyamon*, an Arabic word signifying "the substance, or constitution of anything"; *Chymos* (Gr.) "a juice"; or from *Chim*, or *Kim*, "darkness," the ancient name of Egypt; in which country, the science probably attracted attention at an early date.

18. A **Mechanical Compound** is one in which no union exists between the constituents, the particles simply lying side by side, without actual change in their characteristic properties.

19. A **Chemical Compound** is one in which two, or more elements are united together, forming a substance differing in most of its properties from those of its constituents, which have consequently lost their distinguishing characteristics.

20. For the explanation of many of the phenomena of chemical action, it has been found convenient to adopt what is called the **Atomic Theory** propounded by Dalton, in 1803. This theory is not to be regarded, in its entirety, as anything more than a convenient exposition of actual facts; and the laws, enunciated in connection with it, as regulating the combination and decomposition of substances, maintain their force, and truth, although the doctrine of atoms be abandoned. According to the Atomic Theory, all matter is built up of minute particles, incapable of further subdivision, which are termed atoms; and these atoms unite, among themselves, to form molecules. The atoms of an element are all equal in weight, and similar; but the atoms of one element are not necessarily of equal weight to the atoms of another element.

21. An **Atom** is the ultimate **chemical** particle of an element, or is the smallest portion which can enter into a chemical compound. It has been shown by Dr. Thomson, that a portion of lead, which cannot exceed the 888,000,000,000th of a cubic inch, is still visible; so that the hypothetical atom is, by no means, to be thought of as a tangible particle.

22. A **Molecule** is the ultimate **physical** particle of matter, and is an aggregation of atoms; being the smallest portion of an element, or of a compound, capable of an independent existence, or of taking part in a chemical reaction. Elementary molecules are supposed to contain two atoms, but phosphorus, arsenic, mercury, and cadmium are notable exceptions to this hypothesis, the molecules of the former two apparently

containing four atoms; and the molecules of the latter two containing one atom. The atoms of the elements all occupy the same space, in the gaseous condition, and hence the proportional weights of the elements may be ascertained experimentally, when they can be volatilized.

23. The molecule of a **compound** must be carefully distinguished from that of an element. Elementary molecules, with certain exceptions, have been said (22) to contain two atoms, but a molecule of a compound may be built up of two or more atoms; notwithstanding which it still occupies the space of one molecule or two atoms of an element in the gaseous condition, such as hydrogen. This fact may be enunciated as follows:—The molecule of matter, either elementary or compound, occupies in the gaseous condition the volume of two atoms, or one molecule of hydrogen. Thus in the examples HCl, H_2O, H_3N, H_4C, although there are two, three, four, and five atoms combined, the molecule really consists of two atoms, for these formulæ do not imply a mixture of $H + Cl$, $H + H + O$, etc., but express the combination of certain elements to form compounds differing in most of their properties from those of their constituent elements, and since condensation is a common result of chemical combination, it is found that the molecule H_4C, actually occupies the volume of $H + H$, and adopting, for the sake of convenience, the language of the atomic theory, the smallest conceivable portion of H_4C incapable of further subdivision, mechanically, could still be broken up by chemical means into its constituent atoms of hydrogen and car

24. The **Proportional weight, Combining weight,** or **Atomic weight** of an element is found by taking, as a unit, the weight of any known volume of a certain element, in the gaseous condition, and comparing the weight of an equal volume of every other element, in the same condition and at the same temperature, and barometric pressure, with the unit adopted. Whatever the unit may be, the resulting numbers will be proportional. Thus, if a pint of hydrogen gas be taken, and its absolute weight is found to be one grain, the weight of a pint of oxygen will be sixteen grains; the weight of a pint of nitrogen will be fourteen grains; and a pint of mercury in the gaseous condition will weigh 200 grains, etc. This **relative** proportion will evidently hold good, if any other standard of volume be adopted, as—a quart, a gallon, a cubic inch, a cubic foot, or a litre, that is, the **absolute** weights will differ, but not the **relative** weights. If now, it be agreed upon to take any volume of hydrogen, and call its weight 1, this becomes the unit of Atomic, or, more correctly, of Proportional weight; and although oxygen is in certain scales taken as the unit gas, hydrogen, being the lightest known element, is perhaps the most suitable for the purpose, and is the one commonly adopted.

25. In speaking of the combination of two or more elements it is possible to do so either with reference to the **weight** of the elementary atoms entering into the compound, or with reference to the **number** of atoms. Thus, in the compound H_2O, the elements combine in the proportion of 2 atoms or volumes H,

to 1 atom or volume O, or by weight in the proportion of 2 of H, to 16 of O, the ratio between the atom of H, and the atom of O, being 1 : 16. Again, in the compound $KClO_3$, by reference to the table of Atomic weights (13) it will be seen that the above symbols represent, not merely certain elements, but definite proportional quantities of the elements by weight. Thus:—K=39·1; Cl=35·5; $O_3 = 16 \times 3 = 48$; therefore $KClO_3$ expresses a combination by weight of 39·1 + 35·5 + 48, but by atom or volume 1 + 1 + 3.

26. **The force** which causes different elements to unite, to form new substances, is called **Chemical Attraction,** and the act of union is called **Chemical Combination.** Chemical Attraction can, at present, only be defined by stating its effects; as the manner of its operation is not clearly understood.

27. Although the precise **nature** of the force termed chemical attraction is not known, its **results** are always definite; and its operation may be considered as governed by certain constant and well defined laws; they are as follow:—

I. "The same substance consists invariably of the same elements." Thus pure water, no matter whence taken, always consists of hydrogen and oxygen.

II. "The elements which form a chemical compound are always united in it, in the same proportion, by weight." Thus, in water; the proportions, by weight, of H, and O, are always 2 to 16.

III. "If two elements combine in certain proportion with a third, they combine in the same proportion with each other." Thus iodine combines with potassium in the proportion, by weight, of 127 to 39·1, and chlorine combines with potassium in the proportion of 35·5 to 39·1, but iodine and chlorine likewise combine together, in precisely the same proportion of 127 to 35·5.

IV. "When one element combines with another in several proportions, the higher proportions are multiples of the first, or lowest." Thus—N_2O, N_2O_2, N_2O_3, N_2O_4, $N_2O_5 = 28:16$, $28:32$, $28:48$, $28:64$, $28:80$.

V. "The combining proportion of a **compound** substance is the sum of the combining proportions of its constituents." Thus the combining proportion of water (H_2O) is $2+16=18$, of copper oxide (CuO) $63·5+16=79·5$.

Note.—The density of a compound gas is one-half the combining weight, since the molecular volume contains two atomic volumes, *e.g.*, CO_2—molecular weight$=12+32=44$, and atomic weight$=\frac{44}{2}$.

28. The separation of a compound into its constituents is called **Chemical Decomposition.** When chemical decomposition is experimentally performed, for the purpose of ascertaining the composition of a substance, the operation is termed **Analysis**; when the decomposition is effected by galvanic action, the operation is called **Electrolysis**; and if the separation be made by a process of filtration through a membrane, it is termed **Dialysis.** **Atmolysis** expresses the separation of two gases from one another by reason of their different ratio of diffusion through a membrane, or porous partition. When a substance in contact with another substance causes or facilitates a

change of condition of the latter, without being itself effected, it is said to act by **Catalysis.** When a chemical compound is artificially formed, by causing proper proportions of its constituents to unite, the operation is called **Synthesis,** which is just the opposite of analysis.

29. In forming a chemical compound, the atoms of all the elements are not of equal value or **valency**; thus hydrogen and chlorine combine together in the proportion of atom to atom to form HCl (hydrochloric acid gas); hydrogen and oxygen, in the proportion of two atoms to one atom, to form H_2O (water); hydrogen and nitrogen, in the proportion of three atoms to one atom, to form H_3N (ammonia); hydrogen and carbon, in the proportion of four atoms to one atom, to form H_4C (light carburetted hydrogen). The student will remark the somewhat peculiar circumstance that the four most important elements, H, O, N and C, are respectively monad, dyad, triad and tetrad. This **atom-fixing** power is called **atomicity,** or **quantivalence,** and the elements are arranged in groups according as they have the power to fix 1, 2, 3, 4, 5, or 6 atoms of hydrogen, or of an element which combines with hydrogen, in the proportion of atom to atom. Thus, all the elements are either **monads, monatomic, monovalent,** or **univalent** like Cl; **dyads, diatomic,** or **divalent** like O; **triads, triatomic,** or **trivalent** like N; **tetrads, tetratomic** or **quadrivalent** like C; **pentads** like Sb, or **hexads** like Cr; the last two terms are, however, less commonly used, and, although employed by Frank-

land and other chemists of repute, are possibly superfluous. An atom of a dyad may combine with two atoms of a monad as H_2O, or with one atom of a dyad as CuO, and in like manner, an atom of a tetrad may combine with four atoms of a monad as CH_4, or with two atoms of a dyad as CO_2.

30. The distinction between the **atom-fixing** power of the element, or **quantivalence,** and the **molecule-forming** power, or **equivalence,** is to be carefully noted; the former relates to the **valency** of the element only, the latter relates to the **proportion by weight** in which the atoms replace each other, or, the chemical equivalent of an element expresses the **weight** which is required to replace or fix 1 part by weight of H in its combinations. Thus in H_2O, the quantivalence of O is 2, but the equivalence equal to $\frac{O}{H_2}=\frac{16}{2}=8$; in H_4C, valency of $C=4$, equivalence$=\frac{C}{H_4}=\frac{12}{4}=3$; in H_3N, valency of $N=3$, equivalence$=\frac{N}{H_3}=\frac{14}{3}=4{\cdot}66$; in HCl, valency of $Cl=1$, equivalence$=\frac{Cl}{H}=\frac{35{\cdot}5}{1}=35{\cdot}5$.

31. An element is said to be in the **nascent** state, at the moment in which it is liberated from a compound substance; and it is found to combine with much greater energy, in this condition, than when existing in the free state, because, in the latter case, the atoms are aggregated as molecules; while, in the former case, the atoms being for the moment free, but unable to exist in that condition, instantly seize upon atoms of other elements present, to form the readiest possible molecular combination.

32. Since the name of every element has a combining number attached, it follows that the symbol of an element does not merely represent the **name,** but stands for a **definite quantity** of the element; for example: O. does not stand for any quantity of oxygen, but for exactly 16 parts by weight of that element, when compared with an equal volume of H. Hg. stands for 200 parts of mercury. Ag. for 108 parts of silver. If more than one combining proportion of an element be present in a compound, a small numeral indicating the multiple is placed to the right of the symbol, as—N_2O_5, where two proportions of nitrogen are indicated as combining with five proportions of oxygen, or $N=14 \times 2=28$, $O=16 \times 5=80$. N_2O_5 is called a chemical formula, and indicates a union between the elements symbolized; it therefore represents a molecule. If a numeral be placed to the left of a formula it multiplies the proportion of every symbol, as far as the first comma, sign of addition, or period: *e.g.*, $3MnO_2=Mn_3O_4+O_2$. Here a combination of 3 equivalents of $Mn=165$, with $3 \times 16 \times 2$ of $O=96$, on being decomposed gives 165 parts of Mn united to 64 parts of O, while 32 parts of O are set at liberty. Such a representation as the last example is called an equation, and as the symbols on the left side of the sign of equality shew what was the original composition of the body taken, and the symbols on the right side shew the result of decomposition, the equation is said to represent a chemical reaction.

In writing formulæ, it is customary to place the symbol of the element present least resembling oxygen first; and in the case of salts, the symbol of the metal is usually written first.

33. **Formulæ** are either **empirical,** or **rational.** An **empirical** formula simply shews the composition of a compound, that is, shews the elements present and the relative proportion that their atoms bear to one another, without regard to their absolute number, or mode of arrangement. A **rational** formula, on the other hand, represents not merely the elements, but the absolute number of their atoms present; as well as the mode in which they are combined to form the compound. Ex. Hyposulphurous acid contains in 100 parts 66·66 S and 33·34 O, these numbers divided by their atomic weights give their atomic proportions $\frac{66\cdot66}{32}=2\cdot08$; $\frac{33\cdot34}{16}=2\cdot08$. These quotients being equal, it may be concluded that hyposulphurous acid is composed of equal atoms of the two elements. The most simple formula would be SO, but it is evident it might be S_2O_2, or S_3O_3—as they would all agree with the results of analysis, this would then be the empirical formula. The rational formula is found by further calculation to be S_2O_2.

34. It has been stated that the elements are divided, for the sake of convenience, into two classes—**metals** and **metalloids,** or **non-metals.** Metals are described as being solid, opaque, malleable, ductile, tenacious, possessing a characteristic lustre, and capable of forming a base (41), by combining with oxygen; or a salt (42), by combination with a salt radical (38). The comparative absence of the above properties ought accordingly to characterise the non-metals, but

in reality no such broad distinction can be drawn between the classes, which merge insensibly one into the other; while, therefore, the distinction between such metalloids as O, S, P or C and metals like Fe, Ag, Au, or Pb, is sufficiently marked, it is not so when such elements as As, I, or Hg, are dealt with. In the following pages the non-metals are considered as being As, B, Br, C, Cl, F, H, I, N, O, P, Se, Si, S, Te; all other elements are metals.

35. When any two metals, excluding mercury, combine or mix together, they form an **alloy**; the mixture of a metal with mercury is called an **amalgam.** The principal alloys are,—**aluminium-bronze,** a compound of 90 parts copper and 10 parts aluminium; **bell metal,** 78 parts copper and 22 parts tin; **gun metal,** 90·5 parts copper and 9·5 parts tin; **bronze,** 80 parts copper, 4 parts zinc and 16 parts tin; **brass,** 64 parts copper and 36 parts zinc; **German silver,** 51 parts copper, 18·5 parts nickel and 30·5 parts zinc; **speculum metal,** 66·6 parts copper and 33·4 parts tin; **solder,** 2 parts tin and 1 part lead; **pewter,** 4 parts tin and 1 part lead; **fusible metal,** 15 parts bismuth, 8 parts lead, 4 parts tin and 3 parts cadmium; **type metal,** 4 parts lead, 1 part antimony and occasionally a trace of copper; **shot metal,**—lead, with about 40 lbs. of arsenic to the ton; **standard gold,** 22 parts gold and 2 parts copper; **standard silver,** 925 parts silver and 75 parts copper. The fusing point of alloys is generally lower than the mean of the melting points of their constituents. In preparing them, the least fusible metals should be

melted first, and the most fusible added in small quantities at a time. Mercury unites readily with most other metals, iron and platinum being the only ones which are not speedily attacked by it. Mercury, however, **adheres** to platinum, and, when mingled with a little of the amalgam of sodium, will even adhere to iron. An amalgam of zinc and tin—mercury, 6 parts, zinc, 1 part, and tin, 1 part—is used to promote the action of the electrical machine. A curious amalgam of ammonium is also known, and is referred to elsewhere (122).

36. **Compounds of non-metals** with each other, or with the metals, take names terminating in **ide** ;—as oxide, iodide, etc. Occasionally the termination **uret** is used with the same meaning, but rarely. It is oxygen, or the element most resembling oxygen in its mode of combination, which takes the affix—**ide**, and the name of the metal, or element least resembling oxygen, gives the specific name of the compound, thus—hydric ox-**ide** ; potassic iod-**ide** ; ferric ox-**ide** ; lead sulph-**ide** ; sulphur diox-**ide.**

37. A **radical** is a **group** of elements which is found to enter into chemical combination and to behave in reactions in the same manner as an elementary atom. Hence a radical has been defined as being "The proportion in which certain elements, or groups of elements may be substituted for others, or may be transferred from one body to another in the act of double decomposition." A **compound radical** is a group of elements which, in the various changes and decompositions which a substance undergoes, remains

unaffected, and acts as if it were an element. Thus, HNO_3 (nitric acid) may be considered as **water** in which one atom of H has been replaced by the compound radical NO_2, thus—$\left.\begin{matrix}H\\NO_2\end{matrix}\right\}O$. NO_2 is therefore a monad radical; again, in H_2SO_4 (sulphuric acid), the dyad radical SO_2 has replaced two atoms of H, thus—$\left.\begin{matrix}H_2\\SO_2\end{matrix}\right\}O_2$, and in H_3PO_4, the triad radical PO has replaced three atoms of H, thus—$\left.\begin{matrix}H_3\\PO\end{matrix}\right\}O_3$.

38. A **salt-radical, haloid,** or **halogen** is a substance, **simple** or **compound,** combining with H to form an acid. Thus—H + Cl (hydrochloric acid), H + CN (hydrocyanic acid).

39. An **acid** is a hydrogen salt, possessing the following properties in a greater or less degree:—a sour taste, solubility in water, power of acting upon carbonates with effervescence, power of neutralizing alkalies, power of changing blue litmus paper red, and brown turmeric paper yellow. Several compounds are commonly called acids, although they do not contain hydrogen, and are therefore, according to modern theory, excluded from this class. Such are SO_2 (sulphurous acid), SO_3 (sulphuric acid), CO_2 (carbonic acid), SiO_2 (silicic acid).

40. An **alkali** is a compound substance, soluble in water, exerting a destructive effect upon animal matter; neutralizes acids, turns red litmus paper blue, and yellow turmeric paper brown. The principal alkalies are potash, soda, and ammonia. The alkaline earths are the oxides of barium, strontium, calcium, and magnesium. Other metallic oxides, however,

possess alkaline properties, as those of rubidium, lithium, caesium, silver, thallium, lead.

41. A **base** is a compound substance, **not** an alkali, capable of neutralizing an acid, and with it forming a salt.

42. A **salt** is a compound substance, formed by the combination of an **acid** with a **base**; or by a **metal** in combination with a **salt-radical** (38). Thus, ZnO, SO_3, or $ZnSO_4$ (base ZnO + acid SO_3); or NaCl (metal Na + salt-radical Cl). Salts are termed **neutral, acid,** or **alkaline,** according to their taste, and their effect upon vegetable colour.

43. When one combining proportion of an element unites with one combining proportion of oxygen, the resultant is called a **mon**-oxide, or **prot**-oxide; if there be two, three, four, or five proportions of oxygen to the same constant proportion of the other elements, these compounds are called the **di**-oxide, or **bin**-oxide, **tri**-oxide, **tetr**-oxide and **pent**-oxide respectively; such terms as **bi**-sulphide, or **di**-sulphide, are also in use.

44. When an element forms, with oxygen, **two** acids, the name of the one containing the less oxygen takes the termination **ous**; and the one containing more oxygen has the termination **ic**; as H_2SO_3 (sulphur-**ous** acid), and H_2SO_4 (sulphur-**ic** acid); if there happen to be other acid substances formed, by the same elements, intermediate to those, whose names terminate in **ous** and **ic,** the prefixes **hypo** and **hyper,** signifying under and over, are used, as—**hypo**-sulphurous, etc. Instead of **hyper,** the abbreviation **per** is generally used.

45. When an acid, the name of which terminates in **ous**, unites with a base to form a salt, the resulting substance has its name terminating in **ite**; if the name of the acid terminates in **ic**, the name of the salt will terminate in **ate**.

46. In (37) it has been shown that according to what is called the **water-type** theory, an acid such as HNO_3, or H_2SO_4 is looked upon as composed of water and a compound radical. Thus, $HNO_3=\left.\begin{matrix}H\\NO_2\end{matrix}\right\}O$, $H_2SO_4=\left.\begin{matrix}H_2\\SO_2\end{matrix}\right\}O_2$, $H_3PO_4=\left.\begin{matrix}H_3\\PO\end{matrix}\right\}O_3$, in which the radicals NO_2, SO_2, PO, have displaced respectively one, two and three atoms of H from one, two and three molecules of water. This view is supported by the fact that such radicals as NO_2 and SO_2 actually exist in an independent state, but since, in the combination of an acid with a metal, it is the hydrogen alone that is displaced from the acid, there is another, and, for some purposes, a more convenient theory, viz., the **binary theory,** according to which all acids are composed of hydrogen combined with a radical, **simple,** or **compound.** Thus, H combines with Cl to form hydrochloric acid; H_2 combines with SO_4 to form sulphuric acid; and H_3 combines with PO_4 to form phosphoric acid. In the case of the last examples, there is the forcible objection that no such radical as SO_4 or PO_4 is known to exist, while such radicals as SO_2 P_2O_5, from which, by combination with water, the above named acids may be obtained, have an independent existence. This theoretical objection is evaded by many chemists, by the adoption of what is called the **unitary formula,** which recognizes acids as being

compound substances containing hydrogen, by the displacement of the whole or a portion of which, by a metal, salts are formed. According to the unitary theory the formulæ of such compounds as sulphuric acid, carbonic acid, or phosphoric acid, which, according to the binary theory, would be written H_2, SO_4; H_2, CO_3; H_3, PO_4; are written without the comma between the H and the remaining symbols :—H_2SO_4; H_2CO_3; H_3PO_4; the compound being thus expressed as an entity. Either method affords a convenient and graphic means of explaining many chemical reactions; and the formation of salts is readily exhibited by its means. Thus—acid $H \mid Cl$ gives salt $Ag \mid Cl$; acid $H_2 \mid SO_4$ gives salt $Zn \mid SO_4$; acid $H_3 \mid PO_4$ gives salt $Na_3 \mid PO_4$. From the above it is seen that only the H is displaced by the metal, and by this displacement, more or less complete, the acid is changed into a salt. According as the acid contains one, two, or three atoms of H, it is said to be monobasic, dibasic, or tribasic, and the number of atoms of H present is therefore a measure of the basicity of the acid.

47. If hydrogen be present in an acid, or a salt, the term **hydride, hydrate,** or **hydrous** is occasionally used, but if no hydrogen be present **anhydride, anhydrate,** or **anhydrous** is substituted.

48. All **inorganic** solids exist in the form of **crystals,** or are **crystalline,** or **amorphous.** Crystals possess a **definite** form of geometrical exactitude; crystalline substances are composed of **irregular** masses of very minute and imperfect crystals, and amorphous substances possess **no definite** form or structure.

49. **Crystals** are subject to very numerous modifications of shape, by the replacement of angles, or of edges, and appear accordingly to present an endless variety of form to the observer; but careful investigation has shown that all these forms may be reduced to six well defined systems of crystals. In other words it is found that from one primitive form, such as a cube, a great many others may be derived, by the modification of the angular points, and bounding lines; the connection between the modified shape and the original typical crystal being however strictly traceable. Of these typical forms there are six, viz: (1) the cube; (2) the right prism on a square base; (3) the rhomboid; (4) the right prism on a rectangular base; (5) the oblique prism on a rhombic base; (6) the doubly oblique prism, and these characterize the systems of crystallisation as follows:—

I. **The Monometric,** regular, cubical, tesseral or octahedral system.

II. **The Dimetric,** tetragonal, square, prismatic or pyramidal system.

III. **The Rhombohedral,** or hexagonal system.

IV. **The Trimetric,** prismatic, orthotype, or rhombic system.

V. **The Monoclinic,** or oblique system.

VI. **The Triclinic,** or anorthic system.

50. When a substance is capable, according to the conditions to which it is exposed, of becoming crystallized, or of assuming either the amorphous, or crystalline form, often distinguished, in each case, by different properties; it is said to be **allotropic.**

51. A substance which crystallizes according to two different systems, or according to two different forms of the same system possessing different angular elements, is said to be **dimorphous.**

52. A substance which can be obtained in several forms, either crystallized, crystalline or amorphous, is said to be **polymorphous.**

53. Elements, or compound substances which can replace each other, without altering the character of a crystal, are said to be **isomorphous.**

54. When a substance assumes the form of another one, differing from it in composition, it is said to be **pseudomorphous.**

55. **Isomerism,** is a term used in organic chemistry to express the remarkable circumstance that certain compounds may be obtained in several distinct forms, exhibiting different properties, but possessing the same chemical composition.

56. **Osmosis** is the passage of liquids through a porous membrane, and according to the direction of the osmose impulse, it is called **endosmosis** or **exosmosis.** It would appear that the fluid which moistens the membrane most rapidly determines the osmosis from that liquid. Osmosis and Dialysis are closely allied phenomena.

57. Some terminations of names of elements are intended to denote a certain resemblance in properties of these elements, viz: **on,** as Carb-on, Bor-on, Silic-on; and **ine,** as Chlor-ine, Brom-ine, Iod-ine, and Fluor-ine. The characteristics common to these elements will be referred to in the proper place. The

termination, **gen** does not denote any community of properties. The Latin names of all metals end in **um,** and with the exception of Selenium, the name of no non-metal terminates in um.

58. A body is said to be **dissolved** and to form a **solution,** when its molecules co-mingle with the molecules of a liquid in such a manner as to become identified mechanically with them. Should the liquid and the dissolved body be capable of mutual reaction, there will of course be chemical combination as well as mechanical mixture.

59. **Filtration,** is the separation of solid matter held in suspension in a liquid, by straining the liquid through unsized paper, or some other porous substance.

60. If to a liquid solution of a substance, some other substance be added, which has such an affinity for the first substance as to cause it to combine with it and to form a third substance which is insoluble, the latter will sink to the bottom of the liquid in a more or less finely divided state, and it is then said to be **precipitated.**

61. The identification of the metals and acids which constitute chemical compounds, is termed **qualitative analysis** ; the determination of the relative quantities of the metals and acids present in such compounds is termed **quantitative analysis.** The first named operation is, in the cases of the principal metals and acids at least, comparatively easy; while the second operation when accurately performed, is a difficult one, requiring the greatest care,

and demanding the utmost nicety in manipulation. In qualitative analysis, test liquids are prepared. which by their action upon a solution of the salt to be tested, produce, or do not produce a precipitate; and, since a precipitate is simply a new chemical compound formed by the union of certain ingredients of the salt and of the test-liquid, or else is an elementary substance, which has been displaced from the salt solution by the ingredients of the test-liquid, according to the result with the various tests used, and according to the colour of the precipitate obtained, an accurate conclusion can be arrived at, as to the identity of the metal or acid contained in the salt under investigation. The following tables are designed to assist students in gaining an elementary knowledge of the principles of testing. but since they are particularly intended for the purpose of reference to refresh the memory regarding **practical** instruction afforded in the subject, they are necessarily somewhat meagre. The two tables of "Indicating Tests for Metals" and "Indicating Tests for Acids" are borrowed from the excellent little work of Mr. J. J. Griffin, entitled "Chemical Recreations." The **confirming** tests have been selected from various sources according to value and accuracy of result. The student must use very small quantities of the salt, and in adding the caustic potash, he must do so, drop by drop; observing not merely when **precipitation** takes place, but also whether an **excess** of the test solution **re-dissolves** the precipitate. Saturated solutions of the substance to be tested must be used, but dry salt is generally to be used in the blowpipe flame. In the table of indicating tests, where there are blank spaces under the names of some of the test liquids, it is to be understood that nothing farther is to be learned of the substance under examination from the use of these particular tests, and the student may therefore at once proceed to the confirming tests. It is well to apply the indicating tests for both metal and acid, before proceeding to apply the confirming tests for either. Assay notes are to be carefully and constantly used as below.

ASSAY NOTE FOR METALS, NO.	
Hydric Sodium carbonate ($HNaCO_3$)	
Ammonia (NH_4, HO)	
Potassium hydrate (HKO)	
Potassium ferricyanide (K_3 Fe. Cy_6)	
Hydric sulphide (H_2 S)	
Metal indicated.	

ASSAY NOTE FOR ACIDS, NO.	
Barium nitrate (Ba $(NO_3)_2$)	
Argentic Nitrate (Ag NO_3)	
Plumbic Nitrate (Pb $(NO_3)_2$)	
Calcium chloride ($CaCl_2$)	
Acid Indicated	

EXAMPLES OF ASSAY NOTES.

ASSAY NOTE FOR METAL, NO. 1.	
Hydric Sodium carbonate ($HNaCO_3$)	P.
Ammonia (NH_4, HO)	P.
Potassium hydrate (HKO)	White P. soluble in excess.
Potassium ferricyanide (K_3 Fe Cy_6)	P.
Hydric sulphide H_2 S)	Black P.
Metal indicated	Lead.

ASSAY NOTE FOR ACIDS, NO. 1.	
Barium nitrate (Ba $(NO_3)_2$)	White P. soluble in nitric acid without effervescence.
Argentic Nitrate (Ag NO_3)	
Plumbic Nitrate (Pb $(NO_3)_2$)	
Calcium chloride ($CaCl_2$)	White P. insoluble in water.
Acid indicated	Oxalic acid.

62 **Indicating Precipitants for Metals in Salts.**

Solutions to be Neutral.					Solutions to be acid.	METALS INDICATED.
Hydric Sodium Carbonate (HNa CO_3)	Hydrate of Ammonia (NH_4HO)	Caustic Potash. (HKO)		Potassium Ferricyanide (K_3FeCy_6)	Hydric Sulphide (H_2S)	
None.		(See 121)				1 Potassium.
None.						2 Sodium.
None.						3 Ammonium.
	None.					4 Barium.
	None.					5 Strontium.
	None.					6 Calcium.
		White.	All five are insoluble in excess.	Brown.		7 Manganese.
		White.		Blue.		8 Iron, protosalts
		White.		None.		9 Magnesium.
		White.			Yellow.	10 Cadmium.
		White.			Black.	11 Bismuth.
		White.	All six are soluble in excess.	Yellow-red		12 Zinc.
		White.		White.		13 Tin, protosalts.
		White.			None.	14 Aluminum.
		White.			Black.	15 Lead.
		White.			Yellow.	16 Tin, persalts.
		White.			Orange.	17 Antimony.
		Black, see Gold, No. 25.		Red-brown.		18 Mercury, its protosalts.
		Blue, if boiled, red.				19 Cobalt.
		Blue, if boiled, black.				20 Copper.
		Green.		Yellowgreen		21 Nickel.
		Green.		None.		22 Chromium.
		Green.		Light blue.		23 Iron, persalts & protosalts, mixed
		Yellow		Yellow red, but none from the Perchloride.		24 Mercury, its persalts.
		Yellow, sometimes slightly, and black.		None.		25 Gold
		Brown.		None.		26 Iron persalts.
		Brown.		Brown.		27 Silver.

63 Indicating Precipitants for Acids in Salts.

Barium Nitrate $(Ba(NO_3)_2)$		Argentic Nitrate $(Ag NO_3)$	Plumbic Nitrate $(Pb (NO_3)_2)$	Calcium Chloride $(CaCl_2.)$	SALTS INDICATED.
None.		None.			1 Nitrates.
None.		None.			2 Chlorates.
None.		White.			3 Chlorides.
None.			Yellow.		4 Iodides.
None.			White.		5 Arsenites.
None.		Black.			6 Sulphides.
White.	All five soluble in Nitric Acid without effervescence.	None.			7 Fluorides.
White.		Yellow.			8 Phosphates
White.		Brown.			9 Arseniates.
White.				White, soluble in water.	10 Borates.
White.				White, insoluble in water.	11 Oxates.
White.	Soluble in Acids with effervescence.				12 Carbonates
White.	Insoluble in Acids.				13 Sulphates.
Yellow.					14 Chromates.

64. Confirming Tests for Acids.

TESTS (1) NITRATES. RESULTS.

TESTS	RESULTS
Add, to solution, metallic copper and a little sulphuric acid (H_2SO_4).	Dark red fumes of nitric peroxide.
Add, to solution, an equal volume of H_2SO_4; cool; and add solution of ferrous sulphate ($FeSO_4$).	A dark ring formed at junction of two layers of liquid.
Add, to dry nitrate, in test tube, hydrochloric acid (HCl); and heat.	White fumes of HNO_3 are expelled; they redden litmus paper.

(2) CHLORATES.

Add metallic copper and sulphuric acid (H_2SO_4).	No result.
Add sulphuric acid (H_2SO_4) and ferrous sulphate ($FeSO_4$).	No result.
Blowpipe flame, on copper wire with microcosmic salt ($NaNH_4HPO_4$).	Bright blue flame.

(3) CHLORIDES.

Argentic nitrate ($AgNO_3$).	White curdy precip., insoluble in nitric acid, but soluble in ammonia.
Add manganese di-oxide, a few drops sulphuric acid (H_2SO_4), and heat.	Chlorine gas evolved.

(4) IODIDES.

Mercuric chloride ($HgCl_2$).	Scarlet precip.
Add bisulphate of potash ($KHSO_4$) in test tube, and heat.	Violet vapours in tube.
Blowpipe flame, on copper wire with microcosmic salt ($NaNH_4HPO_4$).	Bright green flame.

(5) ARSENITES.

Solution of sulphate of copper ($CuSO_4$), with a little ammonia (NH_3).	Green precip.
Solution of nitrate of silver ($AgNO_3$) and a little ammonia.	Yellow precip.
Blowpipe inner flame, with hydric sodium carbonate ($NaHCO_3$) on charcoal. See (170, 171).	Odour of garlic perceptible.

(6) SULPHIDES.

Heat in a test tube, with a little hydrochloric acid (HCl).	Effervescence produced; sulphuretted hydrogen evolved; test-paper moistened with sugar of lead blackened.
Blowpipe flame on charcoal.	Sulphurous acid gas evolved.

(7) FLUORIDES.

Heat in test-tube with bisulphate of potassium ($KHSO_4$),	Hydrofluoric acid evolved, corrodes the inside of tube.
Apply test-paper, prepared in solution of Brazil wood, to the mouth of heated test-tube.	Test-paper turns yellow.

(8) PHOSPHATES.

TESTS	RESULTS.
Solution of sulphate of magnesia ($MgSO_4$), with addition of ammonia.	White precip.
Solution of molybdate of ammonia $2NH_4, MoO_4$) in nitric acid (HNO_3), with small portion of solution of phosphate, in test tube ; boil.	Yellow precip.

(9) ARSENIATES.

TESTS	RESULTS.
Precipitate solution, by solution of acetate of lead, $Pb(C_2H_3O_2)_2$, collect on filter, wash and dry. Ignite on charcoal in outer flame.	No crystallization.
Solution of molybdate of ammonia $(2(NH_4)MoO_4)$ in nitric acid (HNO_3), boiled with arseniate. See (170, 171).	No result.

(10) BORATES.

TESTS	RESULTS.
Mix with sulphuric acid (H_2SO_4), boil and cool.	Flat shining crystals of boracic acid formed.
Wash the resultant crystals of previous test ; boil with water and test with blue litmus, and brown turmeric.	Blue litmus turns red ; brown turmeric turns yellow.
Moisten with sulphuric acid, mix with alcohol, inflame mixture.	Green flame.

(11) OXALATES.

TESTS	RESULTS.
Add a few drops of sulphuric acid (H_2SO_4), apply heat.	Effervescence ; CO_2 and CO evolved ; on applying a light the CO burns.
Add to solution, solution of calcium sulphate ($CaSO_4$).	White precip.

(12) CARBONATES.

TESTS	RESULTS.
Mix dry carbonate with a little water, and add a few drops of hydrochloric acid (HCl).	CO_2 escapes with effervescence, and, on being passed into lime-water, precipitates carbonate of lime.

(13) SULPHATES.

TESTS	RESULTS.
Mix dry sulphate with dry hydric carbonate of soda ($NaHCO_3$), heat in inner flame on charcoal ; place on bright silver and add a drop of water ; in a minute or two, wash.	Black mark on silver
Baric nitrate ($Ba2NO_3$).	White precip.
Baric chloride ($BaCl_2$).	White precip.

(14) CHROMATES.

TESTS	RESULTS.
Mix dry chromate with dry chloride of sodium (NaCl) and a few drops of sulphuric acid ; heat.	Effervescence ; splendid red gas evolved.
Dihydric sulphide (H_2S).	Green solution.

65. **Qualitative analysis** shews the composition of a compound by determining the **presence** of certain elements. **Quantitative analysis,** on the other hand, has for its object the determination of the relative **quantity** of each element present in a definite quantity, say, one hundred parts by weight, of the compound analysed. From this per-centage composition the empirical formula and possibly the rational formula of the compound may be arrived at, by dividing the relative quantities by the atomic weight of the elements present.

Ex. I. A compound gas is found to be made up of 27·27 parts by weight of C and 72 73 parts by weight of O; the atomic weight of these elements being known, divide the relative quantities by the atomic weights in order to arrive at the relative number of atoms, thus—$\frac{27·27}{12}=2·27$; $\frac{72·73}{16}=4.54$. According to this, 2·27 atoms of C are united with 4·54 atoms of O. Take the lowest number 2 27 as a unit, and divide the other number 4·54 by it, thus—$\frac{4·54}{2·27}=2$, that is, 2·27 : 4·54=1 : 2, consequently one atom of C is combined with two atoms of O; the simplest formula therefore is CO_2.

Ex. II. Per-centages given—44·44 S, 55·56 O, to find the formula; $\frac{44·44}{32}=1·39$; $\frac{55·56}{16}=3·47$; therefore 139 : 347 = 1 : 2·5, there can be no fraction of an atom; therefore clearing of fractions 1 : 2·5 = 2 : 5; the formula is therefore—S_2O_5. To arrive at the rational formula of a substance, its atomic weight must be found. 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 salt 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:—

BaO.	Acid.	Equivalent of BaO.
61·6 :	38·4 : :	153 : $x=96$, atomic weight of acid.

The number of atoms of each constituent of the acid is now to be determined, as follows:—

Acid.	S in 100 parts acid.		Atomic wt. of acid.	
100 :	66·66	: :	96	: $x=64=2$ eq. of S.
Acid.	O.			
100 :	34·34	: :	96	: $x=32=2$ eq. of O.

The rational formula for hyposulphurous acid is accordingly S_2O_2.

66. The **metre** is **nearly** the ten-millionth part of the quadrant of the meridian of Paris. It is equal to 39·37 English inches; it is divided into tenths, hundredths, and thousandths, called respectively decimetres, centimetres, and millimetres. A decimetre (3·93 Eng. inches) cubed, is equal to one litre, the principal measure of capacity, which is therefore equal to 1000 cubic centimetres and equal to 1 76 Eng. pints, or to 61·02 cubic inches. A cubic centimetre of pure water at 4°C. weighed at Paris, is the fundamental measure of weight, called a gramme, equal to 15·43 Eng. grs. The millimetre (0·039 Eng. inch) is the smallest measure of length, and is commonly used to express the height of the barometric column, thus—760 mm. (= 76 cm.). The kilogramme is equal to 1000 grammes, equal to 2·2 Eng. lbs. avoir.

67. The **Barometer** is an instrument for ascertaining the pressure of the atmosphere; it consists in its usual form of a glass tube of about 840 mm., or 33 inches in length, closed at one end, and of uniform bore. This tube being very carefully heated, a portion of the contained air is expelled and the open end is now inverted in a vessel containing mercury. As the residue of the air cools the mercury ascends, and can thus be made to fill the entire tube. When this is the case, the contained mercury is heated to a high degree so as to expel any remaining bubbles of air, and the tube is now permanently inverted in a suitable vessel, or reservoir of mercury, open to the atmosphere. Liquids transmit pressure equally in all directions, therefore the pressure of the atmosphere, upon the surface of the mercury in the reservoir, will be similarly transmitted by it to the column of mercury in the tube. But the surface of this column will be maintained at a certain height, for since there is no air in the tube, the tendency of the mercury to seek the level of the fluid in the reservoir is solely due to the weight of the column, and this tendency is exactly counteracted by the contrary pressure of the atmosphere transmitted through the fluid contents of the reservoir, which pressure will evidently be equal to the weight of a column of air of the same sectional area as that of the tube, but extending through the entire thickness of the atmospheric envelope. The weight of such a column varies slightly on account of changes of temperature and atmospheric disturbances, but at the level of the sea and at a temperature of 0° Cent.

or 32° F. a column of air is found to support, on an average, a column of mercury of equal sectional area of 760 mm., or 30 in. in height; 760 mm., or 30 in., are said accordingly to represent the normal barometric pressure at the sea level. Between the upper surface of the mercurial column and the closed end of the tube there is of course a vacuum, which is technically known as the Torricellian vacuum. A graduated scale is applied to the barometric tube, by observation of which the increase or decrease of the column of mercury may be ascertained. It is evident, that if by any means the atmosphere above the barometer become heavier, it will be able to support a longer column of mercury; but if its weight is lessened, there will be a corresponding decrease in the quantity of mercury supported in the tube. The barometer therefore, certain corrections for temperature, elevation and capillary attraction being applied, is a tolerably accurate measurer of atmospheric pressure. There are many varieties of barometer:—**reservoir** barometers, with or without levelling screws, by means of which the surface of the fluid in the reservoir may be brought level with the zero of the scale; **siphon** barometers, which are very untrustworthy; **water** barometers, rarely made on account of the tube requiring to be about 40 feet in length, the normal elevation of the column of water being 33·3 feet; the **aneroid** barometer, which is a small clock-faced instrument containing a metallic box exhausted of air and hermetically sealed. This box, by its contraction or expansion due to decreased, or increased pressure of the air, moves, by the agency of an arrangement of levers and springs, an index needle which moves on a pivot, indicating on a scale which is graduated in coincidence with a standard barometer, the amount of pressure to which the box is subjected. This instrument is moderately accurate at comparatively low elevations.

68. **The pressure of the Air** enveloping our globe is, at the earth's surface, capable of supporting a column of mercury of about 30 inches in height; but since mercury is 10462 times heavier than air, the pressure of the air upon one square inch of surface must be not less than 14·6 lbs. avoir. This pressure is commonly referred to as "an atmosphere"; two, seven, or thirty-five atmospheres, thus=14·6 × 2; 14·6 × 7; 14·6 × 35; the product in each case representing the amount of pressure on one inch surface.

69. **Mariotte's,** or **Boyle's** law is to the following effect:—"The temperature remaining constant, the volume of a given quantity of a gas is in inverse proportion to the pressure which it supports. Ex.:—

$$\frac{1\text{ atm.}}{1\text{ vol.}}\quad \frac{2\text{ atm.}}{\frac{1}{2}\text{ vol.}}\quad \frac{20\text{ atm.}}{\frac{1}{20}\text{th vol.}}\quad \frac{100\text{ atm.}}{\frac{1}{100}\text{th vol.}}\quad \frac{\frac{1}{2}\text{ atm.}}{2\text{ vols.}}\quad \frac{\frac{1}{20}\text{th atm.}}{20\text{ vols.}}\quad \frac{\frac{1}{100}\text{th atm.}}{100\text{ vols.}}$$

70. **Heat** is supposed to be due to a vibratory movement of the particles of heated bodies, which movement is transmitted to the particles of other bodies, by the medium of an eminently subtile and elastic fluid, which is called **ether,** and in which it is propagated after the manner of sonorous waves, or undulations in air. This **undulatory** theory of heat, known also as the **kinetic,** or **dynamic** theory, is the only one generally admitted at present, in opposition to the **material** theory, formerly propounded.

71. **The different sources of heat** are:—I. Mechanical sources, comprising friction, percussion, and compression.

II. Physical sources, as solar radiation, terrestrial heat, molecular action, changes of state, and electricity.

III. Chemical sources, as molecular combinations, and notably combustion.

72. **Combustion** is the union of substances, under the influence of the force called chemical affinity, attended by the evolution of light and heat; as when antimony is brought into contact with chlorine; a paper dipped in turpentine and thrown into a jar of chlorine; or when carbon combines with oxygen to form carbonic acid gas. Combustion is the means by which we obtain all artificial heat for the general purposes of life, and the form of combustion we employ is the union of carbon, contained in charcoal, coal, wood, and our various fuels, with the oxygen gas contained in the atmosphere. The product is in these cases always the same, viz., carbonic acid gas, accompanied perhaps by water. By what precise means these chemical actions give rise to the production of heat we do not know, but it is believed that the molecules of two substances about to combine are in the condition of a raised weight and the earth, and when they rush together to combine, their kinetic energy becomes heat, as in the case of the weight referred to.

73. Since heat is a rapid reciprocal **motion** of the molecules of matter, it is evident that the addition to a number of molecules, possessing a certain amount

of this motion, of more of the motion, will, by producing a greater commotion, cause the molecules to occupy a larger space. This phenomena is called **expansion**, and is apparent in all forms of matter, solid, liquid or gaseous. Solids expand into liquids, and liquids into gases; gases expand most; liquids, as liquids next (127), and solids, as solids, least. Expansion then is just the opposite of cohesion, and bodies expand in proportion as cohesion of the material particles is overcome; and contraction is merely increasing cohesion of the material particles, as the motor influence—heat approaches its zero. The **linear**, **superficial**, and **cubical** expansion of **solids** may be ascertained; but only the **cubical** expansion of **fluids** can be determined. Linear expansion is shown by fixing one end of a bar of the substance to be experimented upon, and causing the other end to press against a lever, or system of levers, by means of which any lengthening of the bar will be indicated on a graduated scale by a pointer; on heating the bar, the movement of the index is at once perceptible. Linear expansion is not the same for all solids, and in order to ascertain it, each must therefore be experimented upon separately.

74. **Solids** for the most part, when heated uniformly, expand uniformly in length, breadth and thickness; hence the co-efficient of linear expansion being given, the co-efficients of superficial, and cubical expansion can easily be ascertained. The **co-efficient** of linear expansion is the increase in length of a substance, for one degree of temperature, whose length

at some given temperature, generally 0°C. (or 32° F.), is taken as unity. Thus if the length of a brass rod at the freezing point (32° F.) be taken as 1,000,000, its length at the temperature of boiling water (212° F.) is found to be 1·001,867, and the linear co-efficient of brass for 180° F. (212°—32°) is hence 0·001,867, and for 1° F.=0·001,867÷180°=0·000,010,38. The **superficial co-efficient** of a substance is equal to twice its linear expansion, and the cubical expansion to three times the linear. Certain crystals do not expand equally in all directions; some contract in one direction while they expand in another, but the total expansion is greater than the total contraction; others expand unequally in all directions.

75. **Liquids** expand more than solids for an equal increment of heat, and it is obvious that in their case cubical expansion can alone be considered, but as the containing vessel expands also, it is to be observed that there is both an **absolute** and an **apparent** expansion of a liquid. This distinction may even be of the greatest importance, as in the cases of the mercurial thermometer, and the barometer, in which the absolute expansion of the mercurial column requires to be very carefully distinguished from the apparent expansion, due to the joint expansion of the mercury and the glass tube containing it.

76. **Water** is a notable **exception** to the general law that all bodies expand when heated, and contract when cooled. This law when applied to water, bismuth, certain chemical compounds and gems, is only true within certain limits. Water contracts when

heated from 0°C. (32°F.) to 4°C (39·2°F), and above this point it expands. In other words the point of greatest density of water is 4°C. and when heated above, or cooled below that point it expands.

77. The **co-efficient** of **expansion** of **gases** is for an increment of 1°C. ·003665. That is, one volume of a gas being taken at 0°C. and at the normal barometric pressure—760 mm. and raised one degree temperature on the centigrade scale, the volume becomes vol. 1·003665; at 2°C., it becomes vol. 1·007330; at 3°C., vol. 1·010995; increasing in volume by ·003665 vol. for every degree rise of temperature. For 100 volumes the corresponding increase will evidently be—at 1°C., 100·3665; at 2°C., 100.7330; and at 3°, 101·0995. $\frac{\cdot003665}{1000000} = \frac{1}{273}$; hence a gas expands $\frac{1}{273}$ of its volume for an increase of 1°C. If now a gas has been measured off at a known temperature, and it is required to ascertain its volume at some other temperature, the calculation is easy. Ex. I. 1000cbc. of a gas are measured off at 0° and the temperature is raised to 20°, what would be the volume of the gas if free to expand? The gas would increase its original volume by $20 \times \frac{1}{273}$ of that volume, hence $273 : 273 + 20 :: 1000 : x = 1073$cbc. Ex. II. 200cbc. of a gas are measured off at 20°C. what will be the volume if the temperature be lowered to 4°C.? Since decrease of volume due to abstraction of heat takes place, in precisely the same ratio as the increase due to increments of heat, the method of calculation will be as follows:—$273 + 20 : 273 + 4 :: 200 : x = 190$cbc. In these calculations no attention has been paid to

the atmospheric pressure, but since the volume of gas varies inversely as the pressure to which it is subjected (69), this neglect will necessarily cause the results of the above calculation to be erroneous. Supposing that in Ex. I. the barometric pressure under which the gas was measured off was 760 mm. and this pressure fell to 740 mm., the statement of the problem would be $\underline{\frac{273}{740}}:\underline{\frac{293}{760}}::1000:x=1102$cbc. In Ex. II. Suppose the pressure at the time of first measurement to be 755 mm. and at the time of second measurement to be 763 mm. the statement will then be $\underline{\frac{293}{763}}:\underline{\frac{277}{755}}::200:x=187$cbc.

Note:—The co-efficient of expansion of gases on Fahrenheit's scale, corresponding to $\frac{1}{273}$ is $\frac{1}{490}$

78. For the measurement of relative amounts of heat, instruments called **thermometers** and **pyrometers** are used. The principle of construction of these instruments is simply an application of the laws of expansion, and of contraction. In constructing a common thermometer a narrow glass tube of several inches in length, of small and uniform bore, with a bulb blown upon one end, is taken. This bulb, with a small portion of the tube, is filled with either mercury or coloured alcohol in the following manner. The entire tube is gently heated in order to expel the contained air, and the open end is then inverted in a vessel of mercury or alcohol. As the air remaining in the tube cools, the liquid in the vessel ascends to fill up the space previously occupied by the expelled air. By carefully repeating this operation as often as may be required, the bulb is at length filled, and being

heated until the liquid expands so as to fill the entire tube, the latter is now hermetically sealed, and the whole allowed to cool slowly. The contained liquid gradually contracts on cooling, leaving a vacuum between its surface and the upper end of the tube. Since mercury expands more than twenty times as much as glass for equal increments of heat, and the liquid is now freed from superficial pressure, it is very susceptible to the slightest changes of temperature, and these changes are readily observed by affixing the tube to a graduated scale. All thermometer makers have not adopted the same graduations, and there are consequently four distinct scales in use, viz: **Fahrenheit's, Celsius', or the Centigrade, Reaumur's** and **De Lisle's**. The first named is used by all English speaking peoples; the second is largely used on the continent of Europe, and by scientific men of all nations; the third is used in Germany and Russia; and the fourth is only used in Russia. Although the graduation of these scales is different, there is a coincident selection of the **freezing** and **boiling** points of water under a constant pressure as fixed points. In graduation therefore the bulb is immersed in a vessel containing melting ice, and the surface level of the mercury, or alcohol, is accurately marked on the tube, establishing the freezing point. In like manner the entire tube is immersed in steam arising from water boiling under a barometric pressure of 760mm., and the level of the contained fluid is again accurately marked, establishing the boiling point. Fahrenheit, under a mistaken impression, placed the zero of his scale 32° **below** the freezing point, and marked the boiling point 212°, or 180° above the freezing point. On the Centigrade scale the freezing point **is** zero, and the space between zero and the boiling point is divided into one hundred degrees, hence the name of the instrument. On Réaumur's scale, the freezing point is zero and the boiling point is 80°. In De Lisle's thermometer the freezing point is 150° and the boiling point is zero. Since the number of graduations on these scales between the freezing and the boiling point is respectively 180° : 100° : 80 : 150; an easy means is afforded of reducing one scale to another. Neglecting De Lisle's thermometer, as being of little practical importance, the relation between Fahrenheit's, the Centigrade, and Reaumur's thermometer is evidently 9 : 5 : 4; hence to reduce Fah. to Cent.—subtract 32° and multiply by $\frac{5}{9}$; in reducing Fah. to Reaumur—subtract 32° and multiply by $\frac{4}{9}$. In reducing Cent. or Reaumur to Fah. multiply by $\frac{9}{5}$ or $\frac{9}{4}$ respectively and add 32°. To convert Cent. to Reaumur, multiply by $\frac{4}{5}$, or to convert Reaumur to Cent. multiply by $\frac{5}{4}$. Thus, $140°\text{F.} = (140 - 32)\frac{5}{9} = 60°\text{C.}$, or $140°\text{F.} = (140 - 32)\frac{4}{9} = 46°\text{R.}$ $50°\text{C.} = (50 \times \frac{9}{5}) + 32 = 122°\text{F.}$ or $50°\text{C} = 50 \times \frac{4}{5} = 40°\text{R.}$ $50°\text{R.} = (50 \times \frac{9}{4}) + 32 = 144{\cdot}5°\text{F.}$ or $50°\text{R.} = 50 \times \frac{5}{4} = 62{\cdot}5°\text{C.}$ The **alcohol** thermometer is used for measuring low temperatures, since this liquid has never been frozen, but as it boils at the comparatively low temperature of 173°F. it is useless at temperatures approaching the boiling point of water. **Mercury** on the other hand solidifies at —38°F. but does not boil until raised to a temperature of about 660°F. A mercurial thermometer, having a small metallic needle **above** the liquid column, when placed in a horizontal position, shews the **maximum** temperature reached in any given space of time, since the ascending column pushes the needle before it, and when descending leaves it behind. An alcohol thermometer having a similar needle immersed **in** the liquid column, when placed in a horizontal position, shows the **minimum** temperature reached in any given space of time, since the descending surface of the column bears the needle with it by capillary attraction, but, when it re-ascends, leaves it behind at the lowest point reached. The delicacy of the mercurial thermometer is increased by reducing the size of the bore, and by having the walls of the bulb as thin as possible, but it must be considered as giving only approximate results since there are several corrections necessary, to attain even a moderate degree of accuracy, viz: (*a*) for **change of zero**, due to a slight contraction of the bulb and tube after graduation, probably caused by imperfect annealling of the glass, (*b*) **for position**, since a perpendicular column of mercury will tend to increase the size of the bulb and thereby cause a lower reading of the scale than would be the case in a horizontal position; (*c*) for **unequal expansion of the glass** and the contained fluid. The **air** thermometer consists of a bulb of considerable size communicating with a small vessel containing mercury by means of a tube of small bore. When the contained air expands, the mercury is partially expelled from the tube; when the air contracts, the mercury rises in the tube. Since the liquid column is exposed to the pressure of the atmosphere a correction must be applied for this, before there can be any comparison between the air thermometer and the mercurial thermometer. **Bre′guet's thermometer** consists of three thin bands of platinum, gold and silver soldered together, so as to form a fine metallic ribbon, which is twisted into a spiral coil fixed at its upper extremity, and at the lower end attached to a copper needle free to move on a pivot over a centigrade scale. This instrument possesses extreme sensibility due to the unequal expansion of the three metals composing the coil. The silver forms the interior face of the coil, and is most expansible; the platinum forms the external face and is least expansible; whilst the gold is intermediate in position and expansibility. When the temperature rises, the expansion of the silver causes the coil to unroll itself, and when the temperature falls the spiral coils itself more closely.

79. Since gases increase by $\frac{1}{273}$rd of their volume for every increment of 1°C., or $\frac{1}{490}$th of their volume for every increment of 1°F., and since contraction of volume takes place in exactly the same ratio on abstraction of heat, it follows that, supposing the law to hold good at very low temperatures, at—273°C., or at—458°F., there could be no further contraction of volume, for volume would no longer exist, neither could there be any further reduction of temperature, hence the **absolute zero** would have been reached. That is **absolute zero** is 273° **below** freezing point

on the Centigrade scale; 490° below freezing point on Fahrenheit's scale, and 218° below freezing point on Reaumur's scale.

80. **Absolute temperature**, is the temperature of a substance measured from the absolute zero instead of from the relative zero of thermometric scales. Absolute temperature will be obtained, therefore, by **adding** to the **relative** temperature of a substance, 458° on the Fahrenheit scale; 273° on the Centigrade scale, and 218° on Reaumur's scale.

81. When sufficient heat is applied to a liquid to cause it to assume the condition of vapor, which is liberated in bubbles producing violent agitation in the liquid; the latter is said to be in a state of **ebullition**, or to be at the boiling point. The boiling point for pure water under a pressure of 760 mm. is always 100°C., or at a pressure of 30 inches=212°F. A liquid containing matter in solution boils at a **higher** temperature than would be required by the pure liquid. The kind of material composing the vessel in which a liquid is boiled affects the boiling point; water boiled in a glass vessel for example, under the normal pressure, has been found to boil only at a temperature of 101°C., while in copper it boils at 100°C. This phenomenon has been explained by attributing to glass a **peculiar affinity** for water. It is to be carefully noted that although the **boiling point of a liquid** containing substances in solution, or which is boiled in a glass vessel, may be above 100°C., yet at the normal pressure the **temperature of the resulting vapor** is found to

be **invariably** 100°C. The boiling point of water is reduced 1°F., for an ascent above the level of the sea of about every 590 feet. (1.) Every liquid boils at the moment when the tension of its vapor equals the super-incumbent pressure. (2.) The boiling point is raised directly as the pressure is increased. (3.) For a given pressure the boiling point is always the same for the same liquid, but it varies for different liquids. (4.) Whatever may be the intensity of the source of heat, from the moment when ebullition commences the temperature of the liquid remains the same.

82. **The distinction** between **gases** and **vapours** is not very clear, but it is usual to consider as gases those elastic fluids which retain at the normal temperature and pressure the gaseous form of matter, while those which under these conditions assume the liquid form are called vapours. Another method of division, classifies as gases those only which are permanent elastic fluids, under every condition of temperature and pressure to which they have hitherto been submitted, while those which, either by reduction of temperature, or by augmented pressure, have been liquified, are called non-permanent gases, or vapours. As it is possible, and from recent discoveries, even probable, that all gases may be ultimately liquified, this classification is evidently an unreliable one.

83. **Distillation** is an operation by which liquids are separated from substances which are held by them in solution. The solution is placed in a closed vessel called a retort, which communicates, by means of a

tube-like prolongation, with another closed vessel called a receiver. The communicating tube is enclosed within a larger tube, in such a manner that it is constantly surrounded by cold water. On sufficient heat being applied to the retort, the liquid is raised to its boiling point, and rapidly evaporates; it escapes in the state of vapour from the retort towards the receiver, but in its course becomes cooled down, or condensed, by passing through the cold tube, and therefore reaches the receiver in the liquid condition. On a large scale the condensation is caused by means of a worm, or spiral coil of tubing arranged inside a suitable vessel. By this operation a volatile liquid will be separated from a less volatile liquid, or from non-volatile substances; the less volatile liquid, or the non-volatile matter, being left behind in the retort. In the case of two liquids, whenever it is desired to separate the more volatile from the less volatile, care must of course be taken that the temperature be not raised to the boiling point of the latter. The distinctive name of "**fractional distillation**," is given to this separation of two liquids, which is much used in the case of hydro-carbons, between the vaporisation points of which, there is often no greater difference than a few degrees of temperature.

84. **When liquid matter** assumes the gaseous condition it is said to **evaporate**, but the term evaporation is usually confined to the slow production of vapour, from the surface of a liquid, while the rapid production of vapour from the whole mass of liquid is called ebullition. There is no determinate

temperature at which evaporation takes place, therein notably differing from ebullition; but it is believed that, below a certain degree of refrigeration, all evaporation ceases—*e. g.*, mercury below—10°, or sulphuric acid below 30°.

85. **Sublimation** of solids is a process analogous to vaporisation of liquids. Volatile solid substances are converted by heat into vapour, or are sublimed, and, on cooling, they re-assume the solid form.

86. **When heat is applied** to matter, expansion follows. In the case of gases this expansion appears to be unlimited; liquids expand until they reach their boiling point, when they rapidly assume the gaseous condition; while solids, on the application of heat sufficient to evercome the cohesive force of the molecules followed by consequent cubical expansion of the volume, gradually liquefy, and are said to be in a state of **fusion.** Substances of organic origin whether direct or indirect, usually however, undergo decomposition and therefore cannot be fused. Fusion is subject to the following laws:—(1.) Every body fuses at a determinate temperature, invariable for each substance, the pressure remaining constant. (2.) Whatever may be the source of heat, from the moment when fusion commences, the temperature of the substance ceases to rise and remains constant until fusion is complete.

87. **Solidification** is the transition of the liquid condition of matter into the solid condition, and this transition is effected by lowering the temperature to a sufficient degree. In a few cases, however, such as

those of ether or alcohol, solidification has not been arrived at, although the last named liquid is said to have been reduced by the application of a powerful freezing mixture to such a state of consistency as to be poured with difficulty from one vessel to another. The laws of solidification are as follow :—(1) Solidification is produced for each body at a determinate temperature which is precisely that of its fusion. (2.) From the moment when solidification commences until it is completed, the temperature of the liquid remains constant.

88. The fact that bodies passing from the solid to the liquid condition absorb a quantity of heat from adjacent matter is utilized, by the formation of what are called **freezing mixtures**, to produce a degree of artificial cold of greater or less intensity. There should be chemical affinity between the components of the mixture, and one of them at least must be a solid. The following table exhibits some of the more common freezing mixtures, and the resultant refrigeration :—

(1)	Sulphate of soda,	8 lbs.	+ 10° to—17°.
	Hydrochloric acid,	5 lbs.	
(2)	Broken ice or snow,	2 lbs.	+ 10° to—18°.
	Sea salt	1 lb.	
(3)	Sulphate of soda,	2 lbs.	+ 10° to—19°.
	Nitric acid (dilute)	2 lbs.	
(4)	Phosphate of soda,	9 lbs.	+ 10° to—29°.
	Nitric acid (dilute)	4 lbs.	
(5)	Sulphate of soda,	6 lbs.	+ 10° to—26°.
	Nitrate of ammonium,	5 lbs.	
	Nitric acid (dilute)	4 lbs.	

89. **Conduction of heat** is the transmission of the vibratory motion, which constitutes heat, from the source of that motion through the molecules of a body; causing a corresponding rise in its temperature. Substances composed of compact or dense matter are generally much better conductors than those of a loose or porous nature. Metals are therefore, as a rule, better conductors than stone; stone than wood; wood than silk or wool. Fur, feathers, sawdust, bark of trees, and similar substances are all bad conductors. The utility of woolen or silk clothing depends largely upon this lack of conductive power, and according to some, it is chiefly due to the loose texture of the woven material, the interspaces being filled with air, which is a bad conductor; and thus the heat of the body is not permitted to escape. Glass and brick, although of a compact consistency, are poor conductors, because they are not homogeneous substances, but are mechanical mixtures of substances possessing very different physical characteristics. Good conductors are cold to the touch, because of the rapidity with which the heat of the hand is propagated through the molecules of the body. Liquids are bad conductors of heat, and so probably are gases; but in the latter case there is still much room for investigation, and the conductive power of gases, is, according to Dr. Tyndall, an open question

90. When a liquid is heated from above, its temperature rises very slowly on account of the defective conductive power of liquids, and the fact that the surface liquid becoming lighter as it is heated, has no

tendency to make way for the heavier liquid below; but when the source of heat is placed below the containing vessel, the temperature rises with greater or less rapidity. This is due to the expansion of the particles of liquid immediately in contact with the source of heat, and their consequent ascent towards the surface; a new layer of particles being thus constantly brought in contact with the source of heat, until the whole mass attains a uniform temperature, which is that of ebullition. The **convective** power of liquids may be exemplified by reference to the Gulf-stream, and other great ocean currents. Gases, as they are more expansible than liquids, possess accordingly greater convective power, and hence the susceptibility of the atmosphere to comparatively slight changes of temperature, arising from increased or reduced terrestrial radiation, and resulting in such phenomena as the trade-winds, land and sea breezes, and winds in general.

91. **Heated substances** communicate or **radiate** their heat in straight lines, by propagating an undulatory motion through the medium—ether. Substances differ much in their radiating power. Bright, polished surfaces radiate least, and rough, blackened surfaces radiate best. Those substances which radiate best are also the best absorbents of heat, but it has been found that white lead has quite as great an absorbent power as lamp-black. The power of reflecting heat is found to be the reciprocal of the absorbent power, that is the worst absorbents are the best reflectors. Radiation takes place **in vacuo**, as is

sufficiently proved by the fact of the solar heat reaching the earth, although it traverses what is believed to be a perfect vacuum before doing so.

92. **The quantity of heat** which a body absorbs when its sensible temperature is raised from zero to 1°, compared with that which under similar conditions an equal weight of water would absorb, is called the **specific heat** of the body; or it is a measure of its capacity for heat. *e.g.*, If one kilogramme of mercury at 100° be mixed with a kilogramme of water at zero, the resulting temperature of the mixture is only about 3°; that is the mercury has been cooled by 97°, but this quantity of heat lost by it has only sufficed to raise the same weight of water through 3°. The heat capacity of water then is about 32 times as great as that of mercury for an equal elevation of temperature.

93. When a solid is passing into the liquid condition, or when a liquid is passing into the gaseous condition, the temperature of the solid and of the liquid remains constant, throughout the duration of the process of fusion, or of vaporisation, whatever may be the intensity of the heat applied. A large amount of heat, consequently, must be absorbed during the change of state, the sole effect of which is to maintain the liquid or gaseous state respectively. This amount of heat which does not affect the thermometer, and which combines in some way with the molecules of the body, is called **Latent Heat.** This term which simply means hidden heat, does not express the operation or destination of the absorbed heat, which is used up in conferring potential energy upon the

molecules of matter. In order to liquefy ice, as much heat is consumed as would suffice to raise an equal weight of water through 79·25°C., or through 142.65°F.; or what is the same thing differently expressed, it would raise 79·25 times that weight of water through 1°C., 79·25°C. is therefore the latent heat of water. If the water obtained by melting ice be heated until it reaches a temperature of 100°C., water-gas is given off, and there is no further rise in the temperature of the water, until the operation of vaporisation is completed. A large amount of heat is being absorbed notwithstanding, and this is consumed in separating the molecules, and overcoming the atmospheric pressure. The latent heat of vaporisation of a given weight of water is sufficient to raise an equal weight of water through 537·2°C., or 967°F., or 537·2 times that weight of water through 1°C. The latent heat of steam is therefore 537°C. The cooling of the atmosphere, by the falling of a shower of rain; or, by watering streets, or floors of rooms, is explained by the evaporation of the liquid and the consequent absorption of heat from adjacent matter. In like manner when steam, which has been formed under a pressure of several atmospheres, and therefore possesses a temperature considerably above 100°C., is permitted to escape into the air, the hand may be held in it with perfect impunity, since the pressure being now less than that to which the steam was previously exposed in the boiler, the water-gas will at once expand, the super-heat will become latent or will assume the potential condition, and the heat will not sensibly affect the hand thrust into it. **Superheated steam**, that is steam which has been passed through a coil of piping heated to a high temperature, also permits of the hand being passed through it without scalding. This is supposed to be due to the fact that superheated steam being in the condition of a pure gas is a bad conductor of heat, therein differing from ordinary steam, which is simply a vapour and a much better conductor of heat. Every gas, on expanding, if it performs work must likewise absorb heat. When a gas is liquefied, or a liquid is solidified, the previously latent heat becomes sensible, and this explains the action of freezing mixtures, and of such processes as that of Carrè's freezing machine.

94. A **thermal unit** is the amount of heat requisite to raise 1 kilogramme of water through 1°C., or, in other terms, it is the amount of heat requisite to raise 1 lb. avoir. of water through 1°F. The first expression is the French unit, called the **calorie.** A calorie, converted into mechanical force, would raise a weight of 1 kilogramme to a height of 425 metres, and conversely the fall of 1 kilogramme through a space of 425 metres would produce 1 calorie of heat; or the amount of heat required to raise 1 lb. of water through 1°F. would raise a weight of 1 lb. through 772 ft., and the fall of 1 lb. through 772 ft. would produce heat enough to raise 1 lb. of water through 1°F. This latter measure of the dynamical force of heat is known as "Joules' equivalent."

95. When two elements combine together by **equivalent** weights, heat is evolved. This is known as

Heat of Chemical Combination, or calorific value, and its nature may be best understood by means of the following examples:—The combination of one gramme of hydrogen with its equivalent—eight grammes of oxygen would evolve as much heat as would raise 34462 grammes of water from 0°C. to 1°C., or 39·1 grammes of potassium combining with 35·5 grammes of chlorine would evolve sufficient heat to raise 104476 grammes of water from 0°C. to 1°C., or, again, 23 grammes of sodium combining with 35·5 grammes of chlorine would evolve sufficient heat to raise 94847 grammes of water from 0°C. to 1°C. The determination of the heat of chemical combination is very difficult, and requires accurate experiment in each individual case.

96. **Calorific value** is the **heating power** of a substance during combustion, but calorific **intensity** is the **actual temperature** of the burning substance, and this calorific intensity is calculated from the calorific value. When the combustion goes on in oxygen, the following is the method of calculation:—Divide the calorific value of the relative weight of the combining element in the compound, by the product of the specific heat of the compound into its total relative weight.

97. **The atomic heat** of an element is obtained by multiplying its specific heat into its atomic weight. Thus—sp. heat of copper$=0·0951$, atomic weight$=63·5$, atomic heat$=0·0951\times63·5=6·0389$. Sp. heat of zinc$=0·0955$, atomic weight$=65$, atomic heat$=0·0955\times65=6·2075$. In like manner the atomic heats

of iron, tin and silver are respectively 6·3728, 6·6316, and 6·1560, from which examples it appears that there is an approximation to an identity. The divergences from the general law may be partially accounted for by the different molecular conditions of the elements during the determination of their specific heat, and by the differences in their fusion points. The atomic heats of gases are about one-half that of solids; thus the atomic heats of hydrogen, oxygen and nitrogen are respectively 3·4090, 3·48 and 3·41. The importance of this law of atomic heat is evident from a consideration of the assistance which it yields in determining the atomic weight of an element the sp. heat of which has been ascertained. Still it is to be noted that, although its truth is distinctly **indicated,** it has not in all cases been clearly established. It is believed that this identity of atomic heats will be found to exist likewise in chemical compounds of the same group, as in chlorides, iodides, etc.

98. **The specific gravity** of a body is the ratio of its weight to an equal volume of pure water at a known temperature, say, 15·55°C. As it would often be impossible to obtain equal volumes of the substances whose specific gravity it is desired to ascertain, advantage is taken of the principle of Archimedes, that a body immersed in water displaces a mass of the water equal in volume to itself, and has its weight diminished by that of the equal volume of water it displaces. To determine, then, the sp. gravity of a solid heavier than water, weigh the substance in air, and then in pure water at 15·55°C., or 60°F. The sp.

gravity of the substance is equal to its weight in air divided by the weight in air less the weight in water. Let A be the weight in air, and W the weight in water; then sp. gr. $=\frac{A}{A-W}$. In accurate calculations the weight of the mass of air displaced by the body when weighed in air must be taken into account. Water is 815 times heavier than air, so that from the result of the above calculation must be subtracted the result of the following one—$\frac{W}{815\ (A-W)}$. Ex. A piece of prismatic quartz is found to weigh in air 311·91 grains, and in water 195·46 grains, hence sp. gr. $=\frac{311{\cdot}91}{311{\cdot}91-195{\cdot}46}=$ 2·678; but the weight of air displaced in the first weighing $=\frac{195{\cdot}46}{815\ (311{\cdot}91-195{\cdot}46)}=$ ·002, therefore the true specific gravity is 2·678—·002=2·676. If the substance be too light to sink of itself in water, it is attached to a sinker, the weight of which in pure water is B.; then sp. gr. $=\frac{A}{A+B-(W+B)}$. For the determination of the specific gravity of liquids, the following method is commonly adopted. Weigh a small cylinder of glass, containing mercury, first in air, then in water, and then in the liquid the specific gravity of which is to be estimated. The loss of weight in water shows the weight of a volume of water equal to the volume of the cylinder, and the loss in the liquid to be tested shows the weight of an equal volume of that liquid. Divide the latter result by the former, and the quotient is the specific gravity required. Ex. The glass cylinder is weighed in air, and then in water, and loses in weight 442·8 grains; it is then carefully dried and weighed in the liquid to be tested, and it loses in weight 354·3 grains; the specific gravity therefore is $\frac{354\cdot3}{442\cdot8}=0\cdot8$. A second and direct method of ascertaining the specific gravity of liquids, is to take a bottle so fitted as, when balanced by a counterpoise, to hold exactly 1000 grains of pure water; if now filled with nitric acid, it weighs 1517 grains; if filled with benzol, it weighs 0·850 grains. An instrument called the hydrometer is also used to ascertain the specific gravity of liquids. This instrument is known under various names, as—lactometer, areometer, saccharometer, etc., according to its special application. It usually consists of a glass bulb bearing a slender stem or spindle; the bulb is so weighted with mercury or shot that it sinks to a certain depth in liquid and maintains the stem in an upright position. The spindle is graduated in such a manner that its zero marks exactly the point to which it sinks in pure water. If the instrument be placed in a liquid of greater density than pure water, the spindle will accordingly stand higher; or if the liquid be lighter than water, the spindle will sink deeper. In practice, different spindles are employed, according as the liquid to be tested is heavier, or lighter than pure water. To ascertain the specific gravity of a gas, a light glass globe of known weight, and of a capacity of about 50 cubic inches is used. This globe, in a perfectly dry state, is carefully filled with dry atmospheric air, and accurately weighed. It is then exhausted of air and filled with the dry gas of which it is required to ascertain the specific gravity, and is again weighed. These weighings, less the weight of the globe, will evidently give the ratio existing between the weight of air and the gas. "If the globe employed be sufficiently large to contain, at 60°F. and 30 inches bar., 46·7 cubic inches of gas, the bulk will represent one grain of hydrogen gas, and that globe will contain the quantities of the elementary gases which are represented by the atomic weight of these gases. That is to say,—

1 vol. of hydrogen being = 1 grain.
1 vol. of oxygen will be = 16 grains.
1 vol. of nitrogen " = 14 "
1 vol. of chlorine " = 35·5 "

And the quantity of a compound gas will be represented by its atomic weight divided by its atomic measure. Thus,—

1 vol. carbonic acid gas (CO_2), will be = 44 ÷ 2 = 22 grs.
1 vol. carbonic oxide gas (CO), will be = 28 ÷ 2 = 14 grs.

The same volume of atmospheric air will be 14·47 grains."—*Griffin.*

99. It may often be necessary for the student to ascertain the **absolute** weight of a certain volume of a gas, and to do this he has only to remember the following facts. The weight of one litre (equal to 61·02 cubic inches) of hydrogen, at 0°C., and at 760 mm. bar. pressure, is 0·08936 grammes : and, since the combining weight of elementary gases, or the density of componnd gases, is simply an expression of their relative weight compared with that of hydrogen, to find the absolute weight of a litre of any of these gases —multiply 0·08936 by the number representing the combining weight of an elementary gas, or the density of a compound gas. Thus :—

1 litre	hydrogen	(H= 1)	weighs	0·08936	grammes.
" "	nitrogen	(N=14)	"	14×0·08936	"
" "	oxygen	(O=16)	"	16×0·08936	"
" "	marsh gas (CH_4),	density=16÷2=8	"	8×0·08936	"
" "	ammonia (NH_3),	" =17÷2=8·5	"	8·5×0·08636	"
" "	carbonic acid gas (CO_2),	=44÷2=22	"	22×0·08936	"

Prof. Williamson's "absolute volume," which serves the same purpose, is 11·2 litres; that is, this absolute volume is simply the bulk of one gramme of hydrogen; 14 grammes of nitrogen; 16 grammes of oxygen; 8 grammes of marsh gas; 8·5 grammes of ammonia, or 22 grammes of carbonic acid gas; at 0°C., and at 760 mm. bar. It is useful to remember also that, in English measurement, 100 cubic inches of hydrogen at 32°F. and at 30 inches bar. weigh 2·22 grains; or, at 60°F., and at 30 inches bar., 2·14 grains.

100. When a plate of zinc and a plate of copper are immersed in a vessel containing dilute sulphuric acid, electrical action is set up; the zinc becomes **positively** electrified and the copper **negatively** electrified; but, as the current, or transmission of electrical force, passes through the liquid from the zinc to the copper, the copper is technically said to be **positively** electrified, and the zinc **negatively** electrified; and if the two plates be joined outside the liquid by means of a copper wire, an electrical current passes from the copper to the zinc; hence the copper plate, by which the current leaves the cell, is called the positive pole, and the zinc plate, by which the current re-enters the cell, is called the negative pole. If, now, a series of such vessels furnished with zinc and copper plates and dilute sulphuric acid be arranged together, so that the copper plate of one vessel be joined to the

zinc plate of the adjoining one, by means of a copper band or wire, the arrangement is called a galvanic battery, and each vessel is called a cell, or an "element." There are many varieties of galvanic batteries, one of the most valuable of which, perhaps, is Groves' battery.

101. **Groves' battery** consists of a series of cells, each cell being constituted as follows :—(I.) A vessel of glazed earthenware, or of glass containing dilute sulphuric acid (one part acid to four parts water). (II.) A lesser vessel of porous earthenware, containing concentrated nitric acid. (III.) A bent plate of amalgamated zinc, which fits into the larger vessel and permits of the porous vessel fitting in its bend. (IV.) A plate of platinum which fits into the porous vessel. The platinum plate of one cell is fastened by means of a binding screw to the zinc plate of the adjoining cell; there will thus be a free platinum, and zinc plate, the former being the positive pole, the latter the negative pole. The sulphuric acid is decomposed by the action of the zinc, hydrogen is evolved, and effects the partial decomposition of the nitric acid, evolving nitric oxide, and thereby preventing the polarization of the platinum plate. This is a powerful battery, but is not constant.

102. **Opposite electricities** attract, and similar electricities repel each other; hence it is that elements which appear during electrolysis at the positive pole are called **electro-negative,** and those which appear at the negative pole are called **electro-positive.**

103. **Electrolysis** is the resolution of a chemical compound in the liquid condition, into its constituent elements, by means of a galvanic current. Let it be

required, for instance, to decompose water into its constituents. A glass vessel is inserted upon a suitable base, usually of mahogany, through which are passed two copper wires terminating inside the vessel by small platinum plates, and terminating at the other end in small brass pillars fixed in the base and supplied with binding screws. This vessel is partially filled with slightly acidulated water, and two test tubes of equal size filled with acidulated water are inserted in the vessel, a test tube over each platinum plate. If, now, wires from the terminal plates of a Groves' battery, of four or five cells, be connected with the small brass pillars above referred to, the circuit will be closed, electrical action is at once set up in the acidulated water and an accumulation of gas will be observed in each of the two test tubes. Since it is the platinum plate in a cell of Groves' battery, by which the current leaves the battery, the test tube which is inverted over the small platinum plate connected with it is evidently at the positive pole, and in like manner the test tube inverted over the platinum plate which is connected with the terminal zinc plate of the battery is at the negative pole. The water connecting the poles requires to be acidulated, because pure water conducts the current very imperfectly. It is not to be supposed that there is any transmission of gas between the poles, but only an interchange of elementary atoms, so that while the molecules of water in immediate contact with the poles liberate atoms of the constituent gases, the intervening molecules simply exchange atoms. If the galvanic circuit be broken before either test tube is full of gas, it will be found that one test tube contains about twice as much gas as the other. By applying the proper tests it will be seen that the larger quantity consists of hydrogen and the lesser quantity of oxygen. By a variety of experiments it can be shewn that the proportion ought to be exactly two of hydrogen to one of oxygen, but oxygen being rather more soluble than hydrogen in water, the apparently contradictory result mentioned above is obtained. Since oxygen appears at the positive pole it is called an electro-negative, and hydrogen appearing at the negative pole it is called an electro-positive.

When compounds of metals and non-metals are decomposed by electrolysis, the non-metals appear at the positive pole, and the metals at the negative pole, hence metals are classified as electro-positive, and non-metals as electro-negative elements.

104. **An induction coil** consists of (I) a primary coil of silk-covered or insulated wire, of a few yards in length, wound round a hollow cylinder, and communicating at one extremity with the positive electrode of a battery, and at the other with the current break; (II) a secondary coil of very fine insulated wire of great length, wound round the primary or inducing coil, (III) a bundle of soft iron wires packed in the interior and forming the core; (IV) the hammer, a small piece of soft iron affixed to a spring, which in its normal position is pressed down upon the anvil, and through which the current passes from the coil to the anvil, and thence returns to the negative electrode of the battery to complete the circuit; (V) the anvil,

a small piece of soft iron through which the current passes from the hammer. When the circuit is completed, the current passes through the primary coil and then through the hammer and anvil, but, while the current passes, the core becomes magnetic, and the hammer is therefore attracted to its projecting end; but so soon as the hammer leaves contact with the anvil the current is of course broken, the core ceases to be magnetic, and the hammer being released is immediately brought back into contact with the anvil by means of the spring, the current again passes, is again broken and so repeated action goes on, with very great rapidity. The hammer and anvil are accordingly known as the current break. Each time the current is closed or broken, an induced current is manifested in the secondary coil, from the extremities of which visible discharges are obtained.

105. When gases of different densities are brought in contact with one another they display a constant tendency to intermingle, and this intermixture maintains, notwithstanding that the gases may be of very different densities, thus—hydrogen and oxygen, although the latter gas is sixteen times as heavy as the former, will not merely intermingle, but will, after intermixture, shew no tendency towards separation. The rate of diffusion of any gas is ascertained by means of the diffusion tube. This is simply a graduated tube of about a foot in length, open at one end and at the other stoppered with a thin plate of plaster of Paris. If the tube be filled with a gas, and the open end inverted in mercury, the mercury will be

seen to begin to ascend, shewing that the gas is escaping through the porous plaster of Paris, and that the mercury is consequently being forced up in the tube by atmospheric pressure outside the tube. The diffusive rate of gases is in inverse ratio to the square root of their density. Thus, the density of hydrogen being 1 and the density of oxygen being 16, and the square root therefore being as 1 to 4; four times as much of hydrogen would pass through the plaster of Paris, in a given time, as of oxygen.

PART II.

CHAPTER I.

OXYGEN—OZONE.

Chemistry of the Non-Metals.

106. **Oxygen** ($O^{II}=16$. Molecular formula O_2). Discovered by Dr. Priestley, 1774; by Scheele, 1775. Examined and named by Lavoisier, 1778. A colourless, tasteless, odourless gas; the supporter of all ordinary combustion; does not burn; not condensible to a liquid; sp. gravity 1·1056; sp. heat 0·2175; will not combine with fluorine under any known conditions; combines under artificial conditions with gold, silver, platinum, chlorine, bromine and iodine; and with most of the remaining elements it combines in nature. It is the most abundantly distributed element known, making nearly 50 per cent. of the solid matter of the globe, eight-ninths by weight of water, and about one-fifth by weight of air. It is slightly soluble in water. Obtained—(I). By application of heat to mercuric oxide —$2HgO=Hg_2+O_2$. Heated mercuric oxide gives—metallic mercury and oxygen. (II). Most cheaply, in large quantity, by decomposing manganese dioxide—(MnO_2);—$3MnO_2=Mn_3O_4+O_2$. Heated manganese dioxide, or black oxide of manganese gives—brown oxide of manganese and oxygen. (III). Most readily

and conveniently, by decomposing potassium chlorate —($KClO_3$);—$KClO_3 = KCl + O_3$. Heated potassium chlorate gives — potassium chloride and oxygen. NOTE:—The addition of a little manganese dioxide (which acts by catalysis) causes the oxygen to come off at a somewhat lower temperature than that at which the unmixed potassium chlorate liberates it. (IV). By electrolysis (103). (V). From the air.—First operation—A porcelain tube containing sodium manganate (Na_2MnO_4) is strongly heated and steam is passed through it, oxygen is evolved and may be collected in a jar inverted over water. The reaction is represented by the equation—$2Na_2MnO_4 + 2H_2O$ (in the form of steam)$= 4NaHO + Mn_2O_3 + O_3$. Heated sodium manganate and steam give caustic soda, sesquioxide of manganese and O_3. Second operation.—The current of steam is now discontinued, and a current of air is allowed to pass over the contents of the porcelain tube, when sodium manganate is again formed through absorption of oxygen from the air, while the nitrogen of the air passes on and may be either collected or allowed to escape. The second reaction is—$4NaHO + Mn_2O_3 + 3(O + N_4) = 2Na_2MnO_4 + 2H_2O + N_{12}$. Heated caustic soda, manganese sesquioxide, and air give sodium manganate, water, and nitrogen. The water will be driven off in the form of steam, and the operation may now be repeated. One hundred cubic inches of oxygen at 60°F. and 30 in. bar. weigh 34·203 grs. One litre at 0°C. and 760 mm. bar. weighs 1·4298 grammes, or 11·2 ll. weigh 16 grammes.

Ex. I. Phosphorus enflamed in oxygen in a bell-jar over water, burns with great energy and brilliancy, evolving fumes of phosphorus pent-oxide (P_2O_5), which speedily dissolve in water, forming phosphoric acid H_3PO_4; thus:—$P_2O_5 + 3H_2O = 2H_3PO_4$.

Ex. II. Charcoal at a red heat placed in a jar of oxygen, burns with brilliant scintillations, forming carbonic acid gas (CO_2).

Ex. III. Sulphur enflamed in a jar of oxygen, burns with a fine violet flame, forming sulphurous acid gas (SO_2), which, dissolved in water, gives the unstable hydrated acid—$SO_2 + H_2O = H_2SO_3$.

Ex. IV. Zinc armed with a little burning sulphur and placed in a jar of oxygen, burns with a fine green flame, forming zinc oxide (ZnO).

Ex. V. Fine iron, or steel wire in the form of a spiral coil, armed with burning sulphur and dipped into a jar of oxygen, burns with bright scintillations, forming the compound oxide—Fe_3O_4 (magnetic oxide of iron)$=FeO$ (protoxide of iron) + Fe_2O_3 (peroxide of iron).

Metals in the dry condition are rarely acted upon by oxygen, but moisture promotes combination, and rusting is a familiar instance of oxidation.

107. **Ozone** is oxygen in an allotropic condition, apparently consisting of three atoms united to form a molecule of two atoms. The rate of diffusion of ozone agrees with this view; some chemists, however, consider that it is really a trioxide of hydrogen (H_2O_3). Ozone is a gaseous substance possessing a peculiar smell, whence its name. Given off, in comparative abundance, when an electrical machine is worked.

Traces of it are observable in the oxygen obtained by the electrolysis of water. A series of electric sparks from a coil, passed through oxygen, changes a portion of it into ozone, and the oxygen diminishes by about one-twelfth of its volume. Ozone may be prepared by suspending a stick of phosphorus in moist air in a bell-jar, but better by partially covering with water in the bottom of a bell-jar, a freshly-scraped stick of phosphorus. It exists to a slight extent in the free state in the atmosphere, and is supposed to exercise a beneficial influence by oxidising noxious matter. The common test for its presence is unsized paper prepared in starch paste, in which some crystals of iodide of potassium (KI) are dissolved. The ozone oxidises the potassium, liberating the iodine, which imparts a blue colour to starch. This test cannot be depended upon, as nitrogen tri-oxide, ether, turpentine, etc., have a similar power of liberating iodine by absorption of oxygen. A better test is gum guaiacum, to which ozone imparts a blue colour. Ozone bleaches indigo, corrodes vulcanized caoutchouc, oxidises silver in a finely divided condition, and generally displays powerful oxidising properties.

NOTE.—Day's Blood Test; the suspected stain is first moistened with a solution of gum guaiacum in alcohol, and then with a solution of hydrogen peroxide (H_2O_2), in ether (ozonic ether), if the stain be a blood spot, it assumes a bright blue colour, which readily leaves an impression upon white blotting paper. This reaction is due to the decomposition of the H_2O_2 in contact with blood, the liberation of oxygen and the consequent blueing of the resin.

CHAPTER II.

HYDROGEN—WATER.

108. **Hydrogen** ($H^{I} = 1$. Molecular formula H^{2}). Probably known to Paracelsus, in the 16th century; rediscovered and examined by Mr. Cavendish 1781. A colourless, tasteless, odourless gas; a non-supporter of combustion; burns with a nearly colourless flame, combining with oxygen to form water only; not condensible to a liquid; sp. gravity 0·0693; sp. heat 3·409; not met with in the free state in nature; combines directly with only six elements—oxygen, chlorine, bromine, iodine, carbon and sulphur. With the last three it combines with difficulty, and it combines with chlorine and bromine alone at ordinary temperature, and even in these cases only in the presence of light. It is soluble in water to a very slight extent. Obtained, —(I.) By the action of sodium upon water—$2Na + 2H_2O = 2HNaO + 2H$. Sodium upon water gives caustic soda, and hydrogen. (II.) By the action of potassium upon water—$2K + 2H_2O = 2HKO + 2H$. Potassium and water give caustic potash and hydrogen. In this reaction so much heat is evolved that the gas takes fire and the flame is coloured violet, because of the sublimation of a portion of the potassium. (III) By the action of dilute sulphuric acid upon zinc—$Zn + H_2So_4 = ZnSO_4 + H_2$. Dilute sulphuric acid (one part H_2SO_4 and six parts water) and zinc give sulphate of zinc or white vitriol, and hydrogen. (IV.) By the action of dilute sulphuric acid upon iron—$Fe + H_2$

$SO_4 = FeSO_4 + H_2$. Sulphuric acid and iron give sulphate of iron, copperas or green vitriol, and hydrogen. (V.) By electrolysis (103). (VI.) By passing steam through an iron tube containing iron filings heated to a high temperature—$4H_2O + Fe_3 = Fe_3O_4 + H_8$. Black oxide of iron is formed in the tube and hydrogen is liberated. Collected by displacement either of air or water, dried by passing over calcic chloride, quick lime, or pumice stone saturated with sulphuric acid. Burns with a livid blue flame if there be traces of arsenic present, and with a yellow flame if burnt while issuing from a jet of glass containing soda in its composition. Its flame gives very little light, but intense heat. Hydrogen is the lightest known substance being 14.47 times lighter than air, and 11162 times lighter than water; one hundred cubic inches at 60°F. and 30 in bar., weigh 2·14 grains. One litre at 0°C and 760mm. bar., weighs .08936 gramme, or 11.2ll. weigh one gramme. If a moderately wide tube of about 20 inches in length be held over a hydrogen flame, the combination of the hydrogen with the limited quantity of oxygen entering the tube causes a series of small detonations or explosions of the mixed gases to succeed each other, with such rapidity as to produce what is called the musical flame, or the hydrogen harmonicon. The dry gas is used to fill balloons, and to produce the oxy-hydrogen flame.

109. **Water** (H_2O combining weight=18. Density of water-gas=9.) A compound of hydrogen and oxygen in the proportion, by volume, of two of hydro-

gen to one of oxygen and, by weight, of two of hydrogen to sixteen of oxygen. By electrolysis (103) water is decomposed into its constituent elements; and by passing a series of electric sparks by means of an induction coil, through steam generated in a flask which communicates by a delivery tube with a test tube inverted over water, steam is likewise decomposed; the water in the test tube will be expelled by the mixed gases collecting in it, and on a light being applied to the mouth of the test tube an explosion will follow, denoting the re-combination of the gases to form water. If hydrogen and oxygen be passed into a graduated tube, over mercury, in the proportion of two of hydrogen to one of oxygen, and the electric spark be passed through the mixed gases, they will immediately combine to form water occupying the $\frac{1}{2000}$th part of the space previously occupied by the gases, and the mercury will ascend, and practically fill the entire tube. Certain metals have so powerful an affinity for oxygen that they are able to decompose water at ordinary temperatures; these are—potassium, sodium, barium, strontium, calcium. The following metals decompose water by combination with its oxygen, at a red heat—iron, lead, zinc, bismuth, cobalt, copper, chromium, nickel, tin, antimony, aluminium. The following do not decompose water at any known temperature—gold, platinum, silver, mercury. Chlorine and bromine are the only elements which combine with water, no other elements are even dissolved by it to any considerable degree. It has been shewn elsewhere, that when hydrogen is burned in air, or in oxygen, water is the sole product, and the accurate performance of this experiment in a modified form, is the means of determining the composition of water by weight. Hydrogen is generated in the usual way, by the action of sulphuric acid (H_2SO_4) upon zinc, in a Woulfe's bottle, and the gas is passed through a series of drying tubes containing 1st, a solution of caustic potash (HKO), to absorb sulphuretted hydrogen (H_2S); 2nd, pumice stone, saturated with nitrate of silver ($AgNO_3$) to absorb arsenic and antimony. 3rd. Pumice stone saturated with sulphuric acid (H_2SO_4) to absorb moisture. The pure, dry, hydrogen now passes through a tube having a bulb enlargement at its middle point in which is placed a known weight of cupric oxide (Cu. O.) this bulb-tube is in turn connected with a receiver of known weight, kept cool during the experiment, by a constant stream of cold water; and this receiver is finally connected with a drying tube of known weight, containing pumice stone saturated with sulphuric acid (H_2SO_4) to absorb moisture. When the copper oxide is raised to a high temperature and the dry hydrogen is passed over it, the oxygen of the oxide at once combines with the hydrogen, and the water gas formed passes on to the receiver where it is almost entirely condensed to the liquid condition, and any vapour that does escape from the receiver is captured in the drying tube connected with it. The gain in weight of the receiver and of the last drying tube evidently represents the weight of the water formed, the loss of weight of the copper oxide bulb must represent the weight of liberated oxygen only, if therefore the weight of the oxygen be subtracted from the weight of the water formed, the remaining weight is evidently that of the hydrogen. By this experiment, accurately performed, it is ascertained that 100 parts water, by weight, contain 11·11 parts hydrogen and 88·89 parts oxygen. Pure water is colourless, tasteless and odourless, but in mass it appears of a bluish colour. It is almost non-elastic and is a remarkable exception to the general laws of expansion and contraction, since it reaches its maximum density at 4°C. and when heated above, or cooled below that point it expands. At 4° C. a litre of water weighs one kilogramme, or a gallon weighs 70007 grains. The density of ice is .92, that is 92 grammes of ice occupy the same volume as 100 grammes of water at 4°C. When water boils (81), it is converted into water-gas, occupying 1696 times the volume of the liquid. Water is rarely found pure in nature; it is called hard or soft according to its reaction with soap. Soap contains two acids, stearic and oleic acids which are combined with the soda of the soap. When such soap is rubbed in water containing sulphates, as calcium, or magnesium sulphate, the stearate and oleate are decomposed; soluble soda salts are formed while insoluble magnesium or calcium oleates and stearates form a curdy precipitate. Soft water, on the contrary, produces a lather with soap by simple dissolution. The following is **Dr. Clarke's test** for the comparative hardness of water—A known quantity of soap is dissolved in alcohol, and according to the amount of this soap decomposed by water under investigation, compared with the amount decomposed by water known to contain one, two, three etc., grains of calcium carbonate dissolved in 100,000 parts water, the test is said to yield results of one, two, three etc., degrees of hardness. The principal impurities of water are sulphates of soda, magnesia and lime; carbonates of magnesia and lime, carbonic acid gas vegetable and animal matter. **Suspended impurities** are got rid of by means of filtration dissolved impurities must be got rid of by distillation. Distilled water possesses an insipid taste due to the absence of dissolved air, but it may be aërated sufficiently for drinking purposes by passing it over porous charcoal. In the process of distillation, if precautions are not taken to drive off all dissolved gases, before collecting the aqueous vapour in the receiver, some quantity of the more soluble of these gases will of course be re-dissolved in the distilled water, and the same will be true of volatile impurities in general. **Carbonates** do not remain dissolved except in presence of free carbonic acid ($C.O_2$), hence when water containing carbonates is allowed to stand for some time after being drawn, till its dissolved carbonic acid has escaped, the carbonates will be found precipitated to the bottom of the containing vessel. Water percolating through limestone rock into caverns and containing abundance of carbonic acid gas, and carbonate of lime in solution, on reaching the air suffers evaporation to a considerable degree, and most of the carbonic acid gas escapes. The carbonate of lime is consequently deposited as a solid, forming **stalactites**, or pendant columns gradually elongating by the continued trickling of the water ; while that which reaches the floor of such caverns accumulates there in an upward direction forming **stalagmites**. This likewise explains the softening of water by boiling, since the carbonic acid is expelled, and the carbonates are precipitated. Temporary hardness of water is due to the presence of salts, more or less insoluble in hot water, or in water deprived of free carbonic acid ; this hardness will accordingly almost disappear after boiling. Permanent hardness, on the other hand, is due to the presence of salts which remain soluble even in boiling water. Washing soda (Na_2CO_3) destroys both temporary hardness, and permanent hardness, due to sulphates of magnesium and calcium, by forming insoluble carbonates and soluble sulphates :—$CaSO_4 + Na_2CO_3 = CaCO_3 + Na_2SO_4$; or, $MgSO_4 + Na_2CO_3 = MgCO_3 + Na_2SO_4$. The addition of quick lime to hard water serves to neutralise the free carbonic acid, which combines with the lime to form calcium carbonate ($CaCO_3$), and thus the other carbonates present, deprived of the free carbonic acid, are precipitated. **Mineral waters** are called **chalybeate** if they contain salts of iron ; **hepatic** if they contain sulphur ; **effervescing** if they contain carbonic acid. The presence of carbonic acid in water, in itself, cannot be regarded as detrimental since the refreshing and thirst quenching properties of water appear to be largely due to the carbonic acid gas contained. One consequence of the precipitation of carbonates and sulphates from boiling water, is the **furring** of kettles and boilers. This furring is chiefly caused by the carbonates, but, since calcium sulphate ($CaSO_4$), seems to require about 400 parts water for its solution, and is almost insoluble at temperatures above 100°C., as would be the case in boilers, a portion of the deposit is undoubtedly due to the precipitate of the sulphate also. **This furring** is a serious matter, not merely because of the consequent waste of fuel which takes place in heating the mineral deposit, in addition to the metal and the water, but as tending to cause explosions. To prevent furring in kettles, it is not unusual to place a round pebble in the vessel, which by its rolling, prevents the precipitate forming a solid deposit. In boilers, furring may best be prevented by the addition of sal-ammoniac (NH_4Cl), which acts as follows :—$2NH_4Cl + CaCO_3 = CaCl_2 + (NH_4)_2CO_3$. Calcium chloride remains dissolved, and ammonium carbonate escapes as a gas. Sea water contains all the salts found in other waters with a great preponderance of chloride of sodium, common salt ($NaCl$); one gallon contains about 2500 grains of saline matter, of which about 1900 are salt. It is said that clothes once wetted with sea-water never become perfectly dry again, and this is attributed to the presence of magnesium chloride, which is distinguished by a constant tendency to deliquesce in moist air. Well water is usually impure on account of decaying vegetable and animal matter in solution, which percolates through the surface soil, and by its admixture with water tends to generate

typhoid malaria and to spread epidemic disease. Water containing chlorides and nitrates, or nitrites, is always more or less injurious to the human system. The tests for all the impurities mentioned in this article will be found elsewhere (62, 63, 64). In this connection the danger arising from the use of leaden cisterns is to be noted. The interior of such cisterns gradually becomes oxidised by contact with the atmospheric oxygen; this oxide is insoluble in hard water containing carbonates and sulphates, but the nitrates and nitrites, generally present in soft water, cause its solution in a greater or less degree, thereby rendering the water poisonous to a corresponding extent. Many salts contain water, which is in close union with the other constituents, and is hence called **water of crystallisation,** this water may generally be expelled by heating to 100°C. Water which is still more closely connected in chemical union with a salt, and which is not expelled at 100°C., is called **water of constitution.** The property of water of expanding on freezing is most important in the economy of nature, for if it followed the general law and became heavier as it became colder, large bodies of water would freeze as a mass, thereby destroying all contained animal life, and, moreover, since water is heated almost entirely by convection, and therefore from below upwards, such masses of ice could never liquefy again under present conditions. Ice is generally formed on the surface, but it is occasionally formed on rock bottoms of rivers, on account of the more rapid radiation of heat from the mineral matter forming the bed of the river than from the water of the river itself; the water will, therefore, be most cooled down in contact with the bottom, and may even form masses of ice, to which the name of **anchor ice** has been given.

CHAPTER III.

HYDROGEN PEROXIDE—OXY-HYDROGEN FLAME.

110. **Hydrogen peroxide, Oxygenated water** (H_2O_2). An unstable, artificially formed compound. Appears to consist of one molecule of water in combination with one atom of oxygen. A liquid possessing considerably greater consistency than water; Sp. gravity 1·45; has a slight odour of chlorine; readily decomposes, on the application of heat, liberating oxygen. Contact with gold, platinum or silver, which, it will be remembered, have no direct affinity for oxygen, causes immediate decomposition of the peroxide without any alteration of the metal. On the other hand, if the peroxide be dropped upon oxides of the above metals, they are immediately reduced with explosion, to the metallic state. The explanation is supposed to be that the oxygen of the oxides and the oxygen of the peroxide being in different chemical conditions there is mutual attraction between them, as if they were different elements. Used in medicine and in photography. Obtained by the action of hydrochloric acid upon baric oxide—$BaO_2 + 2HCl = H_2O_2 + BaCl_2$; to the resultant solution argentic sulphate

is added, with the precipitation of baric sulphate and argentic chloride—$BaCl_2 + Ag_2SO_4 = 2AgCl + BaSO_4$. The clear liquid is decanted, and concentrated by exposure in the receiver of an air pump, over oil of vitriol, in order to get rid of water, which evaporates more than the peroxide; bleaches litmus. Experiment.—Throw a little manganese dioxide (MnO_2) into a solution of hydrogen peroxide and oxygen will be evolved, as may be seen by the application of the usual test—a splinter of wood in the condition of a red coal. The manganese dioxide acts like the metals mentioned above, without undergoing any decomposition itself.

111. When oxygen and hydrogen are mingled together, in the proportions necessary for complete combustion, blown through a blowpipe nozzle and ignited, the almost colourless flame produced evolves intense heat estimated as being about 8300°C, and which is capable of fusing with ease refractory substances such as platinum, steel, or gold. On account of the explosive character of the gaseous mixture, the oxygen and hydrogen should be kept in separate reservoirs and only brought together at the point of combination, or else the mixture should be passed through a **Hemming's Jet** to avoid risk of the flame passing back to the common reservoir. The Drummond light, or lime light is produced by causing a jet of oxygen to play upon a small cylinder, or ball of close-grained, well burned lime whilst it is heated in a jet of hydrogen gas; the heat evolved by the combination of the two gases being intense, the lime is raised to a state of

brilliant incandescence, and, being infusible, it gives a magnificent light, suitable for signals, or for lighthouse purposes. The same precautions must be adopted as in the use of the oxy-hydrogen blowpipe. Magnesia or zirconia are occasionally substituted for lime, and the experiment may be varied by using the oxy-calcium light, obtained by heating the lime in the flame of a spirit or oil lamp, and playing upon it with the jet of oxygen; or, by substituting the flame of coal gas for that of spirit, or of hydrogen, and still employing the oxygen jet, the oxy-coal-gas light is obtained.

CHAPTER IY.

NITROGEN—ATMOSPHERE.

Respiration of Plants and Animals.

112. **Nitrogen** ($N^{III}=14$. Molecular formula N^2). A colourless, tasteless, odourless gas; does not burn; does not support combustion; not condensible to a liquid; soluble in cold water to a slight extent; is innoxious in itself, but does not support animal life. Sp. gravity 0·972; 100 cubic inches at 60°F. and 30 in. bar., weigh 30 grains; 11·2 ll. at 0°C. and 760 mm. bar. weigh 14 grammes. Occurs free in nature, forming four-fifths of the atmosphere, and enters into combination in many abundantly distributed compounds. Nitrogen is an important element of organic life, and its inert nature is in striking contrast to the energetic characteristics which it appears to confer upon the

compounds into which it enters. By combination with oxygen, it forms one of the most powerful acid radicals known—Nitric pentoxide (N_2O_5), and with hydrogen it forms one of the most powerful of alkalies —ammonia (NH_3). It combines very feebly with most other elements, and hence many of its compounds are very unstable and explosive. Nitrogen affords an excellent illustration of the law of multiple proportions—N_2O; N_2O_2; N_2O_3; N_2O_4; N_2O_5. Obtained by burning phosphorus over water, in a bell jar filled with air. Phosphorus combines with the oxygen of the air forming phosphoric pentoxide (P_2O_5) which is evolved in dense white fumes, speedily dissolving in the water forming phosphoric acid—$P_2O_5 + 3\ H_2O = 2H_3PO_4$, and leaving free nitrogen in the jar.

113. **The atmosphere** is composed chiefly of the two gases nitrogen and oxygen mechanically mixed together, in the proportion of about 79.19 vols. of nitrogen to 21·81 vols. of oxygen, or, by weight, about 76·99 parts nitrogen to 23·01 parts oxygen. The other constituents are aqueous vapour, carbonic acid gas, ozone and ammonia. Since the amount of aqueous vapour varies according to temperature, rainfall, and proximity of water, it is difficult to give anything like a definite statement as to its relative amount, but it is probably on the average about 14 vols. in 1000, or 8·7 parts by weight in 1000. The amount of **carbonic acid** gas is subject to considerable variations according to the locality where the air is tested ; the average amount is about 4· vols. in 10,000, or 6 parts by weight, in 1000. In crowded buildings, or places

where diffusion of gases is more or less obstructed, the proportion often rises much higher. **Ozone** probably fulfils important purifying functions in the atmosphere by oxidation of noxious gases, but its relative quantity cannot be calculated. **Ammonia** exists in the air in variable quantity, but it is in no case very abundant, the maximum amount observed being 135 vols., and the minimum amount 1 vol. in 1,000,000 vols. Ammonia is, notwithstanding its small proportional amount, a most important agent in nature, since plants derive nearly all their nitrogen from it, and thereby perfect their fructification, supplying directly or indirectly, the means of animal nutrition. The determination of the exact relative proportions of oxygen and nitrogen in air, which it is desired to test, is arrived at as follows —A large globe, exhausted of air, and of accurately known weight, is connected with a tube containing metallic copper, but exhausted of air, closed at either end, by a stop-cock, and having its weight also accurately determined. This tube is in turn connected with a series of U tubes containing sulphuric acid, to absorb ammonia and water ; and this with another series of tubes containing potash, to remove carbonic acid gas. On heating the copper to a red heat and opening the stop-cocks, atmospheric air slowly passes through the purifying tubes, getting rid of its carbonic acid, ammonia and aqueous vapour, and, on reaching the copper, the oxygen immediately combines with it to form copper oxide, whilst the nitrogen passes alone into the globe. The increase in weight of the globe and of the tube containing the copper will, subject to sundry corrections, give the relative proportions of the oxygen and nitrogen in the air. That air is a mere mechanical mixture is shewn by the fact that an artificial mixture of oxygen and nitrogen, according to the proportions given above, is found to possess nearly all the properties of ordinary air, but the gases are present neither according to their atomic weights, nor in any multiple of these weights, and when thus mixed there is no evolution of sensible heat, as would be the case if chemical union had taken place; again if air be shaken up in a bottle containing some water a portion of the air will be dissolved, and if this dissolved air be expelled by means of heat it will be found that the proportions of the gases are now 1·87 vols. of nitrogen to 1 vol. of oxygen; this is due to the fact that oxygen is more soluble that nitrogen in water, but to exhibit this difference the gases must have been separated, and it cannot be supposed that, if the gases had been chemically united, mere mechanical action could have disunited them. There are of course many accidental impurities in the air, the products of respiration, combustion, putrefaction and electrical agency; such as—nitric acid; sulphurous acid; carbonic oxide; carbon in a finely divided state; hydro-carbons; material particles, in the shape of dust; and probably germs of both animal and vegetable life. The weight of the atmosphere has been referred to elsewhere (68). Since it has weight and, being composed of gases, is compressible, it follows that the density will be unequal throughout its mass, the lower portion, exposed to the greatest superincumbent pressure, being the most dense, and this variation in density may be considered as approximately stated in the following law—"At a height of seven miles the density of the atmosphere is reduced to one-fourth the density at the sea-level, and for every increase of height by seven miles the rarity of the air is similarly quadrupled." The absolute height of the atmosphere, is an open question; but it is probably not less than 200 miles. It is generally agreed however, that there is a limit to the atmospheric layer, beyond which there is supposed to be a vacuum in which the aërial particles are prevented from expanding by their own weight. In the night time the radiation of heat from the earth, so reduces the temperature of the surface that the lower layers of air coming in contact with it are cooled and condensed, to such a degree as to be unable to retain the contained aqueous vapour, as such; and a portion is therefore deposited upon the earth as *dew*; should the temperature at the moment of deposition be at, or below, the freezing-point, *hoar-frost* and not dew will be formed. *Fogs* over rivers and lakes in summer are due to the partial condensation of the aqueous vapour, rising from the comparatively warm water, by contact with the colder air from the land. When a mass of air comes in contact with a colder current of air the former suffers condensation, and its contained vapour is deposited as rain; or, if the temperature be reduced to the freezing point, the condensed vapour assumes the crystalline form and falls to the earth as *snow*. *Hail* seems to be snow which has been exposed to a peculiar whirling motion, acquiring thereby a number of coats or layers in a partially congealed state.

114. **Oxygen mingled with Nitrogen** is inhaled by animals in the process of respiration. The nitrogen is exhaled without having undergone change, but the oxygen is absorbed by endosmosis into the venous blood of the capillaries of the lungs, and is thence conveyed throughout the system, serving not merely to purify the blood by the oxidation of carbonaceous matter, produced by the wasting of the body, but also assisting to build up new matter to compensate for that waste. This oxidation serves at the same time to maintain the requisite temperature of the blood. A certain quantity of carbonic acid is given off at each expiration, and thus the breathing of animals has a constant tendency to vitiate the air, by the removal of the element *essential* to animal life and the substitution of a compound gas *destructive* to that life. It is estimated that during every twenty-four hours an average adult inhales about 360 cubic feet of air, containing about 76 cubic feet of oxygen, and that he exhales about 15 cubic feet of carbonic acid gas containing 8 oz. solid carbon. The air expired from the lungs of man contains about 3·5 to 4 vols. carbonic acid gas in 100 vols. of air. A demonstration of this relatively large quantity of carbonic acid evolved from the lungs as compared with the amount existing in atmospheric air may be made by passing, by means of a gas holder, a known volume, say 200 cubic inches, of air through a vessel of lime-water, and then passing an equal volume of 200 cubic inches of air from the lungs, collected by displacement of water in the gas holder, through another vessel of lime-water of equal

content to the former one. The relative amount of calcium carbonate precipitated will be a fair test of the amount of carbonic acid present in each case, but since in 200 cubic inches of air there will be, under ordinary circumstances, only about 0·08 cubic inch, and in the same quantity of air from the lungs between 7 and 8 cubic inches of carbonic acid gas a precipitate will practically be obtained in the latter case only. Oxygen imparts to the purplish venous blood, the bright red hue of arterial blood. Pure oxygen would act with too great energy upon the system causing inflammation of the respiratory organs, and hence the necessity for it being diluted with nitrogen.

The **chlorophyl,** or green colouring matter of plants has the power, in the presence of diffused sunlight, of decomposing carbonic acid, absorbing carbon to form vascular tissue, and setting oxygen at liberty, thereby performing a function the reverse of that of animals, and rendering the air, vitiated by admixture of carbonic acid, once more fitted for the support of animal life. Plants, in a sitting room, tend accordingly to purify the air, but they are objectionable in a bedroom, since they can only decompose carbonic acid in diffused sunlight, whilst in the dark they appear to absorb a small quantity of oxygen and to evolve carbonic acid; and air containing as much as 0·1 per cent. of its volume of the latter gas is injurious to the human system, an amount equal to 0·5 per cent is positively dangerous, and 8 per cent produces suffocation. The carbonic acid gas of the atmosphere not merely supplies the plant, through its leaves, with carbon for its growth, but, being washed down to the earth in rain, it acts chemically upon rocks containing alkalies, forming carbonates, and thereby assists in the disintegration of such rocks, supplying nutriment to the plant through its roots both in the form of carbon, and by solution of mineral matter such as phosphate of lime, which water alone would be unable to dissolve, and which the plant can only take up in the dissolved

CHAPTER

NITROUS OXIDE—NITRIC OXIDE—NITRIC TRIOXIDE NITRIC PEROXIDE.

115. **Nitrous oxide, nitric monoxide or Laughing gas** ($N_2O=44$. Density $\frac{44}{2}=22$). A colourless gas possessing a slight odour and sweetish taste; does not burn; supports combustion; condensible to a liquid by a pressure of about 36 atmospheres at 0°C., has a peculiar intoxicating effect upon the human system, and is hence used in the liquid state as an anæsthetic; sp. gravity 1.53. If nitrous oxide be shaken up with water, the latter absorbs about three-fourths of its volume of the gas at the ordinary temperature; or if phosphorus be burned in this gas it liberates nitrogen equal in volume to the original gas; *either* of these tests will serve *to distinguish* nitrous oxide from oxygen. The liquid nitrous oxide solidifies at about—100°C.; and when the liquid is mingled with bisulphide of carbon, and evaporated

in vacuo, it produces the lowest temperature hitherto reached—140°C. Obtained by heating nitrate of ammonia (NH_4NO_3); nitrous oxide and water being liberated —$NH_4NO_3 = N_2O + 2H_2O$. Since the gas is very soluble in cold water it must be collected by displacement of hot water.

116. **Nitric oxide** ($NO=30$; Density$=\frac{30}{2}=15$). A colourless, tasteless, odourless gas; does not burn; supports combustion with great difficulty; not condensible to a liquid; almost insoluble in water sp. gravity 1·04; *readily distinguished* from all other gases by the red fumes produced when brought in contact with free oxygen. It is thus, in turn, *a delicate test* for the presence of oxygen, even in minute quantity. The red fumes consist of nitric peroxide and nitric trioxide. Obtained by heating together, in a retort, nitric acid (HNO_3) and copper turnings—$8HNO_3 + 3Cu = 2NO + 3Cu(NO_3)_2 + 4H_2O$, nitric oxide is evolved and cupric nitrate and water remain in the retort. The student will note that there are generally marked traces of nitrous oxide present, in the nitric oxide prepared in this way. When charcoal is burned in nitric oxide the volume of the gas is not diminished, but it is found to contain equal volumes of carbonic acid gas and nitrogen—$2NO + C = CO_2 + N_2$. Therefore *one volume* of nitrogen is combined with *one volume* of oxygen to form two volumes of nitric oxide, the formula of which must therefore be NO, and not N_2O_2 as formerly stated.

117. **Nitric trioxide,** or **Anhydrous nitrous acid** (N_2O_3). An unstable compound, of which N_2O_3

is the doubtful formula. A volatile blue liquid, obtained by mixing 4 vols. of dry nitric oxide (NO) with 1 vol. of dry oxygen, in a vessel surrounded by a freezing mixture, when condensation to the liquid state takes place; said to exist in rain and well waters in combination with alkalies.

118. **Nitric peroxide** ($NO_2=46$). **An** orange coloured liquid, at the ordinary temperature, becoming deeper in colour as the temperature rises, and becoming nearly colourless at 0°C. Boils at 21°C., forming a reddish-brown gas, which becomes darker in colour as the temperature rises, and which is capable of supporting the combustion of substances which burn with energy; oxidises many of the metals, and especially potassium, which spontaneously takes fire when introduced into it. It is supposed that fuming nitric acid owes much of its oxidising power to the presence of the peroxide in it. Nitric peroxide varies in density according to temperature; at high temperatures the density of the volume, as compared with hydrogen, is found to be 23, but at low temperatures the formula is supposed to be N_2O_4, giving a density of 46. Since at low temperatures it is a liquid, and at high temperatures a gas, the **preferable molecular formula** is NO_2. Obtained by heating plumbic nitrate—$Pb(NO_3)_2=2NO_2+PbO+O$, nitric peroxide and oxygen are evolved, and plumbic oxide remains

CHAPTER VI.

NITRIC PENTOXIDE—NITRIC ACID.

119. **Nitric pentoxide, Anhydrous nitric acid** (N_2O_5). An unstable solid, in the form of transparent, colourless crystals, which liquefy at about 30°C. and boil at 45°C. It decomposes at a higher temperature, and it is said, when enclosed in a tube, to explode with violence. When brought in contact with water it dissolves, forming nitric acid (HNO_3),—$N_2O_5 + H_2O = 2HNO_3$. Obtained by passing a current of chlorine gas over argentic nitrate ($AgNO_3$):—$2AgNO_3 + Cl_2 = N_2O_5 + 2AgCl$; the nitric pentoxide evolved is condensed in a receiver, surrounded by a freezing mixture, and argentic chloride remains in the retort.

120. **Nitric acid** (HNO_3). A colourless, transparent liquid, when pure and not exposed to sunlight; fuming when brought in contact with moist air, on account of the absorption of moisture by the vapour of the acid; sp. gravity of strongest acid (HNO_3) 1·52; sp. gravity of ordinary aquafortis 1·29, with only 46·6 per cent. of HNO_3 present; sp. gravity of **commercial** nitric acid, or **double aquafortis** 1·42, with 67·6 per cent. of HNO_3. The strong acid solidifies at—55°C., forming a butter-like mass; boils at 86°C.; stains the skin and most animal and vegetable substances yellow, more especially if they contain nitrogen. Nitric acid is a powerful oxidising agent, and

readily attacks all common metals, with the exception of gold and platinum; it is therefore used to distinguish gold from the baser metals; the usual way of doing this, by touching the surface of the substance to be tested with a glass rod, moistened with the acid, is however very inaccurate, as, if the substance be well plated with gold, the result will be the same as if it were entirely composed of gold; a fine file ought accordingly to be used to penetrate the outer surface, and the test acid may then be applied. Even the weight of the metal is no criterion, since bars of platinum have been coated with gold. If a piece of red-hot charcoal be plunged in strong nitric acid, the oxidation is energetic enough to support the combustion of the charcoal. Nitric acid is obtained (I) by heating, in a retort, equal weights of potassium nitrate, or saltpetre (KNO_3) and sulphuric acid (H_2SO_4),—$KNO_3 + H_2SO_4 = HNO_3 + HKSO_4$, nitric acid is distilled into a receiver, and potassic bisulphate remains in the retort; an equal weight of sulphuric acid is used in the reaction, because a less quantity requires the application of a higher temperature, which causes sundry inconvenient results. (II.) More cheaply, on the large scale, by heating, in an iron retort lined with fire-clay, sodium nitrate, or Chili saltpetre ($NaNO_3$), with half its weight of sulphuric acid,—$2NaNO_3 + H_2SO_4 = 2HNO_3 + Na_2SO_4$, nitric acid distils over, and sodium sulphate remains in the retort. This residuum of sodium sulphate is utilised in the manufacture of glass.

CHAPTER VII.

AMMONIA—AMMONIUM—CARRE'S FREEZING MACHINE.

121. **Ammonia** ($NH_3=17$. Density$=\frac{17}{2}=8·5$). A colourless gas, possessing an acrid taste, and pungent smell; burns in air with great difficulty with a livid flame, forming water and liberating nitrogen; does not support combustion; readily turns red litmus paper blue, or yellow turmeric paper brown; condenses to a liquid at a temperature of—40°C., or under a pressure of six atmospheres at 10°C.; the liquid ammonia solidifies at—90°C., or under a pressure of 20 atmospheres at—75°C. Ammonia dissolves freely in water, forming the *liquor ammoniae* or spirits of hartshorn of druggists; at 0°C., water dissolves 1050 times its vol. of ammonia; at 59°, 727 vols. and at 78°, 586 vols. The existence of ammonia in the free state and its important functions have been alluded to elsewhere (113). It is obtained experimentally by heating sal-ammoniac, or hydrochlorate of ammonia, with quick-lime; —$2(NH_4Cl.) + CaO = 2NH_3 + CaCl_2 + H_2O$, ammonia is evolved, and calcium chloride and water remain in the vessel employed; another method of obtaining the gas is to heat a quantity of *liquor ammoniae* in a retort, when ammonia will readily be given off at a low temperature; collected by upward displacement, since its sp. gravity is only 0·590, and it cannot be collected over water on account of its solubility. The sal-ammoniac of commerce is pre-

pared from the ammoniacal liquor deposited in the preparation of coal gas; this liquor is treated with hydrochloric acid, and the solution is evaporated, when crystals of impure sal-ammoniac are formed, these are subjected to further purification, which terminates in the formation of the fibrous substance sold as sal-ammoniac. The most delicate test for the presence of ammonia, in solution, is that known as Nessler's test; it is as follows:—saturate a solution of potassic iodide (KI), with mercuric iodide (HgI_2), and add excess of caustic potash; on this test being added to a solution containing ammonia a brownish yellow precipitate is at once formed—$2HgI_2 + 3KHO + NH_3 = 3KI + 2H_2O + NHg_2I, H_2O$. Mercuric iodide, caustic potash and ammonia give potassic iodide, water, and tetra-mercurammonia iodide. So delicate is this test that $\frac{1}{100}$th grain of ammonia in half a pint of water gives a distinct precipitate.

122. **Ammonium,** (NH_4). The salts of ammonia are found to possess a great resemblance to those of potassium and sodium, and an amalgam of mercury, potassium, and sodium, when moistened with ammonium chloride (NH_4Cl) swells out to eight or nine times its original volume. This last formed amalgam possesses a metallic brilliancy, and if its temperature be lowered to—18°C. it crystallizes in cakes. Hence, on account of these and other circumstances, it has been found convenient to assume the existence of a hypothetical compound metal designated ammonium. For a somewhat similar reason Professor Graham has suggested the existence of a metal, *hydrogenium.* Thus,

by galvanic action, the metal palladium has been made to absorb nearly one thousand times its volume of hydrogen without undergoing any change in its metallic character, such as would naturally be expected on its combination with a non-metal. Strong objections to the existence of this hypothetical metal are the facts that all the hydrogen can be easily recovered on the application of a moderate degree of heat, and that other substances besides palladium are known to be capable of absorbing large quantities of gases without change of property. The hydrogen liberated from palladium is found however to possess far more active combining properties than ordinary hydrogen ; uniting spontaneously with atmospheric oxygen, and combining with iodine and chlorine in the dark.

123. When liquids assume the gaseous condition of matter, a considerable absorption of heat takes place, which heat is said to become **latent** (93). Matter, in contact with the liquid during vaporisation, is consequently deprived of a portion of its heat, and, if itself a liquid, it may even be solidified through this abstraction of heat. In M. Carre's freezing machine advantage is taken of the vaporisation of liquid ammonia and the ready solubility of ammonia gas in cold water, to produce a sufficient reduction of temperature to solidify water. It has been seen (121) that one volume of water at 0°C. is capable of dissolving 1050 vols. of ammonia, but, as the temperature rises, this dissolving power is lost on account of the volatile nature of the gas. Ammonia gas is furthermore capable of being liquefied under a pressure of about

six atmospheres at 10°C. Two gas-tight upright cylinders, which may be referred to as A and B, are connected by a gas-tight pipe; cylinder A contains a strong solution of liquor ammoniæ (121), and has an arrangement by which the solution may readily be heated; cylinder B is externally of the same shape as A, but instead of its top being flat it is depressed, so as to form a deep conical vessel, open at its upper end, or base. When heat is applied to A, the ammonia is driven off from the solution and passes through the connecting pipe into B; as the temperature rises the pressure inside the vessels soon attains to six or seven atmospheres, when liquefaction of the gaseous ammonia takes place; the hollow cone intruding into B has meanwhile been filled with cold water, and on removing the source of heat from A, the consequent condensation of aqueous vapour, which speedily follows, reduces the pressure which is necessary for the continued liquefaction of the gas; evaporation therefore at once takes place, the liquid ammonia assumes the gaseous state, and repassing into A, is absorbed by its contained water once more, but during this evaporation so much heat is absorbed from the water in the conical vessel in B, through the metallic partition, that the water is frozen into a solid mass.

CHAPTER VIII.

CARBON—COAL.

124. **Carbon** (C = 12). An allotropic substance, occurring in the crystallised, crystalline and amorphous

forms. As diamond, carbon crystallises in transparent octohedral forms of the cubical system, usually colourless, but not necessarily so, insoluble in acids; hardness 10·; sp. gravity 3·5—3·6; a non-conductor of electricity. As graphite, plumbago, or black-lead, carbon is crystalline, but sometimes crystallises in six-sided plates of the rhombohedral system; opaque; black or dark gray; insoluble in acids; infusible; hardness 1·0—2·0; sp. gravity 1·8—2·1; a good conductor of electricity; used for the manufacture of lead-pencils; and to coat gunpowder with a fine glaze, to exclude moisture. As charcoal, coke, and lamp-black, carbon is amorphous. Wood charcoal is obtained by subjecting billets of hard wood to destructive distillation, that is, by expelling the volatile constituents by the application of heat, out of contact with air. Animal charcoal, known also as ivory black or bone black, is obtained by heating bones in closed vessels, or by the calcination of blood. Coke is prepared by subjecting coal to destructive distillation in a coke oven.

Lamp-black is obtained by burning hydro-carbons, such as turpentine, or tar, in a supply of air insufficient for complete combustion. When mixed with soap and linseed-oil lamp-black forms printers' ink, or, mixed with gum-water and compressed, it forms China-ink.

If diamond be exposed to the very high temperature resulting from the electric discharge between the terminals of a galvanic battery, in an atmosphere incapable of acting chemically upon it, it swells up and finally forms a spongy black mass resembling graphite, and if a known quantity, say 12 parts by weight, of diamond, or of pure charcoal, be burned in oxygen, the same quantity of oxygen, 32 parts by weight, is required in either case for complete combustion, with the formation of 44 parts by weight of carbonic acid gas (CO_2). The fact that diamond raised to a white heat and plunged into an atmosphere of oxygen slowly burns away, is a sufficient proof that it could not have been formed at a very high temperature.

Diamonds of a cheap description have been used with advantage as drill points in tunnelling through hard rock, as in the Mont Cenis tunnel; diamond dust is used for cutting and polishing diamond itself, other substances being too soft for the purpose; the glazier's diamond is another example of practical use of the mineral. A genuine diamond is known by its extreme hardness, resisting the scratching power of any substance, and enabling it to scratch even the hardest steel; by its high sp. gravity (3·53), and by its insolubility in hydrofluoric acid. The calorific value (95) of carbon is 8080, or in other words a grain of carbon combining with oxygen to form carbonic acid gas evolves heat sufficient to raise 8080 grains of water through 1°C. Although carbon is an invariable constituent of organic substances, it does not, at ordinary temperatures, enter freely into combination with other elements; and this explains the employment of black-lead to coat iron-work, not merely for the purpose of giving a polish, but especially to protect it from rust or oxidation; this is also the reason for charring the extremity of stakes which have to be fixed in the ground; the charcoal, on the imbedded surface retarding the oxidation, or decay of the wood. Charcoal possesses the remarkable property of condensing large quantities of gases in its pores and on its surface. This condensation varies according to the gas; charcoal absorbing 100 times its volume of ammonia; 50 times its volume of sulphuretted hydrogen, and 10 times its volume of oxygen. This explains the **deodorising** and **disinfectant** properties of porous charcoal, for, the condensation of gases in the pores and on the surface being merely a **mechanical** and not a **chemical** operation, noxious gases or effluvia from putrefying matter, being absorbed, come in contact with and are oxidised by the already condensed oxygen derived from the atmosphere, thereby losing their offensive and injurious effects. In like manner water containing organic impurities is purified by filtration through porous charcoal. To exhibit either of the above mentioned properties satisfactorily the charcoal should have been recently heated to a red heat and then cooled under mercury. Charcoal **respirators** are constructed on the same principle, the inhaled air being rendered inodorous and innoxious by passing through powdered charcoal. The decolorising power of charcoal is due to a modification of the same property, by which colouring matter in solution adheres to the surface of charcoal, when filtered through it, and it can be shown to have undergone little chemical change, if any, by being washed from the charcoal by the action of a weak alkali in solution. Since carbon cannot be obtained in the gaseous condition, its vapour density cannot be experimentally determined, but for reasons of analogy and theory, its atomic weight has been assumed to be 12. When carbon is burned in oxygen, the volume of carbonic acid produced is exactly equal to the volume of oxygen taken, so that carbonic acid contains its own volume of oxygen.

125. **Coal** is vegetable matter, which, by exposure to considerable heat resulting from decomposition, under great superincumbent mineral pressure, has become carbonized to a greater or less degree. Geological research teaches and proves, that submergence of considerable tracts of land has been of frequent occurrence; some of these tracts have been covered with dense vegetation, the growth of many centuries; after submergence, overlying deposits of sandstone or limestone have been made, and the evolution of heat caused by slow decomposition would materially affect the whole character of the compressed vegetable mass. The gradual passage of wood into coal is exhibited in the following statement—wood consists of about 50 per cent. carbon, about 42 to 45 per cent. oxygen, the rest being hydrogen and mineral matter, chiefly potash, silica, soda, lime and iron. Peat or turf contains 60 per cent. carbon, in addition to oxygen, hydrogen, nitrogen and ash. Lignite contains 50 to 70 per cent. carbon.

Bituminous coal contains about 57 per cent. carbon; about 37·6 volatile matter and 5 per cent. ash. Steam coal contains 81 to 85 per cent. carbon; 11 to

15 per cent. volatile matter, and about 3 per cent. ash. Anthracite contains 80 to 95 per cent. carbon, with very little ash, and still less volatile matter. Wood generally retains about 20 per cent. water, even when well dried; one pound of green wood will evaporate about five pounds of water; a pound of dry wood seven pounds; and a pound of pure charcoal about fourteen pounds. One and a half cubic feet of turf weighing about 30 lbs. will evaporate about 340 lbs. water. The same volume of well dried wood, weighing about 45 lbs., will evaporate 270 lbs. water. The same volume of lignite, weighing about 110 lbs., will evaporate 800 lbs. water. The some volume of oak charcoal weighing about 12 lbs. will evaporate 150 lbs. water; and the same volume of coal weighing about 100 lbs. will evaporate 1200 lbs. water.

CHAPTER IX.

CARBONIC OXIDE—CARBONIC DIOXIDE.

126. **Carbonic oxide,** or Carbon Monoxide ($CO = 28$. Density$=\frac{28}{2}=14$). A colourless, tasteless gas, possessing a faint odour; does not support combustion; burns with a fine blue flame, forming carbonic acid; not condensible to a liquid; almost insoluble in water; sp. gravity 0·967; very poisonous, one volume in 100 volumes of air, according to Leblanc, rendering the air unfit for the support of animal life. This is the gas which affords the blue flame, often

seen playing over the surface of a coal fire, or even over a fire of wood. The oxygen of the air entering the fire, at the lower part of the grate, or stove, combines with the heated carbon of the coal or wood, to form carbonic acid; this passing through the fire, over red hot coals, is wholly or partially, according to the amount of oxygen entering the fire, decomposed into carbon monoxide:—$CO_2 + C = 2CO$, and this issuing at the surface of the fire and coming in contact with a certain amount of oxygen, takes fire and is wholly, or partially reconverted into carbonic acid. Carbonic oxide is accordingly a powerful reducing agent at a high temperature. It is obtained (1) by heating sulphuric acid with one third of its weight of oxalic acid ($C_2H_2O_4$ + Aq):—$C_2H_2O_4$ + (Sulphuricacid) $= CO + CO_2 + H_2O$; the sulphuric acid absorbs the water, and the mixed gases $CO + CO_2$ are evolved; by passing them through a wash bottle containing caustic potash the **latter gas** will be absorbed, and carbonic oxide will be liberated; (2) by heating sulphuric acid with one third its weight of formic acid (CH_2O_2): —CH_2O_2 + (Sulphuric acid)$= CO + H_2O$; the water is absorbed as before by the sulphuric acid, and carbonic oxide is liberated; (3) by moderately heating sulphuric acid with one-fourth of its weight of potassium ferrocyanide (K_4FeCy_6):—$K_4FeC_6N_6 + 6H_2O + 6H_2SO_4 = 6CO + 2K_2SO_4 + 3[(NH_4)_2SO_4] + FeSO_4$. Carbonic oxide is evolved, and potassium sulphate, ammonium sulphate, and ferric sulphate are left in the retort. Carbonic oxide is liberated abundantly in the operations of the lime kiln and brick kiln. When one volume of carbonic acid (CO_2), containing its own volume of oxygen, is passed over red hot coke, it yields two volumes of carbonic oxide (CO), hence **one volume** of this gas contains **half its volume** of oxygen.

127. **Carbonic acid gas,** or **Carbon dioxide** ($CO_2=44$. Density$=\frac{44}{2}=22$). A colourless gas, possessing a pungent odour, and sharp taste; does not support combustion under ordinary circumstances, although such substances as potassium, sodium, or carbon, sufficiently heated and plunged into carbon dioxide, deprive it of its oxygen, wholly, or partially; sp. gravity 1·529; condensible to a liquid, under a pressure of about 36 atmospheres at 0°C., and this liquid has the remarkable property of expanding more for equal increments of heat than the gaseous form of carbon dioxide. Water dissolves its own bulk of the gas at ordinary temperatures. It exists in the free state in the atmosphere, and escapes from the earth, and from effervescing springs, in many localities; as at the famous Grotto del Cane, near Naples; the Seltzer Spring, and the spring at Nauheim, which is said to liberate 1,000,000 lbs. of the gas annually; it is the common product of fermentation, and hence the danger arising from incautiously entering brewery vats, too soon after the liquid has been drawn off; and, since the gas readily collects at the bottom of wells where the air is very still, workmen should not descend into such places, before testing the purity of the air, with a lighted candle. Obtained (1) by the action of dilute hydrochloric acid upon pow-

dered marble, limestone or chalk :—$CaCO_3 + 2HCl = CO_2 + CaCl_2 + H_2O$; carbonic acid gas is evolved, and calcium chloride and water are left in the generating vessel; in this reaction there is frequently a little arsenic present, due to the impurity of the hydrochloric acid; if therefore the carbon dioxide be required pure, the second method had better be adopted: (2) by the action of dilute sulphuric acid upon powdered marble, limestone, or chalk :—$CaCO_3 + H_2SO_4 = CO_2 + CaSO_4 + H_2O$; carbonic acid gas is evolved, and calcium sulphate and water remain behind. Carbonic acid gas does not support animal life, since on being inhaled into the lungs it prevents the liberation, by exosmosis, of the carbonic acid gas formed in the blood, and also the passage, by endosmosis, of oxygen to the blood, for the performance of the necessary functions of circulation. Even in limited quantity, however, it affects the conditions of animal life injuriously, and hence the necessity of ventilation; for it is not merely the excess, but the presence of carbon dioxide that must be guarded against, so far as is possible. Taken into the stomach, however, it is not merely harmless but grateful, since the thirst-quenching properties of many beverages, not excepting water, seem to be largely due to the presence of this gas in solution. All effervescing liquors owe this property to the dissolved carbon dioxide, which is either generated by the action of re-agents, or is compressed into the liquid by mechanical means. Carbon dioxide is the **choke-damp**, or, **after-damp** of the coal mines, since it is one of the resultants of the explosion of fire-damp (CH_4). It is often referred to also as **fixed air**. In malting, brewing, etc., and all processes in which fermentation takes part this gas is constantly evolved. Since fermentation is simply the generation and evolution of carbonic acid gas, by a process of incipient putrefaction promoted by the growth of fungoid vegetation ; in bread-making, this process is induced by the addition of yeast, which is a mass of minute fungi, in order to cause fermentation in the dough, or in other words to generate carbonic acid gas, for the purpose of imparting a wholesome porosity, or sponginess to the bread. The **rising** of bread then is simply due to the evolution of carbonic acid gas as follows :—Wheaten flour consists largely of starch, gluten, dextrine and sugar; and when flour is moistened the sugar ferments, this fermentation being much accelerated by the addition of a little yeast, and the sugar is converted into alcohol and carbonic acid gas ;—the evolved gas escapes through the dough, perforating it, and honey-combing it with little cells in all directions, thereby much increasing its bulk, or causing it to **rise**. When the bread is heated in the oven, the alcohol is driven off, and the contained carbonic acid gas is greatly expanded, causing an equal degree of expansion in the bread, by increasing its porosity. In making what is called aërated bread, carbonic acid gas is directly supplied, by mixing the flour with water highly charged with the gas under pressure; or the same result is attained by mixing the flour with sodium bicarbonate ($HNaCO_3$), and then forming the dough by the addition of water slightly acidulated with muriatic acid (HCl), chloride of sodium (common salt) is formed, and carbonic acid gas is evolved. When the liquid carbonic acid is allowed to evaporate in the air, it does so with such rapidity, and with absorption of so much heat, that a portion of the liquid is solidified, having a temperature of about—87°C. When this solid is mixed with ether and mercury, the mercury is at once frozen into a solid mass, and intense cold is caused by the rapid evaporation of the ether and the liquefied acid. This cold is estimated to reach—101°C. To distinguish carbonic acid gas, the following test may be employed:—dissolve a little slaked lime in distilled water, and afterwards filter off the clear solution free from all sediment; kept carefully stoppered up, there will be no change in the solution; but if a portion be poured into a vessel containing carbon dioxide, a white precipitate will be at once observed, due to the formation of calcium carbonate:—$CaH_2O_2 + CO_2 = CaCO_3 + H_2O$. Carbonic acid gas can be **separated from other gases**, by passing the mixture through a solution of caustic potash, which readily absorbs carbonic acid. Blue litmus paper dipped into dry carbon dioxide is not affected, but in presence of moist air, or when the paper is wet, a true acid (H_2CO_3) is apparently formed, and the paper is reddened accordingly. If the red paper be now boiled in water the gas is driven off by the heat, and the litmus regains its blue colour. The hydrate (H_2CO_3), if existent, is unstable, and has not been obtained in a separate state; but its existence is probable, since the dry gas produces no acid effects without the addition of water, and does not combine even with lime, unless the latter compound be considerably heated. The compounds of carbonic acid are called carbonates, and many of these, as—carbonate of soda (Na_2CO_3), carbonate of potash (K_2CO_3), carbonate of iron ($FeCO_3$), and carbonate of lime, chalk, or marble ($CaCO_3$), are of the utmost importance either in the arts, or in the economy of nature. The composition of carbon dioxide can be shewn, by passing the dry gas over a pellet of potassium heated in a bulb tube, the potassium combines with the oxygen of the gas, and the carbon is deposited as a black mass; another portion of the gas combines with the potassic oxide to form carbonate of potassium, which is deposited as a white powder:—$3CO_2 + K_4 = 2(K_2CO_3) + C$.

CHAPTER X.

MARSH GAS—OLEFIANT GAS—ACETYLENE—COAL GAS

128. **Light Carburetted Hydrogen, Methyl Hydride, Marsh Gas,** or **Fire-damp** ($CH_4 = 16$. Density $= \frac{16}{2} = 8$). A colourless, tasteless, scentless gas; does not support combustion; burns with a pale, luminous flame; not condensible to the liquid condition; sp. gravity 0·557; very slightly soluble in water. Obtained artificially (1) by heating sodium acetate ($NaC_2H_3O_2$) with caustic soda ($HNaO$) in a copper tube, for the alkali re-acts upon glass:—$NaC_2H_3O_2 +$

$HNaO = CH_4 + Na_2CO_3$; marsh gas is evolved, and sodium carbonate remains in the tube; (2) by heating potassium acetate ($KC_2H_3O_2$) with caustic potash (HKO):—$KC_2H_3O_2 + HKO = CH_4 + K_2CO_3$. As before marsh gas is evolved, and potassium carbonate remains. In practice, a quantity of quick lime is always added to the mixture, to the extent of about three-tenths of the whole. Marsh gas occurs free in nature, issuing from the earth in many localities; it is produced by the decay of vegetable matter, hence the name—marsh gas; it is commonly found in many coal pits, into the workings of which it enters by fissures, often with a singing or hissing sound, which has given rise to the miners' term "blowers"; it often accumulates to a dangerous extent in the upper part or "goaf" of deserted workings, and it is no unusual matter, in some coal pits, for the miners' candles to be surrounded by a livid blue flame, called by the miners themselves "corpse lights," the evidence of a dangerous accumulation of fire-damp. When mingled with the oxygen of the air, the fire-damp, as it is called, forms a most explosive compound, and hence it is a source of the greatest danger to the coal-miner. Since one molecule, CH_4, occupies two volumes, and 12 parts by weight of carbon require 32 parts by weight of oxygen, and 4 parts by weight of hydrogen also require 32 parts by weight of oxygen for complete combustion, and the density of CH_4 being $\frac{16}{2} = 8$, of which 6 parts by weight must be carbon, and 2 parts by weight must be hydrogen, it follows that **one volume** of marsh gas will require **two volumes** of oxygen weighing 16 + 16 for complete combustion. But one volume of air contains only one-fifth of a volume of oxygen, therefore it will require ten volumes of air to supply two volumes of oxygen. When, therefore, fire-damp is mixed with air in the proportion of one volume to ten volumes, the mixture will be at its most explosive point, and on coming in contact with a flame an explosion of tremendous force follows, exerting a pressure of no less than 14 atmospheres, or 204 lbs. on the square inch. Were it not for the presence of the liberated nitrogen, it is calculated that the pressure would be not less than 37 atmospheres, or about 540 lbs. on the square inch. The molecule CH_4 combines with the oxygen of the air to form water ($2H_2O$) and carbonic acid gas (CO_2); and the formation of the latter gas adds to the danger resulting from the explosion, since, by its weight, it finds its way into lower levels, suffocating those who may have escaped the immediate effects of the explosion, hence its name of "choke-damp," or "after-damp." It would evidently be impossible for the miners to work in a pit liable to such explosions, if no means of moderating the danger existed; but this means is provided by the invention of the Davy Safety Lamp (133).

129. **Heavy Carburetted Hydrogen, Ethylene, Bi-carburetted Hydrogen,** or **Olefiant Gas** ($C_2H_4=28$. Density$=\frac{28}{2}=14$). A colourless, tasteless gas, which acts as a dyad radical; possesses a faint odour of ether; does not support combustion; burns with a bright yellow flame; condensible to a liquid under a pressure of about 5 atmospheres at—76°C., or under 27 atmospheres at—18°C.; sp. gravity

0·9784; insoluble in water. Derives the name Olefiant gas from its property of combining with its own volume of chlorine, or with bromine, to form oily liquids. The combination with chlorine—($C_2H_4Cl_2$) is commonly known as "Dutch liquid." Obtained by gently heating concentrated sulphuric acid with alcohol (C_2H_6O), in the proportion of two parts by measure of the former to one of the latter:—C_2H_6O + (sulphuric acid) = $C_2H_4 + H_2O$; the sulphuric acid absorbs the elements of water, and thereby liberates the gaseous ethylene. In this experiment the re-agents must be mixed together very gradually, and the delivery tube ought to be removed from the water as soon as the gas begins to come off slowly. Three ounces by measure of alcohol will give about 500 cubic inches of the gas. It is readily decomposed at high temperature into CH_4, C_2H_2, and H. **One volume** of olefiant gas requires for its complete combustion **three volumes** of oxygen, forming carbonic acid and water.

130. **Acetylene** ($C_2H_2=26$. Density$=\frac{26}{2}=13$). A colourless, tasteless gas, possessing a faint odour; does not support combustion; burns with a bright smoky flame; not condensible to a liquid; slightly soluble in water; sp. gravity 0·92. When passed into ammoniacal solutions containing copper or silver, acetylene combines with these metals, forming **acetylides,** which, when dry, are very explosive, on the application of heat. It inflames with explosion, when brought in contact with chlorine, with the formation of hydrochloric acid, and the liberation of carbon:—$C_2H_2+Cl_2=C_2+2HCl$. On the application of heat

to acetylene, it gradually assumes the forms of much more complex hydro-carbons. Acetylene is a constant constituent of coal-gas, and is a product also of incomplete combustion. It may be obtained in small quantity by passing an electrical discharge between two carbon points in an atmosphere of hydrogen; in larger quantity, it is prepared by acting upon cuprous acetylide with hydrochloric acid; it is said also to be formed when the vapour of Dutch liquid is passed through a red-hot tube. It produces a bright red precipitate when passed into an ammoniacal solution of cuprous chloride (Cu_2Cl_2).

131. **Coal-gas** is a mechanical mixture of a number of volatile hydro-carbons, and the elementary gases hydrogen, oxygen and nitrogen. It is obtained by destructive distillation of cannel coal in iron retorts, grouped five or six together, in a horizontal position. The gaseous matter expelled by heat passes from the retorts into a large pipe, partially filled with water, called the "hydraulic main," and from this into a piece of apparatus filled with water, called the "condenser," in which the gas rids itself of the tar, oil and most of the ammonia with which it has hitherto been mixed; the gas now passes into the "scrubber," containing fragments of wet coke, which take up a further portion of ammonia; and thence into the "lime-purifier," where the carbonic acid gas and sulphuretted hydrogen are absorbed by lime; by now passing the gas through dilute sulphuric acid all the remaining ammonia is got rid of, and the purified coal-gas is stored up over water in a reservoir called a gasometer.

The essential illuminating constituents of coal-gas are marsh-gas, olefiant gas, acetylene, carbonic oxide, benzole vapour and hydrogen. It is of the utmost importance that sulphuretted hydrogen should be removed from coal-gas, for, by combustion, it forms sulphuric acid, which is most injurious to hangings, pictures, furniture, books, etc. The tar and the ammoniacal water, in the hydraulic main and the condenser, are drawn off, and may be subjected to a variety of processes, resulting in the extraction of many important compounds, as—sal-ammoniac and aniline. The value of the illuminating power of coal-gas is determined by the aid of an instrument called a photometer, and by comparison with a spermaceti candle burning 120 grains per hour; the gas, meanwhile, burning at the rate of five cubic feet per hour.

CHAPTER XI.

FLAME—DAVY LAMP—HEMMING'S JET.

132. **Flame** is caused by oxidation, or other chemical combination of gaseous matter, but luminous flame is commonly due to the presence of carbon in a finely divided state, and its maintenance at a white heat, by the heat evolved in the oxidation of the accompanying gas, or gases. It has however been proved by Dr. Frankland, that luminous flames may be produced by increase of pressure alone, in the case of flames that are non-luminous at the ordinary pressure

of the atmosphere, and when solid matter is not present, as in the cases of oxygen and hydrogen, hydrogen and chlorine. As the ordinary materials for the production of artificial light:—tallow, wax, oil, alcohol, coal-gas, etc., are all **hydro-carbons,** that is, are compounds of hydrogen and carbon united together in various proportions, there is no reason to doubt that in these cases the luminosity is chiefly, if not entirely, due to the presence of the carbonaceous particles in a state of incandescence. This statement may be illustrated and proved by the two following experiments :—(1) Prepare hydrogen in a Woulfe's bottle (108) from zinc and sulphuric acid, dry and ignite the gas, place near the bottle a lighted candle, and fix a glass tube of small calibre, so that one end dips into the luminous portion of the candle flame, and the other end just enters the hydrogen flame, the latter will be observed to become luminous through admixture with the particles of carbon drawn off from the candle flame, and which are now raised to a white heat by the heat of the oxidised hydrogen. (2) Remove the glass tube and to the mixture in the Woulfe's bottle add cautiously a few drops of benzine (C_6H_6), gently shake the contents of the bottle, and in a minute or two the hydrogen flame will be seen to become brilliantly luminous, because of the addition of the hydro-carbon. As a variation of the last experiment, the following one may be performed to exhibit the luminosity caused by the presence of solid matter :—pass hydrogen through a bottle in which have been placed a few drops of chlorochromic acid (CrO_2Cl_2), the vapour of which will so charge the gas, that, on the latter being ignited, it will burn with a brilliant white light, due to the presence of chromium, which is deposited on a cold plate as sesquioxide of chromium. A candle flame, or that of an ordinary gas jet, is a hollow cone, as may be shown by neatly pressing down on the former a sheet of white note paper, the resulting soot stain is confined to a circular ring, and not distributed over a circular area. An ordinary flame may be considered as displaying three distinct parts or areas, viz.:—(1) An internal area of **non-combustion**; (2) an intermediate area of **incomplete combustion,** which is the luminous portion of the flame; (3) an external are of **complete combustion,** in which every portion of the hydro-carbons unites freely with the oxygen of the atmosphere. The internal area is really **colourless,** although it usually has a bluish appearance, because it is surrounded by a thin envelope of gas in a state of incomplete combustion. That it contains free gas is shown by dipping into it one end of a tube of small calibre, and applying a light at the other end; a minute flame will be observed, due to the uncombined gas drawn off. In the intermediate area, the hydrogen combines freely with the oxygen of the atmosphere to form water, causing great heat, which serves to raise the particles of carbon to a white heat. In the external area, the oxygen is sufficiently abundant to combine, not merely with the hydrogen, but with all the carbon present, forming carbonic acid gas. When coal-oil is burning with an insufficient supply of oxygen, acetylene (C_2H_2)

is formed, in addition to water and carbonic acid, and to this is partially due the offensive smell emitted under such circumstances. In chemical operations it is generally necessary to have a smokeless flame, and to obtain this, and at the same time the greatest possible amount of heat, means must be adopted to cause, as nearly as possible, complete combustion of the hydro-carbons employed. For this purpose advantage is taken of the Bunsen jet, which consists of a tube of a few inches in height, and of half an inch or more in width, fixed on an iron foot, or stand ; into this tube coal-gas is conducted by means of a horizontal tube inserted at its base, and this gas rises up into the tube through a flattened nib or nozzle of about an inch in height. On either side of the base are two to four apertures for the admission of air, but which may be closed or opened at will. When open, air enters, and rising through the tube along with the gas, the latter becomes permeated with oxygen, and on being ignited at the mouth of the tube it burns with an almost colourless flame, giving off intense heat ; when the apertures are shut a jet of gas alone ascends, and a dimly-luminous flaring flame, principally of incomplete combustion, is the result. The second and third areas of flame become of importance in blowpipe analysis, as each subserves a different function. Thus, since in the second area, or that of incomplete combustion, there is a deficiency of oxygen, if a metallic oxide be exposed before the blowpipe to the action of this inner flame, the oxide will be deprived of its oxygen and be reduced to the metallic state ; hence this intermediate area is technically known as the "inner," or "reducing" flame; but since, in the external area, or that of complete combustion, there is a superabundance of oxygen and the heat is intense, if metals be exposed before the blowpipe to the action of this outer flame, in most cases the metals combine with oxygen or are oxidised, and hence this external area is technically known as the "outer," or "oxidising" flame.

133. **The explosive nature** of a mixture of marsh gas and air has been referred to elsewhere (128), and the frequent occurrence of this dangerous mixture in coal mines induced Sir Humphrey Davy to devise a safety-lamp for the use of coal miners. This lamp is simply a common oil lamp surrounded by a closed cylinder of wire-gauze. This gauze, containing about 600 to 800 meshes in the square inch, readily permits of air or gases passing into the lamp, but does not permit of flame passing outwards, because flame requires a high temperature to exist as such, and the copper or iron, of the wire gauze, being a good conductor of heat, the temperature of the flame is reduced so rapidly by contact with it, that the flame ceases to exist as such, and cannot ignite the explosive mixture, although in almost immediate contact with it. There are probably two important sources of danger in the use of this lamp—the fact that if the explosive gas be abundant, the heat of combustion in the lamp may become so great as to cause the wire itself to take fire, when of course an explosion will follow; or, a current of air, or sudden

movement of the miner may possibly force the flame through the gauze by mechanical force, in which case also explosion will result. The Davy lamp gives a very dim light, and hence the great objection of the miner to its use; in practice it is only used, in most cases, to test the comparative purity of the air in coal pits before the miners descend to their labour; but this makes no provision for the danger arising from the sudden opening of "blowers," or the sudden escape of the fire-damp from "goafs" (128). Experiments to prove that flame does not pass through wire gauze of sufficient fineness:—(1) Hold a piece of wire gauze, about 8 inches square, over a wide beaker; pour alcohol into a large iron spoon or ladle, ignite it, and then pour through the gauze into the beaker; the alcohol will pass through, while the flame will be extinguished on the surface. (2) Take the same piece of wire gauze and depress it upon a strong jet of coal-gas in a state of ignition; the gauze will be found to depress the flame in the same manner that a solid plate would do. (3) Extinguish the jet of gas used in the last experiment, place the gauze two or three inches above the nozzle, and apply a light above the gauze; the gas will burn above but not below the gauze, and by raising it, the flame will likewise be raised, or even entirely removed.

134. **Hemming's Jet** is employed in the combination of hydrogen and oxygen, in using the oxy-hydrogen blowpipe, or the Drummond light. It consists of a heavy brass tube of a few inches in length, and about half an inch internal diameter; into

this tube is closely packed a number of fine copper or brass wires, and either end is closed with a piece of copper-wire gauze, with not less than 800 meshes to the square inch; on one end of the tube is screwed a head bearing a brass nozzle at right angles to the main tube, and on the other end is screwed a terminal piece by which the jet may be attached to tubing conducting the mixed gases from the gas-holder, or gas-bag. On the mixed gases issuing from the nozzle being ignited, it is almost impossible that the flame can pass back through the pipe to the gas-holder, because the wire gauze prevents the flame passing through by depriving it of the heat necessary for its existence as flame, and this deprivation is rendered still more certain by the presence of the wires in the tube, and the very narrow interstices between them.

CHAPTER XII.

CARBOLIC ACID—OXALIC ACID.

135. **Carbolic acid** ($C_6H_6O_2$). A compound, of doubtful acid properties; when pure, crystallizes in long, transparent, prismatic needles; sp. gravity 1·065; melts at 34°C. and boils at 187°C.; the crystals dissolve in about twenty-five times their bulk of water, and are soluble in alcohol and ether; possesses a pleasant odour; does not, either in the pure or dissolved condition, redden litmus paper. Commercial carbolic acid is a mixture of carbolic acid, cresylic

acid, hydro-carbons, etc., and its unpleasant odour is due to the presence, in minute quantity, of sulphur compounds. It is a powerful antiseptic, and has been employed to preserve wood from decay. Obtained from one of the oils of coal-tar, called the "heavy oil," by treatment with caustic potash; the resultant precipitate is partially re-dissolved, yielding potassium carbolate, which is treated with hydrochloric acid, the carbolic acid separating itself and floating on the surface of the solution. A piece of deal moistened first with carbolic acid and afterwards with hydrochloric acid becomes blue on drying.

136. **Oxalic acid** ($C_2H_2O_4 + 2Aq.$), only known as a hydrate; obtained in prismatic crystals, which dissolve readily in warm water, forming a powerful acid; melts at about 100°C.; sublimes at about 160°C.; when heated above this point it is decomposed, forming carbonic acid, carbonic oxide, and water (126). Oxalic acid is very poisonous; alkaline oxalates are moderately soluble in water, but others are insoluble. Obtained by heating sawdust with one part caustic potash and two parts caustic soda; these components are mixed into a paste, which is then maintained at a moderate temperature for some hours; the sawdust is gradually changed into oxalic acid, which combines with the soda to form sodium oxalate, a substance almost insoluble in cold water and hence easily separated from the other components of the heated mass; this first formed oxalate is now boiled with hydrate of lime (CaO, H_2O), and insoluble calcium oxalate and caustic soda are formed—$Na_2C_2O_4 + CaO, H_2O = Ca$

$C_2O_4 + 2(NaHO)$; this second oxalate is now acted upon with dilute sulphuric acid, when sulphate of lime is precipitated and crystals of oxalic acid are obtained by evaporating the solution—($CaC_2O_4 + H_2SO_4 = H_2C_2O_4 + CaSO_4$). Sawdust yields about one-half its weight of the acid. The alkalies employed are recovered for further use. Oxalic acid may also be obtained by heating starch with nitric acid;—nitric trioxide is evolved, and on the solution being evaporated, crystals of oxalic acid are obtained. Strictly speaking, this is a **vegetable** acid, but it is also found in **animal** matter under certain abnormal conditions. It is largely used in calico printing, and in cleaning leather and brass. In weak solution it removes ink stains.

CHAPTER XIII.

CHLORINE—CHLORIC ACID.

137. **Chlorine** ($Cl = 35{\cdot}5$). A greenish yellow gas possessing a suffocating odour and acrid taste; does not burn, and does not support combustion, but certain metals, such as antimony or iron in a finely divided state, take fire when dropped into a jar of chlorine with the evolution of light and heat; condensible to a yellow liquid of sp. gravity 1·33 under pressure of 4 atmospheres, at 15·5°C; sp. gravity 2·47; soluble in half its volume of water, forming **chlorine water**; does not occur in the free state in nature, but forms important and abundant compounds, as

sodium chloride or common salt, and potassium-chloride; obtained by heating common salt ($NaCl$) with manganese di-oxide and sulphuric acid—$2NaCl + MnO_2 + 2H_2SO_4 = Cl_2 + Na_2SO_4 + MnSO_4 + 2H_2O$, chlorine is evolved and manganese sulphate, sodium sulphate and water remain. A readier method of preparing chlorine is by heating hydrochloric acid and manganese di-oxide together—$MnO_2 + 4HCl = Cl_2 + MnCl_2 + 2H_2O$, chlorine is evolved, and manganese chloride and water remain. Collected by downward displacement of air. **Deacon's process** for the preparation of chlorine, on a large scale, for the manufacture of bleaching powder, is also now adopted; it is as follows:—Air and hydrochloric acid gas are passed over heated fire-brick, saturated with a solution of copper sulphate, water is formed and chlorine and nitrogen are liberated—$2HCl +$ air $(N_4 + O) = H_2O + Cl_2 — N_4$, the presence of the nitrogen does not interfere with the utility of the chlorine. **By Weldon's method** the chlorine combining with the metal manganese, in the second reaction, described above, is obtained in union with calcium, and the manganese is recovered for employment in the decomposition of a fresh quantity of hydrochloric acid. The manganese chloride is decomposed by the addition of lime:—$MnCl_2 + CaO = CaCl_2 + MnO$, calcium chloride and manganese protoxide are formed; and by the addition of more lime and under the influence of a strong current of air, the manganese is further oxidised forming the dioxide (MnO_2). Chlorine has a great affinity for hydrogen, even decomposing water to combine with it, and thereby acting indirectly as a powerful oxidising agent, and, in consequence, as an equally powerful bleaching agent. Dry chlorine possesses no bleaching properties, but the addition of water at once causes the destruction of vegetable colours with which it comes in contact. Equal volumes of chlorine and hydrogen mixed and kept in the dark, will not combine, but, in the presence of diffused sunlight, slow combination takes place, and, in direct sunlight, or in the presence of the magnesium light, there is sudden combination with explosion, and the formation of hydrochloric acid (HCl). Most hydrogen compounds, such as ammonia, are decomposed by chlorine, often with violence. Chlorine also combines spontaneously with most of the metals, and among the non-metals with—bromine, iodine, sulphur, selenium, phosphorus and arsenic, forming chlorides. It is largely used in a combined state for the bleaching of linen and cotton articles, but it acts injuriously upon woollen, silk and straw fabrics.

138. **Chloric acid** ($HClO_3$). A yellowish liquid possessing a strong odour; a powerful bleaching and oxidising agent, one drop being sufficient to ignite paper, and it oxidises even the amorphous variety of phosphorus with explosive violence. Obtained by acting upon a solution of chlorate of potash ($KClO_3$) with hydrofluosilicic acid ($(HF)_2SiF_4$) :—$2KClO_3 + (HF)_2SiF_4 = 2HClO_3 + (KF)_2SiF_4$, insoluble potassium silicofluoride is formed, and on separating and evaporating the solution at a temperature below 38°C,

chloric acid remains. It forms important salts called chlorates, such as barium chlorate ($BaClO_3$), much used in the manufacture of fire-works to produce a brilliant green light.

Chlorate of potash ($KClO_3$) is useful as a source of oxygen, in calico printing, in the manufacture of lucifer matches, fire-works and percussion caps. When reduced to a powder by itself no explosive action takes place, but if mixed and powdered with any combustible substance, such as sulphur, a violent explosion follows. Obtained by passing excess of chlorine through caustic potash:—$6(KHO + Cl_6 = KClO_3 + 5KCl + 3H_2O$; with formation of potassium chloride and water. Crystallizes in six-sided plates, which are permanent in air, and soluble in water.

CHAPTER XIV.

HYDROCHLORIC ACID.

139. **Hydrochloric acid** ($HCl = 36{\cdot}5$. Density $= \frac{36{\cdot}5}{2} = 18{\cdot}25$). A colourless gas possessing a suffocating odour, fuming on exposure to air by causing condensation of its moisture; sp. gravity 1·24; does not burn; does not support ordinary combustion, but heated potassium burns in it; condensible to a liquid under a pressure of 40 atmospheres, at 10°C.; it is readily absorbed by water, one volume of water at 5°C. dissolving as much as 480 volumes of the gas and forming 1⅓ volume of the solution, of sp. gravity

1·21, and containing 43 per cent. by weight of the gas. This solution is the strongest muriatic acid, or spirit of salt of commerce. Ordinary hydrochloric acid is usually very impure, hence its yellow colour. Liquefied hydrochloric acid has a very weak action upon metals, and only partially changes the colour of litmus, while the solution has powerful acid properties. Hydrochloric acid is most destructive to vegetation, and this effect is probably due to its affinity for the water contained in growing plants. Obtained by the action of sulphuric acid upon common salt (NaCl) :— $2NaCl + H_2SO_4 = 2HCl + Na_2SO_4$. Hydrochloric acid is evolved and sodium sulphate remains as a solid. This gas is liberated from volcanoes, and is found in springs and rivers of volcanic districts; it is also artificially formed when chlorine and hydrogen are exposed to sunlight. Its composition may be shewn by passing into a tube, over mercury, a measured volume of the gas, and then passing up through the mercury a pellet of sodium; the mercury will gradually rise and finally the gas will be found to be diminished by one-half its previous volume, through combination of the chlorine of the gas with the sodium—$Na + HCl = NaCl + H$.

140. Although **hydrochloric acid** does not attack gold by itself, when mixed with nitric acid (HNO_3) in the proportion of three parts by measure of the former to one part by measure of the latter acid, it forms the so-called **aqua regia,** or **nitro-muriatic acid,** which is capable of dissolving both gold and platinum, forming terchloride of gold ($AuCl_3$), and tetrachloride of platinum ($PtCl_4$).

141. **Bleaching powder** appears to be a mechanical mixture of two chemical compounds—calcium hypochlorite ($CaCl_2O_2$) and calcium oxychloride ($CaCl_2$, $2CaO$). It is prepared by passing chlorine gas into large vessels, or chambers, containing shelves upon which is spread slaked lime (CaO, H_2O);—$4(CaO, H_2O) + Cl_4 = (CaCl_2O_2 + CaCl_2, 2CaO) + 4H_2O$. When the bleaching powder is to be used, it is mixed with water, and the calcium hypochlorite ($CaCl_2O_2$) and calcium chloride ($CaCl_2$) are dissolved, while the insoluble lime is precipitated. Into this bleaching solution, considerably diluted with water, are placed the articles of cotton or linen which are to be bleached, having previously been cleansed from greasy matter and other impurities which might interfere with the bleaching action, by being boiled in lime water and a weak solution of soda. Little or no bleaching action will be visible during this immersion, but on the fabric being removed from the bleaching solution and placed in very dilute sulphuric acid, the colours will be destroyed by the liberation of chlorine—$(CaCl_2O_2 + CaCl_2) + 2H_2SO_4 = 2CaSO_4 + 2H_2O + Cl_4$. Calcium sulphate and water are formed and chlorine gas is evolved. The chlorine decomposes water to combine with its hydrogen, thereby liberating oxygen, which in the nascent condition acts with great energy, and immediately oxidises the colouring matter and consequently destroys it. The partially or entirely bleached material is then removed from the acid or "souring" solution, and the excess of acid is neutralized by immersion in an alkaline solution, and abundant rinsing.

This process is further carried out in calico printing, by bleaching portions of a coloured cloth according to pattern. To do this, the cloth is stamped in patterns or devices with a paste of flour, or gum, containing an acid, such as tartaric or sulphuric acid. When the paste has become dry, the cloth is immersed in a hot weak bleaching solution, when the portions covered with the acidulated paste will be bleached, and the other portions not sensibly affected.

The **disinfecting** properties of chlorine and of chloride of lime are no doubt due to much the same reaction as in bleaching; that is, union of chlorine with the hydrogen of noxious gases, such as ammonia, sulphuretted hydrogen and other hydrogen compounds, the products of animal or vegetable putrefaction, decomposes and therefore destroys them. To use the disinfectant most readily, the following methods may be adopted. Saturate a cloth in a strong solution of bleaching powder and hang it up in a convenient place; the **carbonic acid of the air** causes a slow evolution of hypochlorous acid, which is not inferior to chlorine as a disinfectant; or, if a more powerful effect be desirable, place some bleaching powder in a dish with half its weight of powdered alum, or with some dilute sulphuric acid poured over, when, in either case, chlorine will be rapidly given off.

The application of Deacon's process to the manufacture of bleaching powder has already been referred to (137).

CHAPTER XV.

BROMINE, IODINE, FLUORINE, HYDROFLUORIC ACID.

142. **Bromine** (Br=80) a liquid of dark brownish-red colour; very volatile, evolving deep orange coloured fumes, even at low temperatures; possesses a very peculiar and offensive odour to which it owes its name. It is even more objectionable than chlorine, and produces more pronounced irritation of the mucous membranes; sp. gravity 2·966; boils at 63°C., giving off vapour of sp. gravity 5·54. At—25°C. bromine forms a brown, crystalline, semi-metallic looking solid; it is only slightly soluble in water, one part by weight requiring 33 times as much water for its solution. Obtained from certain mineral springs, such as those of Kreuznach and Kissingen; from the bittern, or mother-liquor of sea-water, remaining after the separation by crystallisation of chloride of sodium, and other salts; and from the mother-liquor of the Stassfurth salt works. Since chlorine displaces bromine from its combination with metals, a current of chlorine is passed into the spring water, or mother-liquor containing bromine, in combination usually with sodium, potassium or magnesium;—$KBr + Cl = KCl + Br$., a chloride is formed and bromine is liberated in the liquid; to the solution, ether ($C_4H_{10}O$) is added, and this liquid, having a much greater solvent power for bromine than water possesses, abstracts it from the solution, and, being lighter than water, it forms a superficial orange coloured layer containing

all the bromine in solution. This surface layer is now carefully decanted off, and is mixed with caustic potash; potassium bromide and potassium bromate are formed, the colour is destroyed, and the ether rising to the surface in a pure state is removed for future use, — $6\ HKO + Br_6 = 5KBr + KBrO_3 + 3H_2O$; this aqueous solution is heated to get rid of the water, and the solid residue of the bromide and bromate of potassium is heated to decompose the bromate —$KBrO_3 = KBr + O_3$. The bromide is now heated with manganese di-oxide and sulphuric acid—$2KBr + MnO_2 + 2H_2SO_4 = K_2SO_4 + MnSO_4 + Br_2$, potassium sulphate and manganese sulphate are formed, whilst bromine distils over and is condensed in a receiver. In most of its chemical properties it resembles chlorine, but being more expensive than the latter, it is of little practical importance. It has however been used as a disinfectant, and in photography; and the bromides of potassium, and ammonium are used in medicine.

143. **Iodine** ($I = 127$). A solid, forming grayish-black brittle scales possessing a metallic lustre; sp. gravity 4·95; volatile even at ordinary temperatures, giving off a faint smell resembling that of sea-air; fuses at 107°C., and boils at 175°C. evolving beautiful mauve coloured fumes. Sp. gravity of vapour 8·716, possessing a strong odour. If a scale be placed upon the hand for a few seconds, it will be found on removal to have left a yellowish-brown stain. Soluble in water to a very slight degree, but dissolving freely in carbon di-sulphide, ether or alcohol; with the last

named forming the tincture of iodine of the drug shops. The best test for the presence of iodine is the deep blue colour it forms by its action upon starch. Thus if a compound containing iodine be added to some weak cold starch paste, and a few drops of chlorine be dropped into the mixture, the iodine will be liberated and combining with the starch will form a characteristic blue colour; if excess of chlorine be added, there may be no colour visible, since there may be enough chlorine to combine, not merely with the constituents formerly united with the iodine, but with the iodine itself. By dissolving excess of iodine, in carbon di-sulphide, a solution is obtained, possessing the peculiar property of permitting all heat rays to pass freely, but intercepting all light rays, it is therefore of the first importance in experiments relating to diathermancy.

Iodide of potassium ($KI=166$) is much the most useful compound of iodine, being of frequent use in the laboratory, in medicine, and in photography. It is obtained in cubical or octahedral translucent crystals, by dissolving iodine in potassic hydrate, which results in the formation of potassic iodide and potassic iodate—$3I_2 + 6HKO = 5KI + KIO_3 + 3H_2O$; the mixture is evaporated to dryness, and the potassic iodate is decomposed by the application of heat.

144. **Fluorine** ($F=19$), a gaseous element, said to be of a greenish colour; does not combine with oxygen, but its affinity for most substances with which it comes in contact is so powerful that it has not been found possible to isolate it, so as to determine its

properties. The most successful attempts at isolation have been made by the employment of vessels of fluorspar, since vessels of glass are speedily corroded in the operation. The principal natural compounds containing fluorine are:—fluorspar, calcium fluoride, Derbyshire spar, or Blue John (CaF_2), which is used for purposes of ornament, being found of various colours—blue, yellow or green, and can be turned on the lathe; and cryolite ($3NaF, AlF_3$), found in Greenland. Fluorspar is so called on account of its employment in metallurgy as a flux.

Chlorine, bromine, iodine and fluorine are called the **halogens,** on account of their tendency to form salts resembling in their constitution sea-salt, and these salts accordingly are known as **haloid salts**; they are also called **salt-radicals,** on account of their forming salts by combination with metals. Each of these elements combines with its own volume of hydrogen to form an acid, occupying the additive volume of the constituents. Their equivalent weights are identical with their atomic weights. The atomic weight of bromine is nearly identical with the mean of the atomic weight of chlorine and iodine; in the same way the sp. gravity of bromine is about equal to the mean of the sp. gravities of liquid chlorine and of iodine.

145. **Hydrofluoric acid** ($HF=20$), a colourless liquid, sp. gravity 0·988; boiling at 19·5°C., evolving dense irritating fumes when brought in contact with air containing moisture, which it readily absorbs, forming aqueous hydrofluoric acid. Obtained by the

action of dilute sulphuric acid upon fluorspar, in a lead retort connected with a receiver of the same metal surrounded by a freezing mixture :—($CaF_2 + H_2SO_4 = 2HF + CaSO_4$). Hydrofluoric acid distils over, and calcium sulphate remains in the retort; the acid, in a dilute state, is generally kept in bottles of gutta percha, or lead. Both the anhydrate and the hydrate exercise a very corrosive effect upon the skin, and the vapour attacks the mucous membrane to a dangerous extent. The anhydrate, the completely anhydrous character of which is doubted by some chemists, dissolves readily in water with a loud hissing sound, and the aqueous solution as well as the fuming vapour of hydrochloric acid exerts a powerful corrosive action upon glass, while the dry acid has little or no effect upon it. This corrosive action is due to the combination of the fluorine of the acid with the silicon of the glass :—$SiO_2 + 4HF = SiF_4 + 2H_2O$). This property is taken advantage of in the arts, to produce elegant patterns upon stained glass, as when there are two layers of different colours, the acid may be employed to cut through the upper one, thereby exposing the lower one to any desired extent; and also for the purpose of etching upon glass, as illustrated in the following experiment :—A strip of glass is coated with beeswax and fine lines are traced through the wax, with a pointed instrument; when exposed to the vapour, or to the solution of hydrofluoric acid, the glass will be eaten into along the exposed lines only. This ready union of fluorine with silicon is taken advantage of in the analysis of silicates refractory to other reagents. With the exception of sodium and potassium the metals are little affected by the pure acid, but the acid in solution dissolves most metals except gold, platinum, silver, lead, magnesium and mercury.

CHAPTER XVI.

SULPHUR.

146. **Sulphur** ($S=32$), a brittle, pale-yellow solid; allotropic; found in nature in the form of octahedral crystals, of the rhombic system, having a sp. gravity of 2·05, and in amorphous masses; it is commonly distributed in volcanic districts throughout the world, but the chief commercial source is Sicily, where it is commonly found in beds of clay, or in veins with gypsum ($CaSO_4$), and celestine ($SrSO_4$). It is also obtained by roasting iron pyrites (FeS_2), or copper pyrites ($Cu_2S + Fe_2S_3$). Sulphur melts at 120°C., forming an amber coloured liquid; at 220°C. it becomes black and viscid, like treacle; and at this point its temperature remains stationary for a time, heat becoming latent; at a higher temperature it again becomes quite fluid, and at 440°C. it boils, evolving reddish-brown fumes; in air, however, it takes fire at about 260°C., burning with a pale blue flame, combining with oxygen to form sulphurous acid gas (SO_2). If plastic sulphur, at a temperature of about 270°C., be poured into water, it remains soft and ductile for some hours, having a sp. gravity of 1·96; but it gra-

dually returns to the form of octahedral crystals, with evolution of the heat previously rendered latent. If, when a crust has formed on melted sulphur in a vessel, the crust be broken and the liquid portion of the sulphur poured out, fine needle-shaped oblique-prismatic crystals will be formed on the sides of the vessel; these crystals, however, soon re-assume, internally at least, the normal octahedral form; conversely, if octahedral crystals be heated to about 110°C., they are changed into minute prismatic crystals. Prismatic sulphur has a sp. gravity of 1·98. Octahedral and prismatic sulphur are soluble, and plastic sulphur is insoluble, in carbon di-sulphide. Sulphur forms many very important compounds, both directly as sulphides, and in combination with oxygen as sulphates; it enters into combination with every non-metal, except nitrogen, and with most of the common metals. The principal sulphides are—copper sulphide (CuS); zinc sulphide, or blende (ZnS); lead sulphide, or galena (PbS); mercuric sulphide, or cinnabar (HgS); silver sulphide, or argentite (AgS); arsenic tri-sulphide, or orpiment (AsS_3); arsenic bi-sulphide, or realgar (AsS_2). If fine iron filings 60 parts, sal-ammoniac 2 parts, and sulphur 1 part, be mixed into a paste with water, it may be used as a hard cement to close the joints of iron tubes, the iron combining with the sulphur. Native sulphur is separated from the impurities with which it is mixed by being heated in earthenware vessels, arranged in rows in a long flue; these jars communicate with similar vessels outside the flue, and these in turn with vessels of water; the sulphur distils from the heated jars into those outside, in which it condenses to a liquid and runs into the vessels of water, in which it solidifies. This is the "rough sulphur" of commerce, and requires to be re-distilled to complete its purification. This second distillation is performed in an iron retort, and the sulphur vapour is passed into a large brick chamber, on the sides of which it condenses as a powder, called "flowers of sulphur"; if the operation be carried on for some time, the walls become sufficiently hot to melt the sulphur, which collects on the floor of the chamber, and being afterwards cast in wooden moulds, forms the roll sulphur, or brimstone of commerce. Sulphur intended for the manufacture of gunpowder is distilled directly into water. From iron pyrites, sulphur is obtained by heating the ore to a very high temperature in vessels nearly closed to the air, arranged horizontally in rows in a furnace; the sulphur distils through perforations at one end of the vessels. Each vessel contains 100 lbs. of pyrites, and yields 14 lbs. of sulphur. About one-half the sulphur of the pyrites may be thus separated—$FeS_2 = FeS + S$.

From copper pyrites sulphur is obtained in the process of roasting the ore preparatory to extracting the metal. The roasting is carried on much in the same way as charcoal burning, in heaps containing as much as 2000 tons of ore, and yielding about 20 tons of sulphur.

Still another source of sulphur is the **tank-waste** of alkali works, from which it is now extracted by decomposing the calcium sulphide (CaS), which is one of the products of the black-ash process, in preparing carbonate of soda. Air is blown through the tank-waste, converting by oxidation the calcium sulphide into calcium bi-sulphide (CaS_2), and calcium hyposulphite (CaS_2O_3):—(1) $2CaS + O = CaO + CaS_2$, (2) $CaS_2 + O_3 = CaS_2O_3$. A yellow liquor is now obtained, containing a mixture of the calcium sulphide and hyposulphite, which being treated with hydrochloric acid, also obtained as a product at the alkali works, in the process of manufacturing carbonate of soda, calcium chloride is formed and sulphur is precipitated—$CaS_2O_3 + 2CaS_2 + 6HCl = S_6 + 3CaCl_2 + 3H_2O$. As muriatic acid is in great demand for the manufacture of bleaching powder, bi-carbonate of soda, etc., another process utilises the waste products —manganese chloride ($MnCl_2$), and perchloride of iron (Fe_2Cl_6), obtained in the manufacture of chlorine, to precipitate the sulphur from the tank waste:—$CaS + MnCl_2 = MnS + CaCl_2$; $3CaS + Fe_2Cl_6 = Fe_2S_3 + 3CaCl_2$. The calcium chloride remains in solution, and by exposing the moist sulphide precipitates to air, the metals are oxidised and sulphur is separated:—$2MnS + O_3 = Mn_2O_3 + S_2$; $Fe_2S_3 + O_3 = Fe_2O_3 + S_3$. Brown oxide of manganese and ferric oxide are formed. By addition of fresh portions of the tank-waste, calcium bi-sulphide and hyposulphite are formed, as in the previous process, and the sulphur is precipitated in the same way by the addition of muriatic acid.

Roll sulphur consists at first of an agglomeration of prismatic crystals, but in course of time it gradually assumes the form of octahedra, and it is believed that this change induces a state of tension, which renders the mass exceedingly brittle and liable to break into fragments, even by the heat of the hand. If sulphur vapour be weighed at 482°C., it is found to weigh 96 times as much as hydrogen, so that its atom occupies only one-third of a volume; but at 1038°C., it weighs only 32 times as much as hydrogen, and its atom occupies one volume. Very large quantities of sulphur are used in the manufacture of gunpowder, lucifer matches, sulphuric acid, sulphurous acid, vulcanized caoutchouc, etc. An analogy may be observed between certain sulphur compounds and oxygen compounds, *e.g.*, water (H_2O) and sulphuretted hydrogen (H_2S), hydrogen peroxide (H_2O_2) and hydrogen disulphide (H_2S_2), carbon dioxide (CO_2) and carbon disulphide (CS_2), etc.; this analogy is not limited to the composition only of these compounds, but their properties display similar correspondence.

CHAPTER XVII.

SULPHUR DIOXIDE—ANHYDROUS SULPHURIC ACID.

147. **Sulphurous acid,** or **sulphur dioxide** (SO_2)=64. Density=$\frac{64}{2}$=32). A colourless gas, possessing a suffocating smell, and unpleasant taste; does not burn; does not support combustion; sp. gravity 2·25; 100 cubic inches weigh 68·69 grains; very soluble in water, one volume of water at 0°C. absorbing 68·86 volumes, and at 20°C., 36 volumes of the gas;

condensible to a colourless liquid of sp. gravity 1.45, under a pressure of about two atmospheres, at 15°C., and this liquid solidifies into a white crystalline mass at—79°C. Sulphur dioxide is not abundant in the free state in nature, for although a volcanic product, and generated to a large extent in large towns as a product of combustion, it is so easily oxidised, and converted into sulphuric acid, that its presence is rarely discernible; it is the sole product of burning sulphur, but is experimentally obtained by heating sulphuric acid with copper—$2H_2SO_4 + Cu = SO_2 + CuSO_4 + 2H_2O$, sulphate of copper and water are formed, and sulphurous acid is evolved. It possesses rather weak acid properties, but combines with bases to form salts, called sulphites, the most important of which are—ammonium sulphite ($(NH_4)_2SO_3, H_2O$), calcium sulphite ($CaSO_3, H_2O$), sodium sulphite (Na_2SO_3, H_2O), which last sulphite is extensively used as an antichlore to "kill the bleach" or neutralize the excess of chlorine, after bleaching rags for paper making:—$Na_2SO_3 + Cl_2 + H_2O = Na_2SO_4 + 2HCl$. With solution of potash also, sulphurous acid combines to form both a sulphite and a disulphite—$SO_2 + 2HKO = K_2SO_3 + H_2O$, and $SO_2 + HKO = KHSO_3$. Sulphurous acid is useful as an **antiseptic,** for destroying the vegetable matter producing fermentation, hence it is used for fumigating casks; it is also an excellent **disinfectant,** and a destroyer of most kinds of vermin; it is obtained for these purposes simply by burning a sufficiency of sulphur with a moderate supply of air. If burning sulphur be placed in a chimney in which the soot is on fire, and the supply of air be almost cut off, the fire will speedily be extinguished. This acid is the principal bleaching agent for fabrics of silk or wool, of straw, sponge, and other animal or vegetable materials which would be injuriously affected by chlorine, or its compounds. The bleaching is performed by hanging the moistened articles in a chamber, where they are exposed to the sulphurous acid obtained by burning sulphur. The colouring matter does not appear in general to be destroyed by the acid, but rather to form a colourless compound with it, although one explanation of the bleaching action is that deoxidation of the colouring matter, or water present takes place, with the formation of sulphuric acid. That the latter explanation is not in all cases correct, is proved by the fact that in course of time the original colour sometimes re-appears, as in the case of straw, flannel, etc., which gradually become yellow, perhaps through the change of sulphurous acid into sulphuric acid, by slow oxidation; but in the case of woollen goods, the yellow colour is probably due to the neutralization of the acid, by the alkalies commonly used in washing materials. Fruit and wine stains can be readily removed from linen by solution of sulphurous acid.

148. **Anhydrous sulphuric acid,** or **sulphur trioxide** ($SO_3 = 80$). SO_2 and SO_3 are the only compounds of sulphur with oxygen which have been obtained in the separate state. Sulphur trioxide is a solid compound of white needle-like fibres; its sp. gravity is 1·9; fumes when exposed to air, through condensation of moisture, and soon deliquesces; when dropped into water it dis-

solves with a loud hissing sound, caused by the rapid evolution of steam; it boils at about 50°C. Its aqueous solution is hydrated sulphuric acid, or oil of vitriol, probably the most important acid known, although the trioxide has in itself no acid properties, producing no change on blue litmus. It is obtained by passing oxygen and sulphurous acid through a tube containing heated platinum, or oxide of copper, or chromium, which appears to act by catalysis, causing the formation of sulphur trioxide. It is better obtained by heating disulphate of soda ($Na_2S_2O_7$). The trioxide distils over and sodium sulphate (N_2SO_4) remains. If 32 grains of sulphur be oxidised by boiling with nitric acid, and the excess of acid expelled by heat; the resultant sulphuric acid mixed with excess, say 300 grains, of lead oxide, and all the water expelled by heating at a high temperature, the mixture of lead oxide and lead sulphate will weigh 380 grains, shewing that 32 parts of sulphur have combined with oxygen of the nitric acid to form 80 grains of sulphuric acid. Hence the sulphuric acid contains 32 grains of sulphur and 48 grains of oxygen, corresponding to the formula SO_3.

CHAPTER XVIII.

SULPHURIC ACID.

149. **Hydrated sulphuric acid** ($H_2SO_4=98$). An oily liquid; when pure, colourless; without any distinctive odour; powerfully corrosive of organic

matter; sp. gravity 1·84; boils at 338°C., its vapour forming dense irritating fumes by combination with the moisture of the air; solidifies at about—34°C., and the solid possesses the remarkable peculiarity of requiring a much higher temperature than that at which it solidifies to liquefy again. Obtained (1) by the distillation of the sulphate of iron, ($FeSO_4 + 7aq.$). The crystals are first exposed to air, so that the sulphate may be reduced to the persulphate—$2(FeSO_4) + O = Fe_2O, 2SO_4$, and after being dried are distilled at a red heat in earthenware retorts; enough water always remains in the persulphate to permit of a hydrate being formed, and it accordingly distils over as $H_2O, 2SO_3$, which may be considered as the formula of Nordhausen Oil of Vitriol, so called from the place in Saxony, where it is prepared; the peroxide of iron (Fe_2O_3), remaining in the retort, is a red powder known by the name of "colcothar," used for polishing plate glass and metals. The sp. gravity of Nordhausen oil of vitriol is 1·9; it is chiefly used in dissolving indigo to produce the Saxon blue dye, and is a convenient source whence to obtain anhydrous sulphuric acid, for if heated in a retort, anhydrate (SO_3) distils over and becomes condensed, in a receiver surrounded by a freezing mixture, while sulphuric acid (H_2SO_4) is left in the retort. The Nordhausen process is simple but expensive, and as enormous quantities of sulphuric acid are now used, a cheaper process is a necessity.

(2) A series of leaden chambers of great capacity has, placed in its close proximity, a furnace of suitable size, which performs three functions, as follow—

(a) it burns iron pyrites (FeS_2) in presence of air, thereby evolving sulphurous acid (SO_2); *(b)* the combustion of the sulphur heats an iron vessel, placed in the upper part of the furnace, containing sodium nitrate ($NaNO_3$), and dilute sulphuric acid, from which the vapour of nitric acid (HNO_3) is evolved; *(c)* it heats a boiler, and thereby supplies steam, which is introduced in jets at different points of the leaden chambers. The air supplied to the burning sulphur of the pyrites is regulated so as to admit of the passage of just about so much oxygen as will, in combination with the SO_2, form SO_3; the nitric acid vapour enters the chambers along with the sulphur dioxide and air; the floor of the chambers is covered with water to a depth of about two inches. The sulphurous acid acts upon the vapour of nitric acid in the presence of the steam, forming nitric oxide and hydrated sulphuric acid, which collects in the water on the floor of the chambers:—$3SO_2 + 2HNO_3 + 2H_2O = 2NO + 3H_2SO_4$. The nitric oxide (NO) again takes up oxygen from the air admitted with the sulphurous acid and becomes nitric peroxide (NO_2), which, in the presence of water, oxidises more sulphurous acid, changing it into sulphuric acid—$2SO_2 + 2NO_2 + 2H_2O = 2H_2SO_4 + 2NO$. The nitric oxide evidently acts the part of a mere carrier, or intermediary, for the transference of oxygen, and it is to be observed that there will be a constantly recurring diminution of volume, since 4 vols. SO_2 and 4 vols. NO_2 yield but 4 vols. NO.

The nitrogen of the atmosphere takes no part in the reactions of the leaden chambers, and to prevent its accumulation it must be got rid of. This was formerly done by permitting of its escape, by a tall chimney at the opposite end of the chambers to that at which the various gases, or vapours, enter; but this also permitted of the escape of a considerable amount of nitric oxide, to avoid which loss, the nitrogen is now made to pass through a leaden chamber filled with coke, over which sulphuric acid trickles; the nitrogen escapes while the acid absorbs the nitric oxide, and being conveyed to another point, the acid is again made to trickle over coke through which the sulphurous acid and air entering the chambers must pass, at the same time taking up the nitric oxide from the sulphuric acid.

Before the introduction of this process, it required an amount of sodium nitrate of about $\frac{1}{10}$th of the weight of the sulphur, to convert it into sulphuric acid, while at present about $\frac{1}{20}$th suffices. The acid is allowed to collect on the floor of the chamber until its sp. gravity is about 1·6, and it contains about 70 per cent. of H_2SO_4. It is now withdrawn, to prevent it absorbing nitric oxide; to form a stronger acid, this weak acid is heated in evaporating pans of lead to drive off a portion of the water, and it is concentrated till the liquid has acquired a sp. gravity of 1·72, and contains about 80 per cent. of H_2SO_4; this is the **brown acid** of commerce, and is commonly used in the rougher manufacturing processes. Since lead would be attacked by the acid on further concentration, this process must be carried out in glass retorts, or in platinum stills. The glass retorts are heated in sand baths, but breakages are frequent on account of the high temperature (338°C.) at which the acid boils, and because it boils with a violent bumping, called "succussion," and this adds largely to the cost of the preparation of the acid; on the other hand, while with a platinum still the risk of fracture disappears and the distillation may be carried on with great rapidity, the first cost of the still itself is great, amounting to not less than $10,000 to $15,000.

In such retorts, or stills, the acid is concentrated till it acquires a density of 1·84. Over 100,000 tons of sulphuric acid are consumed annually in Great Britain, independently of the large quantity exported. Until towards the middle of last century it was sold at about $9.50 per lb., at the present time it costs about 2½ cents per lb.

A peculiar crystalline substance of doubtful composition, but temporarily represented by the formula $2(NO, SO_3) H_2O$, is formed in the production of sulphuric acid when the supply of steam is insufficient, and hence commonly known as the **crystals of the leaden chamber.** According to some chemists, this substance has an important effect in the process; while, according to others, it is an accidental formation of a useless and unprofitable nature.

All ordinary metals, except gold and platinum, are acted upon by heated concentrated sulphuric acid, hence it is used to separate gold from silver or copper. If some lump sugar be moistened with warm water and then treated with sulphuric acid, it swells up, with evolution of heat, into a black carbonaceous mass; this same action upon saccharine matter is taken advantage of in the manufacture of blacking, which contains treacle and sulphuric acid. All such action may be considered as due to the affinity of the acid for water, the removal of which from organic compounds tends to eliminate the carbon. If two measures of acid be added to one of water, the mixture cooled, and paper immersed in it and afterwards washed, the so-called vegetable parchment is obtained; the nature of the change is not known, but there is no difference in the weight of the paper. Even dilute sulphuric acid attacks cloth most injuriously, and the red stains produced should be removed by neutralizing the acid with an alkali, and the spot carefully washed. Strong acid is much used in chemical operations as a drying agent for gases, etc., usually by passing the gases over pumice stone saturated with the acid. The following are the principal compounds of sulphuric acid with the metals:—Sulphate of potash (K_2SO_4); sulphate of soda, or Glauber's Salt ($Na_2SO_4 + 10$ Aq.); sulphate of baryta, or heavy spar ($BaSO_4$); sulphate of lime, or gypsum ($CaSO_4 + 2$ Aq.); sulphate of magnesia, or Epsom Salts ($MgSO_4 + 7$ Aq.); sulphate of iron, copperas, or green vitriol ($FeSO_4 +$ 7 Aq.); sulphate of zinc, or white vitriol ($ZnSO_4 + 7$ Aq.); sulphate of lead ($PbSO_4$); sulphate of copper, blue vitriol or blue stone ($CuSO_4 + 5$ Aq.).

150. **Sulphuretted hydrogen,** or **Hydrosulphuric acid** ($H_2S = 34$; Density$=\frac{34}{2}=17$). A colourless gas possessing a peculiarly offensive odour

and taste, the odour being that of rotten eggs: does not support combustion; burns with a pale blue flame forming sulphurous acid and water—$H_2S + O_3 = SO_2 + H_2O$, a little sulphuric acid (H_2SO_4) is also formed; and, in an insufficient supply of air, sulphur is liberated; sp. gravity 1·1912; soluble in water at 0°C. to the extent of 4·37 volumes of the gas in one volume of water; condensible to a colourless liquid under a pressure of 16 atmospheres, at 15°C.; this liquid is solidified at—86°C. Hydrosulphuric acid is obtained by the action of dilute sulphuric acid upon iron sulphide:—$FeS + H_2SO_4 = H_2S + FeSO_4$, sulphuretted hydrogen is liberated and sulphate of iron is formed; the gas thus prepared generally contains free hydrogen, which does not practically interfere with its action. If the pure gas be required, however, it may be prepared by heating hydrochloric acid with antimony sulphide—$Sb_2S_3 + 6HCl = 3H_2S + 2SbCl_3$, sulphuretted hydrogen is liberated and antimony trichloride formed. The gas is quite irrespirable, and is most injurious to animal life, even when mixed with 1000 times its volume of air. Both the gas and its aqueous solution are feebly acid to blue litmus paper. It occurs free in nature, in mineral springs, and is liberated from volcanoes. It is a product of the decay of organic matter containing sulphur, and hence the comparison of its odour with that of rotten eggs, the smell of the egg being due to liberation of the gas; when water boils over on a coal or coke fire, the same offensive odour may be noticed, due to the combination of the sulphur of the coal with the hydrogen of the water. It attacks silver, forming a black film of silver sulphide; hence the discolouration of silver egg spoons, of silver plate exposed to the fumes of impure coal gas, or of a silver coin in contact with a lucifer match; the tarnish may be removed by washing the silver with strong ammonia, or with cyanide of potassium (KCN), but as the latter compound is a deadly poison, great care must be taken in its use. In the same way white lead paint is blackened by the formation of plumbic sulphide (PbS); and paintings, in the colours of which lead is an ingredient, are injuriously attacked by sulphuretted hydrogen. It has been found, however, that colours so injured are gradually restored to their original hue by exposure to light and air, the black sulphide becoming oxidised and changed into white sulphate of lead ($PbSO_4$). Sulphuretted hydrogen is a useful reagent in the laboratory, as it enables the analytical chemist to arrange the metals in groups according to their behaviour with it. Thus if the gas be passed into an acid solution of arsenic, antimony, tin, gold, platinum, silver, mercury, lead, bismuth, copper or cadmium, insoluble sulphides will be precipitated; this group may be further divided by the addition of ammonic sulphide ($(NH_4)_2S$) which dissolves the first five sulphides, but not the remaining six.

Other eight metals—iron, uranium, chromium, aluminum, cobalt, manganese, nickel and zinc, in an alkaline solution, are precipitated by sulphuretted hydrogen, but chromium and aluminum do not combine with the sulphur. **Hydrogen disulphide** (H_2S_2) is an oily liquid, obtained by acting upon calcium disulphide with muriatic acid—$CaS_2 + 2HCl = H_2S_2 + CaCl_2$, the lighter calcium chloride may be decanted off, leaving the hydrogen disulphide behind. In its properties it resembles hydrogen dioxide, possesses a peculiar smell and is a bleaching agent.

CHAPTER XIX.

CARBON DISULPHIDE—PHOSPHORUS—LUCIFER MATCHES OXIDES OF PHOSPHOROUS—PHOSPHORIC ACID —PHOSPHOROUS ANHYDRIDE—PHOSPHORETTED HYDROGEN.

151. **Carbon Disulphide** ($CS_2 = 76$) a colourless, volatile liquid, possessing a disgusting odour; insoluble in water, but soluble in alcohol, ether and oils; sp. gravity 1·26; boils at 46·5°C. and its vapour has a density of 38; it has never been solidified. Carbon disulphide is very inflammable, taking fire at a very low temperature, and burning with a bright, blue flame, producing carbonic and sulphurous acids ($CS_2 + O_6 = CO_2 + 2SO_2$); its vapour is injurious and ought not be inhaled; it is said to act on the system like sulphuretted hydrogen. Obtained by passing sulphur vapour over charcoal heated to redness. Of much importance in manufactures as a solvent for oils, fats, sulphur, phosphorus, caoutchouc, etc., and for extracting essential oils, as those of roses, jasmine, lavender, etc. It has also been employed to steep seed grain in, in order to kill insects without injuring

the seed. It is of notable service in experiments in diathermancy, since it is found to absorb only about 5 per cent. of the heat rays passing through it, and most of the light rays; but an opaque solution of iodine in the disulphide has been found by Professor Tyndall to absorb all the light rays, and to permit of the passage of nearly all the heat rays.

152. **Phosphorus** (P=31; the vapour of P is 62 times as heavy as H so that its atom only occupies half a volume.) An almost colourless, wax like, vitreous solid, of sp. gravity 1·83, but artificially obtained in dodecahedral crystals of sp. gravity 2·34; transparent when fresh but soon becoming opaque; melts at 44°C, but gives off faintly luminous fumes at ordinary temperature, possessing the odour of garlic; boils at about 290°C., out of contact with air, forming a colourless vapour; density of vapour 4·35. Insoluble in water, but very soluble in carbon disulphide, and to a slight degree in olive oil and benzole. Very inflammable, taking fire when heated above the melting point, or when subjected to a slight degree of friction, burning with a brilliant white light and evolving dense white fumes of phosphorus pentoxide (P_2O_5). Even when exposed to air, at a temperature considerably below the melting point, it slowly oxidises forming phosphorus trioxide (P_2O_3). It is the only element prepared from animal matter. It is obtained from—bones of oxen, imported from Monte Video; exhausted animal charcoal of sugar refineries; and mineral phosphate of lime. These various substances contain from 60 to 90 per cent. of their weight of

phosphate of lime, or from 12 to 16 per cent. of phosphorus. The powdered bone-ash, or bone earth, is acted upon by dilute sulphuric acid and heat, which causes the separation of a portion of the calcium, as insoluble calcium sulphate ($CaSO_4$), calcium superphosphate ($H_4CaP_2O_8$) being left in solution—$Ca_3P_2O_8 + 2H_2SO_4 = 2CaSO_4 + H_4CaP_2O_8$. The superphosphate solution is filtered off and evaporated to a syrup, which is mixed with powdered charcoal, dried in an iron vessel and then in a stone-ware retort. The carbon combines with the oxygen to form carbonic oxide (CO), the phosphorus distils over into a receiver containing water, to prevent combination with the oxygen of the air, and calcium phosphate remains in the retort — $3H_4CaP_2O_8 + 10C = 10CO + P_4 + Ca_3P_2O_8 + 6H_2O$. The phosphorus thus obtained is red and opaque, and is again melted under warm water, and squeezed through wash leather to remove mechanical impurities. It is again melted under ammonia to neutralise acid impurities; and again under acidulated bichromate of potash, to oxidise a lower oxide of phosphorus present to the pentoxide, which dissolves out. The phosphorus is then washed, melted under water, and cast into the sticks, in which it is generally offered for sale. Phosphorus is allotropic, and under the influence of light it becomes white and opaque; exposed to direct sunlight it becomes red; heated to near its melting point and then suddenly cooled, it assumes a viscous condition. When heated to a temperature of about 232°C., under pressure, in an atmosphere of carbonic acid gas, phosphorus is converted into a red amorphous substance of sp. gravity 2·14, which is little affected in air, is not luminous, emits no odour, is not poisonous, inflames at 232°C., and is reconverted into ordinary phosphorus, and is insoluble in disulphide of carbon and other solvents of ordinary phosphorus. The following, with some modifications, are the properties of ordinary and red phosphorus, as contrasted by Mr. G. Gore. **Ordinary phosphorus** is poisonous; evolves a strong odour; luminous in the dark; melts at 44°C.; very transparent; almost colourless; freely soluble, in various liquids; vitreous; soft, may be indented by the nail; flexible as lead. **Red phosphorus** is innocuous; nearly odourless; perfectly illuminous; melts at 260° C.; amorphous; hard as common brick; brittle as glass. At the beginning of last century phosphrous was sold in England at $1.25 per oz., at present its price is about 4 cents per oz.

On account of its inflammability, phosphorus should always be cut under water, as it inflicts painful and dangerous burns. This element is capable of entering into union with oxygen, chlorine, bromine, iodine, sulphur and most of the metals, even gold and platinum; forming phosphides and phosphurets. It has also the peculiar property, for a non-metal, of precipitating metals from the solution of their compounds, uniting itself with the oxygen present. For experimental purposes, a little red amorphous phosphorus may be prepared, by placing small fragments of common phosphorus in contact with some iodine, and quickly wrapping the substances up in a piece of tin foil, combustion will at once take place, and, if excess of phosphorus be present, a portion will be in the amorphous condition. The principal use of red phosphorus is in the manufacture of lucifer matches, in which it is partially replacing the ordinary form.

Although not found in a free state in nature, phosphorus is abundant throughout the world in the form of phosphates, and being an essential ingredient of the food of plants, and consequently of animals, its comparative abundance in the soil of a country, is a measure of the capacity of that soil as a supporter of animal life. It is abundant in the minerals—apatite, coprolite and phosphorite, all of which are eagerly sought after by agriculturists, for use as valuable manures.

153. **Lucifer matches** are prepared by tipping small splints of wood, cut to the proper dimensions by machinery, with some easily inflammable substance, as sulphur, or wax, which serves to communicate flame to the wood. The matches, which are prepared in bundles, are then tipped with yet more combustible matter—a compound of phosphorus, chlorate of potash ($KClO_3$), red lead (Pb_3O_4), fine sand and glue. The chlorate of potash causes the match to ignite with a slight explosion ; but, if what are called silent matches are required, the chlorate is replaced by nitrate of potash (KNO_3), or by nitrate of lead ($Pb(NO_3)_2$). The purpose to be served by the above mentioned compounds, is simply, by their ready deoxidation to accelerate the combustion of the phosphorus, when it is ignited by friction. The glue serves to

bind the constituents together and to the wood, and also to protect the composition from moisture; the sand or powdered glass serves to intensify the friction; and colouring matter is also present as a mere matter of taste. When the match is ignited, the chlorate of potash gives off all its oxygen and is converted into potassic chloride (KCl); the lead compounds are probably reduced by deoxidation to plumbic oxide (PbO); the nitrogen is evolved in the free state; the sulphur and phosphorus combine with the oxygen of the various ingredients, as well as with the oxygen of the air, to form phosphoric pentoxide (P_2O_5), and sulphurous acid (SO_2); and a small portion of the latter compound combines with an additional atom of atmospheric oxygen to form sulphuric acid, which combines with the potassium of the nitre to form potassic sulphate (K_2SO_4).

Safety matches differ from ordinary matches, in having the match composition partially on the match and partially on a rubber, usually affixed to the matchbox. The matches are tipped with sulphur, or wax, sulphide of antimony (Sb_2S_3), chlorate of potash ($KClO_3$), and powdered glass, and the rubber is coated with amorphous phosphorus mixed with powdered glass; sometimes the ends of the match are tipped differently, and ignition only takes place when the match is broken and the two ends rubbed together. On account of the great value of phosphorus compounds as manure, attempts have been made to substitute a mixture of chlorate of potash and hyposulphite of lead for the ordinary match composition. To give some idea of the extent to which this valuable constituent of fertile soils is withdrawn from what may be considered its legitimate use, it may be stated that some English firms manufacture as many as ten millions of matches per day; and one Birmingham firm alone makes daily over eight miles of wick for wax vestas, while in Sweden, Norway, Prussia, and Austria, matches are annually manufactured by thousands of tons.

154. **Phosphorus** forms only two oxides which have been separated and examined—phosphorus acid (P_2O_3), and phosphoric acid (P_2O_5). Phosphoric anhydride, or phosphorus pentoxide (P_2O_5) is readily obtained by burning phosphorus in oxygen or air, when it is evolved in dense white fumes, which condense to a white powder. It combines energetically with water forming the common phosphoric acid—$P_2O_5 + 3H_2O = 2H_3PO_4$. This acid is also called **Orthophosphoric acid**; if, however, the anhydrate combines with only one molecule of water **Metaphosphoric acid** is formed—$P_2O_3 + H_2O = 2HPO_3$· if with two molecules of water **Pyrophosphoric acid**—($H_4P_2O_7$) is obtained.

155. **Metaphosphoric acid** (HPO_3) is best obtained, by gently heating phosphorus with dilute nitric acid until the phosphorus is dissolved, and then evaporating the solution to a syrup in a platinum vessel—$10HNO_3 + P_6 = 10NO + 2H_2O + 6HPO_3$. This form is called glacial phosphoric acid, and by union with one molecule of water forms the ordinary acid—$HPO_3 + H_2O = H_3PO_4$. It forms salts called meta-

phosphates, as, when argentic nitrate ($AgNO_3$) is added to it, a gelatinous precipitate of argentic metaphosphate is formed—$2(AgNO_3) + 2HPO_3 \quad 2HNO_3 + 2 AgPO_3$.

Pyrophosphoric acid ($H_4P_2O_7$) is obtained in combination with metals, forming pyrophosphates. When aqueous solution of metaphosphoric acid is heated for some time it loses the power of forming a precipitate with argentic nitrate, but if the solution be neutralised by the addition of ammonia, a white precipitate of argentic pyrophosphate is obtained—$(2HPO_3 + H_2O) + 4 AgNO_3 + 2 NH_3 = Ag_4P_2O_7 + (2NH_3, 4HNO_3)$. Pyrophosphoric acid has been obtained in crystals, by decomposing plumbic pyrophosphate ($Pb_2P_2O_7$) with sulphuretted hydrogen, and evaporating the clear solution over oil of vitriol *in vacuo.*

Orthophosphoric acid, or common phosphoric acid (H_3PO_4) is obtained either by the union of phosphoric pentoxide (P_2O_5) with water as above, or from metaphosphates or pyrophosphates by boiling for some time in acidified liquid, or, by fusion with excess of caustic alkali, or with a carbonate. It is called the common acid, because most of the phosphates in common use are salts of this acid. It will be observed by the student that these different conditions of phosphoric acid—metaphosphoric, pyrophosphoric and orthophosphoric are monobasic, dibasic or strictly speaking tetrabasic, and tribasic respectively. It is also to be observed that this variety of constitution of phosphoric acid renders it peculiarly fitted to take part in vital phenomena, and it is found accordingly to be a constituent of nerve matter, etc., in the human body. Orthophosphoric and pyrophosphoric acids do not, and metaphosphoric acid does, coagulate albumen. Orthophosphoric acid gives a yellow precipitate, metaphosphoric acid gives a gelatinous precipitate, and pyrophosphoric acid gives no precipitate, except in presence of an alkali, with argentic nitrate ($AgNO_3$).

156. **Phosphorous anhydride** (P_2O_3) is the product of the combustion of phosphorus, in a limited supply of air. Phosphorus is placed in a long glass tube and heated, air being allowed to enter only through a tube of very small bore, the phosphorus burns with a pale blue flame forming white flakes of phosphorous anhydride. This substance dissolves readily in water—$P_2O_3 + 3H_2O = 2H_3PO_3$ and absorbs moisture from the air, and, on being heated in a closed tube, it is decomposed into phosphoric pentoxide and free phosphorus—$5P_2O_3 = 3P_2O_5 + P_4$.

157. **Phosphuretted Hydrogen** ($PH_3 = 34$; Density $= \frac{34}{2} = 17$) a colourless gas, possessing the odour of putrid fish; very poisonous; sp. gravity 1·19, burns with bright white flame, evolving dense vapour of phosphoric pentoxide. It has no acid properties, but it possesses some analogy to ammonia, although destitute of alkaline power; it has been condensed to a liquid under high pressure. Obtained by heating hydrated phosphorous acid (H_3PO_3), when phosphoric acid is formed and phosphuretted hydrogen is evolved. To prepare it for experimental purposes the following method is adopted:—A retort of moderate size is nearly filled with a strong solution of caustic potash,

in which are placed a few pellets of phosphorus; to prevent the spontaneous combustion of the gas in the retort **a few drops of ether** should be added, the solution is then cautiously heated till it boils, and the extremity of the delivery tube may then be dipped under water. In a few minutes small bubbles of white vapour will ascend through the water, giving off a most unpleasant and characteristic odour; other bubbles will soon follow, and these will ignite spontaneously on coming in contact with the air, with a bright flash and evolution of fumes of phosphoric acid. The fumes assume a very peculiar form—that of symmetrical revolving rings, gradually enlarging as they ascend in the air, and apparently made up of an infinite number of small rings, gyrating at right angles to the plane of the primary rings. If the gas be passed into a jar of oxygen, the flash is very vivid, and the concussion will shatter any but a strong jar. To insure the combustion of each bubble a trace of chlorine should be added to the oxygen. The phosphuretted hydrogen represented by the formula PH_3 is not spontaneously inflammable, but this property is due to the presence of another hydride, called liquid phosphide of hydrogen (PH_2). The gas prepared as above appears to be a mixture of phosphuretted hydrogen, liquid phosphide of hydrogen, and hydrogen, the latter gas being liberated from the water by deoxidation, on account of the formation of potassic hypophosphite (KPH_2O_2). A little turpentine added to a jar of the spontaneously inflammable gas deprives it of the property, and, on the other hand, a trace of nitrous acid imparts the property of spontaneous inflammability. Spontaneously inflammable phosphuretted hydrogen may be obtained also, by throwing pieces of calcium phosphide on warm water.

CHAPTER XX.

BORON—BORACIC ACID—BORAX—SILICON — SILICA—HYDRAULIC CEMENT.

158. **Boron** ($B=11$), a solid, obtained in the form of an amorphous greenish powder, by fusing five parts of boron tri-oxide (B_2O_3) with three parts sodium (Na), in an iron crucible. Obtained in octahedral crystals, by heating amorphous boron with aluminum; sp. gravity of crystallised variety 2·68, hardness 10; not attacked by any acid, but dissolved by fused alkaline hydrates; burns when heated in chlorine, forming boron trichloride (BCl_3); partially burns when heated in oxygen, forming boracic acid (B_2O_3). Boron unites directly, at a red heat, with nitrogen.

159. **Boracic acid** (B_2O_3 anhydrate), (H_3BO_3 hydrate) is the only oxide of boron. Obtained chiefly from the volcanic district of Tuscany, called the Maremna, and also from various lakes in California; a colourless, glassy substance, dissolving in water or alcohol; sp. gravity 1.83; gives a fine green flame before the blowpipe; crystallises out of its solution in pearl-coloured scales; gives no acid result with test paper, but unites with bases, and forms borates. In Italy, boracic acid is economically obtained from the

hot springs, in which it is found, by evaporating the water in shallow leaden pans, by the agency of the steam from the springs themselves.

160. **Borax, Biborate of soda** ($2NaBO_2,B_2O_3$+ 10 Aq.) crystallises in transparent prisms, but when heated forms a white spongy mass, soluble in water; before the blowpipe fuses to a colourless glass, and, since it acts as a flux, it is very useful in blowpipe analysis, by forming glasses of characteristic colours, when heated with salts of various metals. Commonly used as a flux in soldering. Obtained native from Thibet and California, under the commercial name of tincal.

161. **Silicon** (Si=28). Does not exist in the free state, but obtained artificially in three conditions—crystallised, amorphous and graphitoidal. Crystallised silicon is in the form of brilliant octahedra, possessing a dark hue, and iridescent lustre; sp. gravity 2·5; hard enough to scratch glass with ease. This form is obtained by fusing silicon at a temperature about that of the melting point of cast iron. Amorphous silicon is a brown powder, which burns with brilliant combustion in oxygen, forming silica (SiO_2); soluble in caustic potash, and in hydrofluoric acid (HF); obtained by heating together fine sand (SiO_2), powdered fluorspar (CaF_2), and sulphuric acid :—$SiO_2 + 2CaF_2 + 2H_2SO_4 = SiF_4 + 2CaSO_4 + 2H_2O$, silicon tetra-fluoride is evolved and is passed under mercury into water; in which it forms silica (SiO_2), and silico-fluoric acid (SiH_2F_6). Mercury must be used in this operation, for, under water, the silica formed would stop up the

delivery pipe, and thereby cause an explosion. The acid liquor is now neutralised by the addition of caustic potash, forming potassic silica fluoride ($2KF, SiF_4$) and this salt being dried, is heated with about its own weight of sodium, when sodium fluoride (NaF), is formed in addition to potassium fluoride (KF), and amorphous silicon is separated by washing. Graphitoidal silicon is obtained by heating the amorphous silicon to a high temperature; it is in black crystalline scales, possessing a semi-metallic lustre; this form does not burn in oxygen, nor does it dissolve in hydrofluoric acid, but it may be dissolved in a mixture of nitric and hydrofluoric acids; silicon differs from carbon in being fusible at a high temperature, in forming only one compound with hydrogen and that one very unstable, and in combining directly with nitrogen at a high temperature, while nitrogen will not combine with carbon except in presence of alkalies. Silicon is capable of displacing carbon from carbonic acid (CO_2). Carbon, boron, and silicon form a group, the members of which resemble each other in their allotropism, their infusibility, and by their combining with oxygen to form feeble acids. The group is allied to the metals through silicon, which in some of its salts resembles tin.

162. **Silica, silicic acid,** or **silicic di-oxide** (SiO_2), is one of the most abundant mineral constituents of the globe; it occurs pure as rock-crystal or quartz, crystallises in six-sided prisms of the rhombohedral system; when pure colourless, but often coloured, forming amethysts, cairngorm stones, Bristol

diamonds, or smoky quartz ; and, in the uncrystallised form, chalcedony, carnelian, onyx, catseye, opal, heliotrope, agate, jasper, flint, sand, etc. Silica is little affected by any acid, except hydrofluoric acid (HF), which decomposes it, forming silicon tetra-fluoride and water—$SiO_2 + 4HF = SiF_4 + 2H_2O$. Notwithstanding this apparent insolubility of silica, it is found in plants, and in many natural waters, such as the Geysers of Iceland. In the crystallised state, silica is infusible before the blowpipe; hardness 7; sp. gravity 2·5–2·8. Pure amorphous silica may be prepared by fusing a silicate, in the powdered condition, with five or six times its weight of the carbonates of potassium and sodium in equal parts ; the glassy mass formed is dissolved in dilute hydrochloric acid, and the mixture evaporated to dryness ; by this process the precipitated silica has lost its solubility and, on the dry mass being acted upon with dilute hydrochloric acid, the other constituents of the mixture are dissolved, whilst the amorphous silica remains as a gritty white powder. In this form silica is soluble in hot alkaline solutions, therein differing from the crystallised variety; its sp. gravity is 2·3. If a very dilute solution of the glassy mass, referred to above as being dissolved in hydrochloric acid, be placed upon a dialiser, the hydrochloric acid, and the sodium chloride formed will be diffused out, leaving behind a pure solution of silicic acid, which, when allowed to stand for a few hours, becomes gelatinous. Silica acts as **a weak acid** at ordinary temperatures, and, at high temperatures, **displaces most** of the other **acids** from their combinations. Since, in general, **acids can only be displaced** from their combinations **by acids,** this will explain the term acid, as applied to the different varieties of silica—flint, sand, quartz, etc., substances which appear to lack all the characteristics of a true acid. With bases, silica forms an abundant class of minerals called silicates, among the most important of which are :—Steatite, or soapstone ; meerschaum ; serpentine ; felspar ; mica ; talc ; augite ; garnet; emerald; beryl; porcelain clay; kaolin. Alkaline silicates, in combination with silicates of lead, calcium and other metals, form the several varieties of glass.

163. **Hydraulic Cement** is prepared by calcining together calcium carbonate with clay, which is chiefly silicate of alumina. The carbonic acid gas is expelled and the calcium unites with silicic acid, forming calcium silicate (CaO, SiO_2) and probably also aluminate of calcium. If the calcination be carefully performed and not carried too far, the resulting compound on being finely powdered and mixed with water is found to set rapidly, the hardening of the best kinds being complete in two or three days, when the cement is found to be unaffected by contact with water. This hardening is due to the formation, by the silicates and the aluminate, of hydrated double silicates and aluminates, upon which water has no further action. About 10 to 25 per cent. of the compound ought to be clay and the remainder calcium carbonate.

CHAPTER XXI.

ARSENIC—ARSENIOUS ACID—ARSENIC ACID.

164. **Arsenic** (As=75). The vapour of **As** is 150 times as heavy as H, so that its atom only occupies half a volume). An element sometimes considered a metal, but, since its characteristics closely connect it with phosphorus and it is incapable of forming a base with oxygen, it is probably best considered as a non-metal. Arsenic possesses a steel-gray colour, and metallic lustre ; soon tarnishes in air by oxidation ; is a conductor of electricity ; very brittle ; crystallises in rhombohedrons ; sp. gravity 5·96 ; volatilises without fusion at 180°C., giving off vapour which possesses a characteristic odour of garlic. The vapour condenses in a compact metallic looking mass, but, if heated in air to about 71°C., white fumes of arsenious acid (As_2O_3) are given off. When arsenic is heated to a red heat it burns with a livid blue flame, forming the above named acid. If powdered arsenic be dropped into chlorine gas, it burns, forming arsenic trichloride ($AsCl_3$). Arsenic is rarely found native, but generally in union with iron, cobalt, copper, or nickel ore, or with sulphur; sometimes, also, it is found in combination with oxygen and metals in arseniates. Obtained from arsenical pyrites (FeS_2, $FeAs_2$) by heating it in earthen cylinders, the arsenic is driven off as a vapour, which distils into iron receivers, in which it condenses as a bright metallic looking solid. It is also prepared from other ores containing it by roast-

ing on the hearth of a reverberatory furnace, in contact with heated air. The arsenic becomes oxidised, by the atmospheric oxygen, forming arsenic trioxide (As_2O_3), which passes off as vapour into long flues, in which it condenses to a white crystalline substance. The trioxide, in a powdered condition, is then mixed with half its weight of charcoal, and heated in a crucible, which is covered by a cap which is protected from the heat below by a perforated iron shield. Carbonic oxide is formed and escapes through a hole in the cap, and arsenic vapour condenses in the cool upper portion of the vessel—$As_2O_3 + C_3 = As_2 + 3CO$. Arsenic is poisonous, both pure and in its compounds, but, in the pure state, the symptoms of poisoning do not appear till a considerable time after administration, probably not until it is oxidised in the stomach and changed to arsenious acid. Arsenic is used to prevent smut in grain, is mixed with the alloys employed in making telescopic specula, and enters into the composition of small shot. The following are the principal arsenides :—Kupfernickel ($NiAs$), Arsenical Nickel ($NiAs_2$), Cobalt Arsenide ($CoAs_2$), Mispickel, or Arsenical pyrites (FeS_2, $FeAs_2$), Cobalt Glance (CoS_2, $CoAs_2$), Red Orpiment, or Realgar (As_2S_2), Nickel Glance (NiS_2NiAs_2), Yellow Orpiment (As_2S_3). The elements nitrogen, phosphorus and arsenic display certain analogies in their oxygen and hydrogen compounds; there are likewise analogies between the hydrogen compounds of arsenic and antimony; and arsenic trioxide is capable of occupying the place of antimony trioxide (Sb_2O_3) in certain salts. The sulphides of arsenic and antimony have also a considerable degree of correspondence in composition, and in some of their properties.

165. **Asenious Acid** ($As_2O_3=198$). A white solid crystalline, or amorphous substance, possessing very poisonous properties. The crystalline variety, sp. gravity 2·69, is obtained when its vapour is quickly condensed, or when it separates from its solutions; the amorphous form, sp. gravity 3·7, is obtained when the vapour condenses on a hot surface. Volatilises at 193·3°C., depositing brilliant octahedral crystals on a cool surface. It is not merely not soluble in water in any great degree, 20 oz. of water in the course of several hours not dissolving more than 20 grs. of arsenious acid, but when thrown upon water it manifests great repulsion to it, the particles collecting in little globular clusters on the surface. This comparative insolubility renders it almost tasteless and delays the developement of its poisonous properties, when it is taken into the stomach. The smallest quantity which has been known to prove fatal is 2·5 grs. By long boiling in water, however, it is possible to obtain a much stronger solution, viz.: about 219 grs. in 20 oz. Arsenious acid is obtained chiefly from arsenical pyrites (FeS_2, $FeAs_2$), by roasting in muffles, or ovens, through which a current of air passes, converting by oxidation the arsenic into arsenious acid, and the sulphur into sulphurous acid; these acids are conveyed into chambers, from which the sulphurous acid is carried off, while the arsenious acid is condensed as a fine white powder. Arsenious acid thus prepared is

again sublimed in small quantities in iron vessels, and is condensed into vitreous arsenious acid, possessing a somewhat glassy appearance, but finally becoming opaque. It is usually sold in the form of a white powder. Arsenious acid very slightly affects blue litmus paper, it is easily dissolved in hydrochloric acid, forming terchloride of arsenic ($AsCl_3$), and octahedral crystals of arsenious acid ; it also dissolves in alkaline solutions, forming alkaline arsenites. When a little is thrown upon a red hot-coal, the peculiar garlic odour of arsenic is perceptible. It is used to prevent putrefaction of pelts, etc., and is accordingly employed in the preservation of stuffed animals. Scheele's green, arsenite of copper ($2CuO,H_2As_2O_4$) is a brilliant green colour used for colouring wall papers, calicoes, feathers, artificial flowers, etc. All materials, or fabrics, so coloured, are more or less poisonous, both to those who make use of them and to those who prepare them.

166. **Arsenic Acid** (As_2O_5). A white amorphous substance, somewhat less poisonous than arsenious acid, cannot be volatilised without decomposition; not soluble to any great degree in water ; has powerful acid properties. Obtained by oxidising arsenious acid with nitric acid—$As_2O_3 + 2HNO_3 + 2H_2O = N_2O_3 + 2H_3AsO_4$. Nitric trioxide fumes are given off, and prismatic crystals of hydrated arsenic acid remain ; when these are heated to about 260°C., all the water is driven off, and arsenic acid remains. It is largely used in calico printing, and in the manufacture of the aniline dye—Magenta. Its most important salt is

arseniate of soda ($H_2Na_4As_2O_8 + 14Aq.$), used extensively by calico printers, on account of its feebly alkaline properties.

CHAPTER XXII.

ARSENIETTED HYDROGEN—REALGAR—ORPIMENT—MARSH'S TEST—REINSCH'S TEST.

167. **Arsenietted hydrogen** (AsH_3). A colourless gas; very poisonous; slightly soluble in water; burns with a livid blue flame, forming water and fumes of arsenious acid—$2AsH_3 + O_6 = As_2O_3 + 3H_2O$; but, in contact with a cold surface, as of porcelain, pure arsenic is deposited. It posseses a sickly, garlic-like, smell; is condensible to a liquid at—40C. Obtained by the action of dilute sulphuric acid upon zincic arsenide—$Zn_3As_2 + 3H_2SO_4 = 2AsH_3 + 3ZnSO_4$. Arsenietted hydrogen is evolved and zinc sulphate remains in solution. The student will observe that the three gases—ammonia, phosphuretted hydrogen, and arsenietted hydrogen form a group possessing certain analogies and properties in common. In each there are three volumes of hydrogen; they all possess peculiar and powerful odours; all are decomposed by heat; all are inflammable, ammonia least so: the first two are alkaline; they are all derived from their corresponding oxygen compounds (N_2O_3, P_2O_3, and As_2O_3) by contact with zinc and sulphuric acid.

168. Realgar, arsenic disulphide (As_2S_2), found native in veins; crystallises in oblique prisms, possessing

a red colour; sp. gravity 3·55. Obtained artificially (1) by heating arsenious acid and sulphur together—$2As_2O_3 + S_7 = 2As_2S_2 + 3SO_2$, sulphurous acid escapes and realgar is left: (2) by distilling arsenical pyrites with iron pyrites—$FeS_2, FeAs_2 + 2FeS_2 = 4FeS + As_2S_2$, realgar distils over and condenses to a red solid, and iron sulphide remains. Realgar burns in air with a blue flame, forming arsenious and sulphurous acids. If thrown into melted saltpetre, it burns with a brilliant white flame, forming arseniated sulphate of potash. It is consequently an important ingredient in signal lights, Indian fire and fire works.

169. Orpiment, arsenic tersulphide (As_2S_3), found native in beds and veins; crystallises in prisms; colour bright yellow; sp. gravity 3·48; obtained by heating arsenious acid with sulphur—$2As_2O_3 + S_9 = 2 As_2S_3 + 3SO_2$, sulphurous acid escapes, and yellow orpiment remains. The paint sold as King's Yellow is a mixture of orpiment and arsenious acid. Both realgar and orpiment are poisonous.

170. In the application of what is called **Marsh's test** for arsenic, in cases of poisoning, the operator causes the evolution of hydrogen, in the usual way, by the action of dilute sulphuric acid upon granulated zinc. Care must be taken to ascertain the purity of the metal and the acid, as both are liable to contain traces of arsenic. The Woulfe's bottle, employed in the evolution of the gas, is provided with a thistle tube as usual, and a delivery tube of hard German glass bent at right angles, and terminating in a fine jet. When the escaping hydrogen is ignited, a little of the

liquid matter suspected of containing some form of arsenic is added to the solution in the bottle, through the thistle tube. If arsenic be present, the flame will now assume the livid blue colour characteristic of arsenietted hydrogen, and, on pressing down on the flame a piece of cold porcelain, a dark brown deposit possessing the metallic lustre of arsenic will gradually be formed upon it. If a spirit lamp be placed under the horizontal portion of the delivery tube, the arseniettted hydrogen is decomposed, the livid hue disappears and arsenic is deposited on the sides of the tube. The arsenic deposited may be converted into arsenious acid and the usual tests applied (63 and 64). Antimonietted hydrogen (SbH_3), when subjected to Marsh's test, gives very similar results to arseniettted hydrogen; but the arsenical deposit yields octahedral crystals, and the antimony yields prismatic crystals. The antimony deposit is black, the arsenical is brown, and, finally, antimony is soluble in ammonium bisulphide ($(NH_4)_2 S_2$), which hardly affects the arsenical deposit.

171. **In applying Reinsch's test** for arsenic, the suspected solution is acidulated with hydrochloric acid, a piece of bright copper is introduced into it, and heat is applied. If arsenic be present, an iron-grey deposit of cupric arsenide (Cu_6As_2) will be formed on the surface of the copper. This deposit is carefully scraped off, washed, dried, and heated in a bulb reduction tube, when minute crystals of arsenious acid (As_2O_3) are deposited against the sides of the upper part of the tube. These crystals, on being dissolved

in water, may be subjected to the usual tests (63 and 64). Reinsch's test will apply equally well to arsenious acid or to arsenic acid, but in the latter case an excess of hydrochloric acid must be added.

172. Characteristics of the principal gases.

NAME.	SYMBOL AND DENSITY.	COLOUR	TASTE.	SMELL.	COMBUSTIBLE OR SUPPORTER OF COMBUSTION.	CONDENSIBLE OR INCONDENSIBLE TO A LIQUID.	TESTS.
ACETYLENE	C_2H_2. 13.	none	none	slight	bright smoky flame	condensible	inflames spontaneously in chlorine, with red flame.
AMMONIA	NH_3. 8·5.	"	acrid	pungent	burns with difficulty	condensible	alkaline to moistened turmeric, or red litmus paper; very soluble in water. See Nessler's test, par. 121.
ARSENIETTED HYDROGEN	AsH_3. 39.	"	none	of garlic	livid blue flame	"	See pars. 170, 171.
CARBONIC ACID	CO_2. 22.	"	acid	pungent	incombustible and almost non-supporter	"	precipitates carbonate of lime, when passed into lime-water.
CARBONIC OXIDE	CO. 14	"	none	faint	blue flame	incondensible.	forms CO_2 on burning, when the above test may be applied.
CHLORINE	Cl. 35·5.	pale green	acrid	suffocating	partial supporter	condensible	hydrogen, bromine, iodine and phosphorus combine spontaneously with Cl.
HYDROCHLORIC ACID	HCl. 18·25	none	none	irritating	incombustible and non-supporter	"	soluble to the extent of 480 volumes in one volume of water. See pars. 63, 64.
HYDROGEN	H. 1	"	"	none	pale blue flame	incondensible.	combines with oxygen to form water only. Combines spontaneously with Cl. in presence of sunlight.
MARSH GAS	CH_4. 8	"	"	"	pale illuminating flame	"	distinguished from hydrogen by its depositing soot as well as water, upon a cold porcelain surface held in the flame.

Nitric Oxide	NO. 15..	〃	〃	〃	very weak supporter......	〃 ..	addition of oxygen causes formation of reddish fumes of NO_2 and N_2O_3.
Nitrogen.................	N. 14....	〃	〃	〃	incombustible and non-supporter	〃 ..	distinguished by its negative properties.
Nitrous Oxide............	N_2O. 22.	〃	sweetish..	faint....	good supporter..........	condensible ..	distinguished from oxygen by its solubility in water, to the extent of 3 vols. in 4 vols.; and phosphorus, carefully heated in the gas, removes the oxygen, without diminishing the volume taken.
Olefiant Gas.............	C_2H_4. 14.	〃	〃	of ether.	bright illuminating flame.	〃 ..	combines with an equal volume of chlorine, or bromine to form an oily liquid; decomposed at a high temperature into CH_4, C_2H_2, and H.
Oxygen...................	O. 16...	〃	none......	none....	*the* supporter.	incondensible.	a splinter of wood, in the condition of a red-hot coal, instantly inflames when plunged into oxygen. The addition of nitric oxide (NO) causes the formation of reddish fumes of NO_2 and N_2O_3.
Phosphuretted Hydrogen.	PH_3. 17..	〃	〃	of putrid fish	white flame...	condensible ..	as commonly prepared, inflames spontaneously in air, forming very characteristic gyrating rings of phosphoric pentoxide (P_2O_5).
Sulphuretted Hydrogen..	H_2S. 17..	〃	〃	of rotten eggs..	pale blue flame	〃 ..	abominable smell, and blackens test paper prepared in solution of plumbic acetate—Pb $(C_2H_3O_2)_2$.
Sulphurous Acid.........	SO_2. 32..	〃	sour......	suffocating ..	incombustible and non-supporter	〃 ..	weight, smell, acid and bleaching properties. See pars. 63, 64.

INTERMEDIATE EXAMINATION.

CHEMISTRY.

Questions, with answers, or references to paragraphs, where the answers may be found.

JUNE, 1876.

1. How would you prepare Hydrogen? State fully by what means you would show its most important properties.

Ans. Par. 108.

2. Describe fully the modes of decomposing water, which you have seen. You are asked to say whether a given specimen of water is hard or soft, how will you determine the fact? If the water is hard, describe (with reasons) all the means by which you can make it soft.

Ans. Pars. 103, 109.

3. State all the forms in which Carbon is found in nature. By what experiments would you show its important properties. You are given a black substance like coal, and asked to say whether it is carbon or not; how will you determine this?

Ans. Pars. 124, 125.

4. How would you obtain Carbonic Acid from chalk—represent the reaction by an equation. A current of atmospheric air passes up through a bright coal fire, state all the changes which it undergoes till it enters the atmosphere again.

Ans. Pars. 127, 126.

5. How is Chlorine prepared? State the experiments by which you would show its properties. On what does its bleaching power depend? You are given a piece of calico, and requested to bleach it —state fully how you would proceed.

Ans. Pars. 137, 141.

6. When an ordinary friction match is lighted, what gases are given off? Describe the properties of any of them.

Ans. Par. 153.

7. State what substances are represented by the following formulas, and mention any experiments in which you have seen any of them occur:

MnO_2, Fe_3O_4, P_2O_5, $ZnSO_4$, NH_4Cl, $CaCo_3$.

Ans. MnO_2, manganese dioxide, Pars. 106, 137. Fe_3O_4, magnetic oxide of iron, a compound of protoxide of iron (FeO) and peroxide of iron (Fe_2O_3), Par. 106. P_2O_5 phosphoric pentoxide, Par. 112. $ZnSo_4$ zinc sulphate or white vitriol, Par. 108. NH_4Cl sal-ammoniac, Par. 121. $CaCo_3$ carbonate of lime, Pars. 127, 121.

DECEMBER 1876.

1. Describe and explain some method of obtaining oxygen. How would you shew its principal properties? What quantity of oxygen is required for the complete combustion of 100 grs. of pure charcoal?

Ans. Pars. 106, 127, $CO_2 = 12 + 32 = 44$; therefore $12 : 32 :: 100 : x$.

2. Explain what is meant by the combining measure of a gas, and state what the combining measure of hydrogen, chlorine and hydrochloric acid will be if we assume that of oxygen to be 1.

Ans. Pars. 24, 25, 98, 99.

3. Describe and explain any experiments that illustrate the action of plants and animals upon the air. What substances are found in the air in addition to the two principal gases?

Ans. Pars. 114, 113.

4. It was anciently believed that fire, earth, air and water were elements, state the views which now prevail as to the nature of each of these things. What is now meant by the term element?

Ans. Pars. 11, 12, 9.

5. Explain a method of preparing nitric acid, and state its composition by weight. What is a nitrate? Show how the presence of a nitrate in a liquid may be detected.

Ans. Par. 120, $HNO_3=1+14+48=63$. Pars. 45, 63, 64.

6. Name and give the formulæ of the oxides of nitrogen, sulphur and carbon.

Ans. Pars. 112, 148, 126, 127.

7. Calculate the per centage of the various elements contained in nitric acid, ammonia, sulphuric acid and common salt.

Ans. Par. 120, $HNO_3=1+14+48=63$; therefore 63 : 100 : : 1 : p/c of H. 63 : 100 : : 14 : p/c of N. 63 : 100 : : 48 : p/c of O. Par. 121, $NH_3=14+3=17$; therefore 17 : 100 : : 14 : p/c of N. 17 : 100 : : 3 : p/c of H. Par. 149, $H_2SO_4=2+32+64=98$; therefore 98 : 100 : : 2 : p/c of H. 98 : 100 : : 32 : p/c of S. 98 : 100 : : 64 : p/c of O. Par. 137, NaCl

=23 + 35·5=58·5 ; therefore 58·5 : 100 : : 23 : p/c of Na, 58·5 : 100 : : 35·5 : p/c of Cl.

8. Explain the terms acid, alkali and salt.

Ans. Pars. 39, 40, 42.

JULY EXAMINATIONS, 1877.

SECOND CLASS TEACHERS AND INTERMEDIATE.

1. Give two methods of preparing Hydrogen. By what experiments would you show its most important properties?

Ans. Par. 108.

2. How would you prepare Nitric Acid? Describe any experiments with Nitric Acid which you have seen.

Ans. Par, 120.

3. State the different forms in which Carbon occurs in nature. Port wine filtered through charcoal is deprived of its colour; give the reasons of this. How is charcoal used as a disinfectant? Give the theory of its action.

Ans. Par. 124.

4. How would you prepare Carbonic Acid from Chalk and Sulphuric Acid? Express the reaction by an equation. Bread is raised by the liberation of Carbonic Acid. Explain.

Ans. Par. 127.

5. What is meant by combustion? Explain fully the substances formed when a candle is burned (1) in oxygen, (2) in a limited supply of air.

Ans. Pars. 72, 132.

6. Write down the formulæ and molecular weights of water, ammonia, hydrochloric acid, sulphuric acid, ferrous sulphate, phosphoric acid.

Ans. Pars. 109, 121, 139, 149, 155.

7. (1) How many grammes of oxygen are required to burn 24 grammes of carbon and 32 grammes of sulphur?

(2) How many lbs. of zinc are there in 350 lbs. of zinc sulphate?

Ans. (1) $CO_2=12+32=44$; therefore 12 : 24 : : 32 : Oxygen required; and $SO_2=32+32$.

(2) $ZnSO_4=65{\cdot}2+32+64=161{\cdot}2$, therefore 161·2 : 350 : : 65·2 : amount of zinc.

8. Describe any two experiments which you have performed yourself, and the purpose for which you performed them.

Ans. This question ought sufficiently to impress the student, with the necessity of practical work in Chemistry.—(Author).

9. How would you obtain chlorine from common salt? Give the equation respecting the reaction. Describe any experiments with chlorine you may have seen.

Ans. Par. 137.

DECEMBER 1877.

1. Describe any experiments you may have seen which prove (1) that chemical action generally produces a change of state (2) that chemical action generally produces a change of temperature.

Ans. Pars. 62, 63, 106, 108.

2. Give the principal properties of oxygen. Describe its preparation from potassic chlorate, representing the reaction by an equation.

Ans. Par. 106.

3. What quantity of oxygen by weight and also by volume can be obtained by the decomposition of 100 grains of potassium chlorate?

Ans. $KClO_3 = 39{\cdot}1 + 35{\cdot}5 + 48 = 122{\cdot}6$; therefore $122{\cdot}6 : 100 :: 48 : 39{\cdot}15$. 11·2 litres of oxygen weigh 16 grammes (Par. 99), therefore $16 : 39{\cdot}15 :: 11{\cdot}2 :$ volume of oxygen in litres; or (Par. 98), 46·7 cubic inches of oxygen weigh 16 grains; therefore $16 : 39{\cdot}15 :: 46{\cdot}7 :$ volume of oxygen in cubic inches.

4. Give the symbol, atomic weight, and chief properties of chlorine. To what are its bleaching and deodorizing properties due? Express in words the meaning of the equation—$2NaCl + MnO_2 + 2H_2SO_4 = Cl_2 + Na_2SO_4 + MnSO_4 + 2H_2O$.

Ans. Par. 137.

5. Give the symbol and atomic weight of sulphur. Describe any method of preparing sulphuric acid. How would you prepare crystals of sulphur. What would be their shape?

Ans. Pars. 146, 149.

6. What is the action of water upon each of the following substances? Hydrogen, carbonic anhydride, ammonia, and sodium.

Ans. Hydrogen has no effect upon water beyond dissolving in it to the extent of 2 volumes hydrogen in 100 volumes water.

$CO_2 + H_2O = H_2CO_3$ (carbonic acid, which changes blue litmus paper red). NH_3, ammonia dissolves to the extent of 1090 volumes in one of water, forming a strongly alkaline solution.

$Na_2 + 2H_2O = 2HKO + H_2$. Caustic soda is formed and hydrogen is liberated.

7. What weight and volume of carbonic acid gas would be produced by burning 5 grains of carbon in oxygen gas?

Ans. $CO_2 = 12 + 32 = 44$; therefore $12 : 5 :: 44 : x$ = weight of CO_2 produced. Density of $CO_2 = \frac{44}{2} = 22$; therefore 11·2 litres weigh 22 grammes (Par. 99); therefore $22 : x :: 11{\cdot}2$: volume of CO_2 produced.

8. Give a brief account of the atmosphere, including its extent, pressure, composition and chemical relations.

Ans. Pars. 113, 114, 68, 69.

9. Describe minutely any chemical experiment you have yourself performed.

JULY 1878.

1. Give the names and atomic weights of the elements represented by the following symbols :—Al, C, Ca, Cu, Fe, Cl. Pb. S. P.

Ans. Par. 13.

2. Explain what occurs in the distillation of water, and how the water is purified by the process. What kind of impurities will remain in the distilled water, and how can they be detected?

Ans. Pars. 109, 62, 63, 64.

3. Represent the following statement by means of an equation :—If 100 grammes of marble be mixed with

73 grammes of hydrochloric acid it will yield 111 grammes of calcic chloride, 18 grammes of water, and 44 of carbonic anhydride.

Ans. Par. 127.

4. Describe fully the preparation of O from potassic chlorate, representing the reaction by an equation. How much potassic chlorate must be taken to yield 10 lbs. of oxygen?

Ans. Par. 106. $KClO_3 = 39{\cdot}1 + 35{\cdot}5 + 48 = 122{\cdot}6$; therefore 48 : 10 : : 122·6 : amount of potassic chlorate.

5. Give the properties of hydrogen. Describe the process for obtaining hydrogen which is represented in the equation—$H_2SO_4 + Zn = ZnSO_4 + H_2$.

Ans. Par. 108.

6. Explain the chemical relations between chalk, quick lime and slaked lime; also the preparation of chloride of lime, and the reactions by which that substance evolves chlorine, when acted on by sulphuric acid and when exposed to the air.

Ans. Chalk is calcic carbonate ($CaCO_3$), if this be sufficiently heated, it is decomposed into carbonic acid gas (CO_2), and calcic oxide (CaO) commonly called quick lime; if water be added to quick-lime the hydrated oxide—($CaO + H_2O$) commonly called slaked lime is formed. Par. 141.

7. What is the compostion of lucifer matches? What purpose does each ingredient serve, and what chemical action occurs when you strike a match?

Ans. Par. 153.

8. A compound on an analysis, is found to yield the following percentages :—Potassium, 49.95 ; Nitrogen, 16.45 ; Oxygen, 37.60. Calculate its formula, and give its name.

Ans. $K = \frac{49·95}{39·1} = 1·27$. $N = \frac{16·45}{14} = 1·18$. $O = \frac{37·60}{16} = 2·35$; therefore 1·18 : 1·27 : 2·35 = KNO_2 (Potassic Nitrite).

9. State what experiments you have yourself performed, and describe minutely any one of them.

DECEMBER, 1878.

INTERMEDIATE EXAMINATIONS.

1. State the laws of combining proportions.

In one ounce of each of the following gases what weight of each element would there be :—Carbon monoxide, carbon dioxide, marsh gas (CH_4), olefiant gas (C_2H_4), acetylene (C_2H_2) ?

What would be the volume of an ounce of carbon dioxide, if, at the same temperature and pressure, 50 cubic inches of hydrogen weigh one grain ?

Ans. (1) Par. 27.

(2) $CO = 12 + 16$; therefore one oz. contains of carbon $\frac{3}{7}$ oz. and of oxygen $\frac{4}{7}$ oz.

$CO_2 = 12 + 32$; therefore one oz. contains of carbon $\frac{3}{11}$ oz. and of oxygen $\frac{8}{11}$ oz.

$CH_4 = 12 + 4$; therefore one oz. contains of carbon $\frac{3}{4}$ oz. and of hydrogen $\frac{1}{4}$ oz.

$C_2H_4 = 24 + 4$; therefore one oz. contains of carbon $\frac{6}{7}$ oz. and of hydrogen $\frac{1}{7}$ oz.

$C_2H_2 = 24 + 2$; therefore one oz. contains of carbon $\frac{12}{13}$ oz. and of hydrogen $\frac{1}{13}$ oz.

(3) If one grain of hydrogen measure 50 cubic inches, one ounce (480 grains) will measure $50 \times 480 = 24000$ cubic inches; but carbon dioxide is 22 times heavier than hydrogen (Par. 99); therefore volume of one ounce carbon dioxide $= 24000 \div 22 = 1091$ cubic inches.

2. Describe a method of preparing hydrogen. Write in symbols the reaction occurring.

By what experiments could the most important properties of hydrogen be exhibited?

Ans. Par. 108.

3. By what experiments could air be shown to be a mechanical mixture of two gases, oxygen and nitrogen?

Give the names and symbols of the chief compounds of oxygen and nitrogen.

Write in symbols the reaction that occurs in the preparation of nitric acid from nitre, and calculate the weight of commercial nitric acid ($2HNO_3$, $3H_2O$) that 337 oz. of nitre are capable of yielding, ($K = 39.1$).

Ans. (1) Par. 113. (2) Par. 112. (3) Par. 120. 101·1 parts by weight of nitre yield 63 parts by weight of nitric acid, therefore 101·1 : 337 :: 63 : commercial acid yielded by 337 oz. = 209 oz.

4. Name the allotropic forms of carbon.

In preparing carbon monoxide from oxalic acid a mixture of carbon monoxide and carbon dioxide is obtained; how can the carbon dioxide be removed?

Ans. Pars. 124, 126.

5. Describe a method of preparing and collecting chlorine. Represent the reaction by an equation.

What are the principal properties of chlorine?

Ans. Par. 137.

6. How many gallons of oil of vitriol, sp. gravity 1·85, could be obtained from 111 lbs. of sulphur, a gallon of water weighing 10 lbs.?

You are given two bottles, one containing sulphuric acid, the other containing nitric acid, how could you determine which held the sulphuric acid?

Ans. (1) Par. 149. (2) 98 parts by weight of oil of vitriol contain 32 parts by weight of sulphur, therefore 32 : 111 : : 98 : 340 lbs. and 340 lbs., according to data$=\frac{340}{10\times1{\cdot}85}=18{\cdot}4$ gallons. (3) Pars. 63, 64 (1 and 13).

7. Describe the structure of the flame of a candle.

Ans. Par. 132,

JULY, 1879.

1. What is understood in chemistry by the expression an "element" or an "elementary body"?

How could you show that air is not an element?

What is the difference between a mechanical mixture and a chemical compound?

How could you show that Nitrogen Monoxide is a chemical compound?

Ans. (1) Par. 9. (2) Par. 113. (3) Pars. 18, 19. (4) Par. 115.

2. Describe any method of preparing Oxygen.

Write in symbols the reaction that occurs when Oxygen is prepared from Potassium Chlorate.

You are given three vessels, and are told that one contains Oxygen; one, Nitrogen Monoxide; and one, common Air; how would you determine which vessel contains the Oxygen?

What volume of Oxygen will 8 ounces of Potassium Chlorate yield; a cubic foot of Hydrogen at 60°F. and 30 ins. bar. weighing 37 grains? ($K=39{\cdot}1$).

Ans. (1) Par. 106. (2) Par. 106. (3) Par. 116. (4) 122·6 parts by weight potassic chlorate yield 48 parts by weight of oxygen, therefore—122·6 : 8 : : 48 : 3·13, and, (par. 98), 46·7 cubic inches of oxygen weigh 16 grains, therefore 16 : 3·13 : : 46·7 : 9·14= volume of oxygen in cubic inches.

3. How may Nitrogen, Nitric Oxide (NO), Nitrous Anhydride (N_2O_3), and Nitrogen Peroxide (NO_2) be severally obtained from Nitric Acid or a Nitrate?

Ans. Nitrogen may be obtained by decomposing ammonia, by passing it through a red-hot tube, when nitrogen and hydrogen are liberated. Pars. 116, 117, 118.

4. How could you distinguish Carbon Dioxide from Nitrogen?

The gas that sometimes collects at the bottom of deep wells is said to be Carbon Dioxide. By what experiments could you test the correctness of this statement?

How could you distinguish between Marsh Gas and Hydrogen?

Between Olefiant Gas and Carbon Monoxide?

Ans. (1) Pars. 112, 127. (2) Par. 127. (3) Pars. 108, 128. (4) Par. 126, 129.

5. In what respect does Sulphur resemble Oxygen? By what other means, besides burning Sulphur, can Sulphur Dioxide be prepared?

Explain its action with solutions (1) of Potash, (2) of Chlorine.

Ans. (1) Par. 146. (2) Par. 147. (3) Par. 147.

6. How much Phosphorus is contained in 120 lbs. of bone-ash, consisting of 88·4 per cent. of $Ca_3\,(PO_4)_2$ and 11·5 per cent. of $CaCO_3$? ($Ca = 40$).

What volume of Hydrogen is contained in one ounce of Microcosmic Salt $NaNH_4HPO_4,\ 4H_2O$? (37 grains of hydrogen to the cubic foot; $Na = 23$).

Ans. (1) 100 lbs. bone-ash contain 88·4 per cent. of calcium phosphate, therefore 120 lbs. bone-ash contain 106·08 lbs. calcium phosphate; but the combining weight of calcium phosphate ($Ca_3\,(PO_4)_2$) $= 120 + 62 + 128 = 310$ parts by weight, therefore $310 : 106{\cdot}08 :: 62 : 21{\cdot}21$ = the amount of phosphorus in 120 lbs. bone-ash. (2) The combining weight of the salt —$NaNH_4,\ HPO_4,\ 4H_2O = 23 + 14 + 4 + 1 + 31 + 64 + 8 + 64 = 209$ parts by weight, containing 13 parts by weight of hydrogen, therefore $209 : 480 :: 13 : 29{\cdot}8$ = amount in grains of hydrogen; and $37 : 29{\cdot}8 :: 1728 : 1392$ cubic inches, the volume of hydrogen present.

7. What is the simplest formula that can be assigned to a substance containing

$$\left.\begin{array}{ll}\text{Carbon,} & 54{\cdot}5\\ \text{Hydrogen,} & 9{\cdot}2\\ \text{Oxygen,} & 36{\cdot}3\end{array}\right\}\text{ per cent.?}$$

Ans. Oxygen $\frac{36{\cdot}3}{16} = 2{\cdot}27$, Carbon $\frac{54{\cdot}5}{12} = 4{\cdot}54$, Hydrogen $\frac{9{\cdot}2}{1} = 9{\cdot}2$; therefore $2{\cdot}27 : 4{\cdot}54 : 9{\cdot}2 = 1 : 2 : 4$ $= OC_2H_4$, that is, C_2H_4O (Vinic aldehyde).

8. The chimney-glass increases the brightness of the flame of the common coal-oil lamp. Why does it do so?

If you drive a current of air *into* the flame of an ordinary candle, the flame appears less bright than it did before the introduction of the air. Explain why this is the case?

Ans. Par. 132. See especially—" Bunsen's Jet."

SELECTION OF QUESTIONS FROM THE PAPERS OF FIRST-CLASS CANDIDATES.

NOTE.—Questions and answers—34, 37, 38, have been taken from the Quarterly Magazine of the Hamilton Coll. Institute.

1st CLASS PROVINCIAL CERTIFICATES.

1. Explain the processes by which the composition of water has been ascertained with reference to both relative weights and volumes of its constituents. Name some of the impurities of water, and state how you would detect them.

Ans. Pars. 103, 109, 62, 63, 64.

2. Give an account of the preparation and properties of sulphuric acid (oil of vitriol). State the action, when heated, it has with (1) potassium bichromate, (2) mercury, (3) potassium chlorate. What is the test for detecting it?

Ans. Par. 149. (1) $K_2O, 2CrO_3 + 4H_2SO_4 = K_2SO_4 + Cr_23SO_4 + 4H_2O + O_3$. Bichromate of potash and sulphuric acid give—potassium sulphate, sulphate of the sesquioxide of chromium, water and oxygen. (2) $Hg + H_2SO_4 = HgSO_4 + H_2$. Mercury and sulphuric acid give mercuric sulphate and hydrogen. (3) $3KClO_3 + 2H_2SO_4 = KClO_4 + 2KHSO_4 + 2ClO_2 + H_2O$. Chlorate of potash and sulphuric acid give—perchlorate of potash, bi-sulphate of potash, chloric dioxide and water. Pars. 63, 64.

3. What substances are manufactured from common salt? Describe the processes employed.

Ans. Pars. 137, 139. Na_2CO_3.

4. The density of a gaseous hydro-carbon is 15 times that of hydrogen; the weight of the carbon is 4 times that of the hydrogen. Find the formula which represents its molecular composition.

Ans. The density of a compound gas is one-half the combining weight; therefore the density being 15, the combining weight of the hydro-carbon is 30, and four-fifths of this, that is 24 parts by weight are carbon, and one-fifth, or 6 parts by weight is hydrogen. But the combining weight of carbon is 12, and that of hydrogen is 1; therefore the formula is evidently C_2H_6 (methyl).

5. A franc weighing 5 grains is dissolved in nitric acid, and the addition of hydrochloric acid to the solution gives a precipitate which, when washed and dried, weighs 5·97916 grains. Find the percentage of silver in the French silver coinage. $Cl = 35·5$, $Ag. = 108$.

Ans. $AgNO_3 + HCl = AgCl + HNO_3$. $Ag = 108$, $Cl = 35·5$. $AgCl = 143·5$. *(a)* $5·97916 \times 108 \div 143·5 = 4.5$. *(b)* $4·5 \times 100 \div 5 = 90$. French silver coinage, accordingly, contains 90 p. c. of silver.

6. Define a radical in chemistry, and explain what is meant by the quantivalence of a radical.

Ans. Pars. 37, 38, 46.

7. What is Ozone? How is it prepared, and what are the physical and chemical differences between it and oxygen?

Ans. Par. 107.

8. You have given you a few iron nails, some pure tin foil, copper filings, and a little granulated zinc, with concentrated nitric acid, and distilled water. State what chemical changes you can produce with these materials, and express the changes by equations.

Ans. (1) Concentrated nitric acid does not act upon iron, and, if the iron be immersed in concentrated acid and then in dilute acid, there will still be no reaction, unless the iron has been carefully dried after being taken from the strong acid. In this refractory condition, the iron is said to be in the "passive state." Dilute acid readily attacks iron, forming ferrous nitrate—$Fe + 2HNO_3 = Fe(NO_3)_2 + H_2$. (2) Tin is reduced to the state of an oxide by the action of nitric acid—$4HNO_3 + Sn = SnO_2 + 2H_2O + 4NO_2$. Stannic oxide, water and nitric peroxide are formed. (3) $Cu_3 + 8HNO_3 = 3(Cu(NO_3)_2) + 4H_2O + 2NO$. Dilute nitric acid and copper give cupric nitrate, water and nitric oxide. (4) $Zn + 9HNO_3 = 4Zn(NO_3)_2 + 3H_2O + NH_3$. Zinc and dilute nitric acid give zinc nitrate, water and ammonia.

9. How would you obtain evidence of the presence of Ammonia, whether pure or combined, in a given solution?

Ans. Par. 121.

10. We inhale air and throw off carbonic acid from our lungs. How would you show experimentally that the amount of CO_2, in a given volume of air, which comes from our lungs, is far greater than the quantity of carbonic acid, which is found in an equal volume of the air which we inhale?

Ans. Par. 114.

11. The value of a ton of Sicilian sulphur, containing 94 per cent. of S, is $25, that of a ton of *iron pyrites*, FeS_2, containing 46.5 per cent. of sulphur, is $7.10: Ascertain which can be more profitably worked in the manufacture of sulphuric acid, having regard merely to the respective sources of sulphur.

Ans. $H_2SO_4 = 98$, containing 32 parts by weight of S. (1) One ton Sicilian sulphur contains 1880 lbs. of sulphur, and this amount would permit of the formation of 5757·5 lbs. of sulphuric acid. (2) One ton of pyrites contains 930 lbs. of sulphur, which would permit of the formation of 2848·12 lbs. of sulphuric acid. Equal quantities may now be compared, to obtain the true comparison of the cost of manufacture in each case.

12. A Specimen of spring water is supposed to con-

tain sulphuretted hydrogen. How would you ascertain whether sulphuretted hydrogen is really present?

Ans. Par. 150.

13. By what experiment would you prove that common phosphorus, and red or amorphous phosphorus are allotropic modifications of the element phosphorus?

Ans. By heating a little red or amorphous phosphorus in a narrow test tube, when it will gradually be converted into vitreous or common phosphorus.

14. Describe Marsh's test for arsenic, with its modifications and fallacies.

Ans. Par. 170.

15. 100 cubic centimetres of ammonia gas are completely decomposed by a series of electric sparks, yielding 200 centimetres of mixed hydrogen and nitrogen; an excess of oxygen is next added, when the volume of the mixed gases is found to amount to 290 cubic centimetres; the mixture is now exploded, when 65 cubic centimetres of gas remain: Show from these data that the symbol of ammonia is NH_3.

Ans. The amount of oxygen added is evidently 90 cubic centimetres. After explosion only 65 cubic centimetres remain; therefore 290—65=225 cubic centimetres which have been condensed, but this amount must have gone to form water, containing 150 cubic centimetres of hydrogen and 75 cubic centimetres of oxygen. 90 cubic centimetres of oxygen were added to the mixture; therefore 90—75=15; the amount remaining after explosion. 65—15=50, which must be the amount of nitrogen. The original mix-

ture therefore was—50 cubic centimetres of nitrogen and 150 cubic centimetres of hydrogen, that is 50 : 150 : : 1 : 3; therefore the formula is NH_3.

16. A watch spring is burned in a closed vessel of Oxygen, state—

(1) Whether the weight of the bottle and its contents is affected by the combustion?

(2) What is the nature of the products formed by the combustion?

(3) Whether the whole of the oxygen originally present filling the bottle, is still present, and if so in what form?

Ans. Par. 106.

17. Flint is said to be a compound of silex, which, although it has no acid or sour taste, is also called silicic acid; why is it so called?

Ans. Par. 162.

18. Under what conditions is carbonic oxide converted into carbonic acid, and carbonic acid into carbonic oxide? Explain the action of carbonic acid on plants in daytime and at night.

Ans. Pars. 126, 114.

19. I pour hydrochloric acid upon some marble, iron, and lime, each placed in a separate vessel with a little water. I perform a similar experiment with sulphuric acid, and with nitric acid; describe the result produced in each case.

Ans. (1) $2HCl + CaCO_3 = CaCl_2 + H_2O + CO_2$. Hydrochloric acid and marble give calcium chloride, water, and carbonic acid gas. (2) $2HCl + Fe = H_2 + FeCl_2$, hydrochloric acid and iron give hydrogen and chloride of iron. (3) $2HCl + CaO = CaCl_2 + H_2O$, hydrochloric acid and lime give calcium chloride and water. (4) $CaCO_3 + H_2SO_4 = CaSO_4 + H_2O + CO_2$, sulphuric acid and marble give calcium sulphate, water, and carbonic acid gas. (5) $Fe + H_2SO_4 = Fe SO_4 + H_2$, sulphuric acid and iron give iron sulphate and hydrogen. (6) $CaO + H_2SO_4 = CaSO_4 + H_2O$, sulphuric acid and lime give calcium sulphate and water. (7) $CaCO_3 + 2HNO_3 = Ca(NO_3)_2 + CO_2 + H_2O$, nitric acid and marble give calcic nitrate, carbonic acid gas, and water. (8) See answer to question 8 (9) $CaO + 2HNO_3 = Ca(NO_3)_2 + H_2O$, nitric acid and lime give calcium nitrate and water.

20. Give some account of the manufacture of coal gas, mentioning the useful, the useless, and the hurtful products; and the methods of removing the last.

Ans. Par. 131.

21. A solution of potassium chlorate was reduced to chloride and then precipitated by an excess of silver nitrate; 7·275 grammes of silver chloride were obtained: what was the weight ot the chlorate in the solution?

Ans. $Ag = 108$, $Cl = 35·5$, $AgCl = 143·5$. (1) 143·5 : 7·275 : : 35·5 : 1·8. $K = 39·1$, $Cl = 35·5$, $O_3 = 48$, $KClO_3 = 122·6$. (2) 35·5 : 1·8 : : 122 6 : 6·2. The weight of potassium chlorate in solution was therefore 6·2 grammes.

22. A mineral water, in addition to chlorides, contains small quantities of iodides and bromides: how would you detect the presence of these salts in water?

Ans. Pars. 63, 64.

23. Describe the properties of carbon, which tend to show that diamond cannot have been formed at a temperature, at which pure iron melts. How would you show that carbonic acid (CO_2) is a compound of carbon and oxygen, and that it contains (very nearly) its own volume of oxygen?

Ans. Pars. 124, 127.

24. Describe how you would prove bone-ash to consist chiefly of calcium phosphate. Explain the decomposition of bone-ash by diluted sulphuric acid. Explain, by means of symbols, the reaction which takes place, when a solution of sodium carbonate is added to one of phosphoric acid.

Ans. Par. 152. $Na_2CO_3 + H_3PO_4 = Na_2HPO_4 + CO_2 + H_2O$. Sodium carbonate and orthophosphoric acid give hydric sodium phosphate, carbonic acid, and water.

25. Describe the leading properties of arsenic, and name those elements that are usually grouped with it. What means do we possess for the detection of small quantities of arsenic?

Ans. Pars. 164, 170, 171.

26. Distinguish between atomic, equivalent, and molecular weights. Give the atomic and equivalent weights of mercury, zinc, chlorine, iodine, sulphur, iron, and copper. Write down the molecular weights of H_2S, PCl_5, AsH_3, H_2SO_4.

Ans. Pars. 24, 25, 30, 13.

27. Half-a-pound of pure zinc is put into a vessel containing a small quantity of water; H_2SO_4 is then added in quantity just sufficient to dissolve the zinc,

and leave no free acid: name, describe briefly, and give the exact weight of all the resulting products, whether gaseous or solid, the superfluous water being evaporated.

Ans. Par. 108.

28. Draw a diagram representing the structure of flame, and explain briefly. Of three lamps, one is burning in the ordinary way, another has the wick turned up so high as to give off a large amount of smoke, while the third is so much agitated by the wind as to be rendered almost non-luminous: describe, accurately, the chemical processes going on in each of these cases.

Ans. Par. 132.

29. Certain hard waters become soft after boiling, while others retain their hardness: explain the reason, naming the substances present in each case, stating how the latter class may be rendered soft, and representing by equations the chemical changes that take place.

Ans. Par. 109.

30. How would you prove that the burning of diamond in a jar of oxygen, and the consuming of particles of carbon in the lungs are really the same processes and produce the same results?

Ans. In either case, if the resultant gas be passed into lime water, a precipitate of the same substance—calcium carbonate ($CaCO_3$) will be formed, shewing that the product of both operations is the same—carbonic acid gas (CO_2).

31. The analysis of a compound leads to these numbers :—

Carbon	37·20
Hydrogen	7·90
Chlorine	54·95
	100·05

Prove that the formula C_2H_5Cl represents correctly the composition of the body.

Ans. C $37.20 \div 12 = 3·10$. H$7·90 \div 1 = 7·90$. Cl. $54·95 \div 35·5 = 1·54$. $1·54 : 3·10 : 7·90 + 1 : 2 : 5$. The formula is therefore ClC_2H_5, or C_2H_5Cl.

32. A piece of bright green wall paper supposed to contain arsenic is given you: describe fully all the experiments by which you could ascertain the presence of arsenic in the paper.

Ans. Pars. 170, 171.

33. The formula of water was formerly written H O, and subsequently for some years H_2O_2 (assuming $O=8$). Discuss both these formulæ, pointing out any inconsistencies you may detect in them. Give reasons for adopting the formula now in use.

Ans. The formula HO expresses the union of one atomic volume of hydrogen with one of oxygen. On the other hand the formula H_2O_2 expresses the chemcal union of two atomic volumes of hydrogen with two of oxygen, but decomposition of water by electrolysis (103) proves that the actual composition of water is two atomic volumes of hydrogen to one of oxygen, giving the formula H_2O, and this is further justified, when the composition of water by weight is ascertained by synthesis (109).

34. A solution contains Potassic Chlorate and Potassic Chloride ; a precipitate of 2·87 grammes of Silver Chloride is produced when Silver Nitrate is added, and separated by filtration ; the remaining solution is acted on by nascent Hydrogen, when a further precipitate of 0·359 grammes of Silver Chloride is produced by Silver Nitrate. Calculate the amount of Potassic Chloride, and Potassic Chlorate present.

Ans. Argentic Nitrate precipitates only the Chloride.

$$KCl + AgNO_3 + AgCl.$$

$$(39+35\cdot5)+(108+14+48)=(39+14+48)+(108+35\cdot5.)$$

$$74\cdot5 \quad + \quad 170 \qquad\quad 101 \qquad\quad 143\cdot5$$

From this equation we see that 143·5 parts AgCl correspond to 35·5 of Chlorine, or to 74·5 of Potassic Chloride (KCl); therefore, 2·87 grammes of Silver Chloride, the precipitate from the solution of Chloride, would, by proportion, correspond to 1·49 gramme of (KCl) Potassic Chloride.

$$KClO_3+3H_2=KCl+3H_2O.$$

$$(39+35\cdot5+48) \quad + \quad 6=(39+35\cdot5)+3(2+16).$$

$$122\cdot5 \quad + \quad 6= \quad 74\cdot5+ \quad 54.$$

From this equation it is seen that every 74·5 parts of Potassic Chloride, (KCl) correspond to 122·5 parts of Potassic Chlorate, ($KClO_3$). Above, it is found that 143·5 of AgCl correspond to 74·5 of K Cl, therefore, 143·5 parts of AgCl correspond to 122·5 parts of Potassic Chlorate, ($KClO_3$); therefore 0·359 grammes of AgCl precipitated represents 0·306 grammes of Potassic Chlorate ($KClO_3$) in the original solution.

35. Write equations for the manufacture of Carbonic Oxide, Nitric Oxide, Iodine, Bromine, Chlorine.

Ans. Pars. 126, 116, 143. 142, 137.

36. Describe the manufacture of "*Bleaching Powder*," giving equations. Explain fully its bleaching power.

Ans. Par. 141.

37. 560 litres of chlorine act on *slacked lime* what weight of "bleaching powder" is produced?

Ans. 560 litres of chlorine weigh 1,775 grammes, (11·2 litres of chlorine weigh 35·5 grammes)

$$2(CaO,H2O) + 4Cl = CaCl2 + CaCl2O2 + 2H2O.$$

$$2(40 + 16 + 2 + 16) + 142 = (40 + 71) + (40 + 71 + 32) + 2(2 + 16)$$

$$148 \quad + 142 = \quad 111 \quad + \quad 143 \quad + \quad 36$$

Bleaching powder is a mechanical mixture of all the substances on the right side of the equation; then 142 grammes of chlorine would produce 290 grammes of bleaching powder, and 1.775 grammes of chlorine would yield 3,625 grammes of bleaching powder.

38. 1120 litres of hydric sulphide at 15°C. and 720 mm. pressure are required; how much ferrous sulphide will just yield this quantity? What weight of oxygen would be required to burn up the above gas?

Ans. 1120 litres of Hydric Sulphate, at 15°C. and 720 mm. pressure, become $1120\left(\frac{1}{1+\frac{15}{273}}\right) \times \frac{720}{760}$, or 1005·78 litres at Zero C. and 760 mm. pressure.

11·2 litres of Hydric sulphide weigh 17 grammes, therefore, 1005·78 litres weigh 1526·63 grammes, the weight of gas required.

$$FeS + H_2SO_4 = H_2S. + FeS\,O_4$$

$$(56 + 32) + (2 + 32 + 64) = (2 + 32) + (56 + 32 + 64)$$

$$88 \quad + \quad 98 \quad + \quad 34 \quad + \quad 152.$$

34 parts of Hydric Sulphide require 88 parts of Ferrous Sulphide, therefore, 1526·63 grammes of Sulphuretted Hydrogen require 3951·28 grammes of Ferrous Sulphide.

Each molecule of H_2S requires three atoms of Oxygen to completely burn it.

$$
\begin{array}{ccccccc}
H_2S & = & O_3 & = & H_2O. & + & SO_2 \\
(2+32) & + & 48 & = & (2+16) & + & (32+32) \\
34 & + & 48 & = & 18 & & 64
\end{array}
$$

therefore, every 34 parts of H_2 S. require 48 of Oxygen, or 1526·63 grammes require 2155·24 grammes of Oxygen for complete combustion.

39. Define the term "Co-efficient of Expansion." If the co-efficient of expansion of atmospheric air for the centigrade scale be $\frac{1}{273}$, find the temperature to which 500 cubic centimetres of air (measured at 15°C.) must be raised in order that its volume may become 700 cubic centimetres, no change of pressure taking place meanwhile.

Ans. Par. 74. $\frac{700\,(273+15)}{500} = 403{\cdot}2$; therefore $403{\cdot}2 - 273 = 130{\cdot}2$°C., = the temperature to which the gas must be raised.

40. Explain the principles on which the determination of atomic weights is based. One part by weight of hydrogen is combined with three parts by weight of carbon in marsh-gas, with six parts by weight of carbon in olefiant-gas, and with twelve parts by weight of carbon in acetylene. Again, one part by weight of hydrogen is combined with eight parts by weight of oxygen in water, and eight parts by weight

of oxygen are combined with three parts by weight of carbon in carbonic anhydride, and with six parts by weight of carbon in carbonic oxide. Why is the atomic weight of carbon taken as 12, instead of as 6 or as three?

Ans. Par. 20. Marsh-gas (CH_4) and carbonic acid gas (CO_2) are natural products, while olefiant gas (C_2H_4) and carbonic oxide (CO) can only be obtained by artificial means; moreover, the last named gases have a tendency to pass into the form of the first named. Thus, carbonic oxide when heated in presence of oxygen, invariably passes into carbonic acid, and when olefiant gas is heated to a high temperature, it is decomposed into marsh gas, acetylene and hydrogen, both of these gases therefore appear to be unstable compounds. Now the composition of marsh gas (CH_4) indicates that carbon is a tetrad element, and the composition of carbonic acid gas, in which one atom of carbon combines with two atoms of the dyad element oxygen, justifies this conclusion.

41. What is understood by the theory of atomicity? What atomicity or quantivalence do you assign to nitrogen, arsenic, iron, and copper respectively, and why?

Ans. Pars. 29, 13.

42. What is *a compound radical?* Give examples. Select the compound radicals from among the following: KCl, H_3N, H_4N, H_2O, KHO, SO_2, SO_3.

Ans. Par. 37.

43. Ten grains of air are passed at a very high temperature over an excess of carbon. What pro-

duct is formed, and what is the approximate weight of it?

Ans. Par. 126.

44. What compounds of sulphur are there, which, in their constitution and general reactions resemble the corresponding compounds of oxygen? How is sulphur now recovered from alkali-waste? What are the respective formulæ of iron pyrites, copper pyrites, zinc blende, realgar, galena, and cinnabar? What are the products furnished by these several minerals when heated in presence of air?

Ans. Par. 146.

45. On testing a certain liquid you find that it reddens blue litmus-paper. What conclusion can you draw from this? Had the liquid burned reddened litmus-paper blue, what conclusion could you have drawn?

Ans. Pars. 39, 40.

46. What chemical changes occur when an aqueous solution of potassic iodide is added to an aqueous solution of each of the following salts:—Mercuric chloride, lead nitrate, sodium sulphate, silver nitrate, and sodium sulphite?

Ans. $2KI + HgCl_2 = HgI_2 + 2KCl$. Potassic iodide and mercuric chloride give mercuric iodide and potassic chloride.

$2KI + Pb(NO_3)_2 = PbI_2 + 2KNO_3$. Potassic iodide and plumbic nitrate, give plumbic iodide and nitre.

$2KI + Na_2SO_4 = K_2SO_4 + 2NaI$. Potassic iodide and sodium sulphate give potassic sulphate and sodium iodide.

$KI + AgNO_3 = KNO_3 + AgI$. Potassic iodide and argentic nitrate, give nitre and argentic iodide.

$2KI + Na_2SO_3 = K_2SO_3 + 2NaI$. Potassic iodide and sodium sulphite give potassic sulphite and sodium iodide.

47. You are given seven test tubes, and are told that in one there is pure water, and, in the other six, there are respectively aqueous solutions of silver nitrate, copper nitrate, zinc sulphate, calcium chloride, magsium sulphate, and potassium nitrate. How could you determine which test tube contains the pure water, which the silver nitrate, which the copper nitrate, etc.?

Ans. Pars. 62, 63, 64.

48. Give the composition of the atmosphere in, say, 1000 parts. State in full your reasons for believing that the combination of the two principal gases is only a mixture, and not a chemical union.

Ans. Par. 113.

49. "4°C. is said to be the point of maximum density of water." Explain the exact meaning of this statement, and discuss the general bearing of the fact upon the economy of nature.

Ans. Pars. 76, 109.

50. One litre of hydrogen at the standard pressure and temperature being ·08936 grammes, what will be the weight of one litre of steam, ammonia, or carbonic acid?

Ans. Par. 99.

FINIS.

JULY, 1880.

1. Describe the chief characteristics of (1) ammonia; (2) ammonium carbonate; and the process by which they are usually prepared. Give also the chemical reactions which occur in these processes.

Ans. (1) Par. 121. (2) There are *three* carbonates of ammonium, viz.:—(1) The normal carbonate [$(NH_4)_2CO_3$), a very volatile, unstable compound, probably formed when sal-ammoniac (NH_4Cl) and lime ($CaCO_3$) are heated together, but, if so, in contact with air it at once decomposes, forming (2) ammonium sesqui-carbonate, which is a more or less fibrous solid, prepared by heating sal-ammoniac with lime $6(NH_4Cl) + 3CaCO_3 = (NH_4)_4C_3O_8 + 2NH_3 + H_2O + 3CaCl_2$, producing ammonium sesqui-carbonate, ammonia, water and calcium chloride. This latter-named carbonate is the common carbonate of ammonia of the druggists, and is used in medicine, and by confectioners to *raise* their pastry, etc. If freshly prepared sesqui-carbonate be exposed to the air it evolves ammonia and carbon di-oxide, and is converted into (3) ammonium bi-carbonate; $(NH_4)_4C_3O_8 = 2NH_3 + CO_2 + (NH_4)_2C_2O_6$. This last-named carbonate is an amorphous substance of no practical importance.

2. Describe fully the modes of decomposing water which you have seen. State how you would determine whether a given specimen of water is hard or soft. If the water is found to be hard, state (with reasons) the various means by which it could be made soft.

See Ans. to Ques. 2, Exam. Paper, June, 1876.

3. What means are best employed for the collection of nitric oxide, chlorine, ammonia, carbonic acid, sulphur di-oxide and nitrous oxide gases?

Ans. Pars. 116, 137, 121, 127, 147, 115.

4. Describe fully the experiment in which the reactions are given by the equation

$$CaCO_3 + 2HCl = CaCl_2 + H_2O + CO_2.$$

Ans. Par. 127.

5. Describe some of the properties of sulphur, and state its allotropic modifications, and how they are obtained. Sulphur is said to be a dimorphous body. Explain.

Ans. Pars. 146, 51.

6. Calculate the percentage composition by weight of potassium nitrate, and of the two oxides of carbon.

For method see Ans. to Question 7, Dec., 1876.

7. Write down the atomic weight, the molecular weight, the relative weight, the specific gravity, the atomic and molecular volume of chlorine, and fully explain the meaning of these terms.

Ans. Atomic weight, 35·5; molecular weight, 71. By relative weight is here probably meant the weight of a litre of chlorine; and since the litre of hydrogen weighs ·08936 grammes and chlorine is 35·5 times heavier than hydrogen, the answer is readily obtained. Specific gravity, 2·47. Adopting Prof. Williamson's "absolute volume" (Par. 99), the atomic volume of chlorine is 11·2 ll., and the molecular volume 22·4 ll. *See* Pars. 23, 24, 98, 99, 137.

8. Complete the following equations :—

	Completion.
$Fe\,S + H_2SO_4 =$	$H_2S + FeSO_4$. (Par. 150.)
$Na_2SO_3 + S =$	$Na_2S_2O_3$. (*a.*)
$CaO + Na_2CO_3 + H_2O =$	$2NaHO + CaCO_3$. (*b.*)
$SiO_2 + 4HF =$	$SiF_4 + 2H_2O$. (Par. 162.)

(*a*) $Na_2SO_3 + S = Na_2S_2O_3$. Sodium sulphite heated with sulphur gives sodium hyposulphite, used like the sulphite as an antichlore (Par. 147), and also in photography to dissolve silver chloride. (*b*) Sodium carbonate, Na_2CO_3, acted upon with slaked lime (CaO, H_2O) is converted into sodium hydrate or caustic soda, with formation of calcium carbonate,

$$Na_2CO_3 + CaO,\ H_2O = 2NHO + CaCO_3.$$

9. Describe a mode of preparing sulphur di-oxide, and give and explain the equations representing the reactions. Explain the difference between the bleaching action of chlorine and sulphurous acid.

Ans. Pars. 147, 137.

10. On completely decomposing by heat a certain weight of potassium chlorate, 20·246 grains of potassium chloride were obtained. What weight of potassium was used, and how much oxygen was evolved?

Ans. $$KClO_3 = KCl + O_3,$$

$$39{\cdot}1 + 35{\cdot}5 + 48 = 39{\cdot}1 + 35{\cdot}5 + 48,$$

$$122{\cdot}6 = \quad 74{\cdot}6 + 48.$$

$$(1)\ \frac{20{\cdot}246 \times 39{\cdot}1}{74{\cdot}6} = x, \quad (2)\ \frac{20{\cdot}246 \times 48}{74{\cdot}6} = y.$$

JULY, 1881.

1. $KNO_3 + H_2SO_4 = HNO_3 + KHSO_4$.

(i.) Give, first, the names of the compounds entering into the reaction represented by above equation, and, second, the names of the elements, with their combining weights, entering into the constitution of these compounds.

(ii.) Represent, by diagram, the necessary apparatus for conducting the experiment indicated by the equation.

(iii.) What effect would H_2SO_4, HNO_3 and KNO_3, each have upon a solution of blue litmus?

Ans. Pars. 120, 39, 42.

2. It is required to make 3½ pounds of HNO_3 by experiment 1. (ii.). How much H_2SO_4 is required?

Ans.	HNO_3	H_2SO_4
	1 + 14 + 48,	2 + 32 + 64.
	63	98

It is seen by the reaction in Question 1 that 63 parts nitric acid require for their production 98 parts sulphuric acid, therefore $\frac{3\frac{1}{2} \times 98}{63} = x$.

3. Explain the principle of Davy's safety lamp.

Ans. Par. 133.

4. It is required to prepare the elements hydrogen and nitrogen for class purposes:

(i.) Describe the apparatus and name the substances needed for the preparation of each of the elements.

(ii.) Write out the equations representing the reactions occurring in their elimination.

(iii.) Describe the experiments you would perform to demonstrate their distinguishing properties.

Ans. Pars. 108, 112.

5. Assign reasons for assuming that charcoal, graphite and diamond are different modifications of the same element.

Ans. Par. 124.

6. Complete the following equations:—

$$Ca\ CO_3 + 2(HCl) =$$
$$Na + H_2O =$$
$$2(NaCl) + 2(H_2SO_4) + MnO_2 =$$
$$P_2O_5 + 3(H_2O) =$$

Ans. Pars. 127, 108, 137, 154.

7. Coal gas and phosphorus burn with a luminous, sulphur and hydrogen with a non-luminous, flame. Account for this difference.

Ans. Par. 132. When phosphorus burns, phosphoric pentoxide is formed, supplying the solid matter necessary, under ordinary circumstances, to produce luminosity in flame.

8. A certain quantity of zinc furnished, when treated with sulphuric acid, 3¾ pounds of zinc sulphate. How much zinc was employed? Zn—65.

$$\text{Ans. } \underset{65}{Zn} + H_2SO_4 = H_2 + \underset{\substack{65+32+64,\\ 161}}{ZnSO_4}$$

$$\text{therefore } \frac{3\frac{3}{4} \times 65}{161} = x.$$

ERRATA ET ADDENDA.

Page 3, twenty-fifth line, *for* Kuppernickel *read* Kupfernickel.
“ 10, second line, *for* effected *read* affected.
“ 11, sixth line, *add* or with one monad atom and one triad atom as CHN.
“ 20, twentieth line, *omit* the comma between square and prismatic.
“ 35, third line, *for* phenomena *read* phenomenon.
“ 56, seventh line, *for* 0·850 *read* 850.
“ 57, twenty-fourth line, *after* grammes *add* a unit of weight known as Dr. Hoffmann's “crith.”
“ 80, nineteenth line, *for* 21·81 *read* 20·81.
“ 89, eleventh line, *after* 2AgCl *add* $+O$.
“ 119, eighteenth line, *for* $-N_4$ *read* $+N_4$.
“ 137, twelfth line, *for* N_2SO_4 *read* Na_2SO_4.
“ 145, seventh line, *for* Phosphorous *read* Phosphorus.
“ 145, eighth line, *for* Phosphoretted *read* Phosphuretted.
“ 151, twenty-first line, *for* P_2O_3 *read* P_2O_5.
“ 160, twenty-first line, *for* or nickel ore *read* in nickel ore.
“ 186, first line, *read* Zn_4, etc.
“ 192, tenth line, *for* + read $=1:2:5$.

July, 1877, Examination Paper, Question 8, *for* Ans. *read* Note.

December, 1878, Examination Paper, last part of Ans. 3, *for* 209 oz. *read* 210 oz., and *add* but by the question 126 parts pure acid combine with 54 parts water to form 180 parts commercial acid, therefore 210 oz. require 90 parts water, forming $210+90=300$ parts commercial acid.

July, 1879, Examination Paper, last part of Ans. 2, *read*
16 : 1502·4 :: 46·7 : 4385·13 vol. of oxygen in cubic inches.

July, 1879, Examination Paper, Question 3, for previous preparation of ammonia from nitric acid see page 186, first line.