

water. Let the arrangement rest for a short time for the fumes of phosphoric anhydride to subside and dissolve in the water, and then decant the gas into test-tubes in the manner indicated in Fig. 9, using a tub or other vessel of water of sufficient depth to permit the glass containing the nitrogen gas to be turned on one side without air gaining access.

Larger quantities of nitrogen gas are made in the same way. Other combustibles, as sulphur or a candle, might be used to burn out the oxygen gas from the air, but none answers so quickly and completely as phosphorus; added to which, the product of their combustion would not always be dissolved by water, but would remain with the nitrogen.

Mem.—The statement concerning the composition of the air is roughly confirmed in isolating nitrogen, about one-fifth of the volume of the air originally in the glass vessel having disappeared, its place being occupied by water.

Properties.—Like oxygen and hydrogen, nitrogen gas is invisible, tasteless, and inodorous. By pressure Cailletet and Pictet condensed it to a liquid. Wroblewski and Obszewski have obtained it in some amount as a definite, colorless, transparent fluid. It is only slightly soluble in water. Free nitrogen is distinguished from all other gases by the absence of any characteristic or positive properties. Apply a flame to some contained in a tube; it will be found to be incombustible. Immerse a lighted match in the gas; the flame is extinguished, showing that nitrogen is a non-supporter of combustion.

The chief office of the free nitrogen in the air is to dilute the energetic oxygen, a mere *mechanical* mixture resulting.

Nitrogen is fourteen times as heavy as hydrogen.

The air is nearly fourteen and a half (14.44) times as heavy as hydrogen. Its average composition, including minor constituents, which will be referred to subsequently, is as follows:—

Composition of the Atmosphere.

	In 100 volumes.
Oxygen	20.61
Nitrogen	77.95
Carbonic acid gas04
Aqueous vapor	1.40
Nitric acid	traces.
Ammonia	
Carburetted hydrogen	traces in towns.
Sulphuretted hydrogen	
Sulphurous acid	

The above proportions are by volume. By weight there will be nearly 23 parts of oxygen to nearly 77 of nitrogen, oxygen being the heavier in the ratio of 16 to 14. Ozone (*vide* Index) is also said to be a normal constituent of air.

Free Nitrogen and Combined Nitrogen.

The comparative inactivity or negative character of nitrogen in its free condition, that is, when uncombined with other elements, contrasts strongly with its apparent influence in a state of combination. When its compounds with hydrogen come to be studied, it will be found to be, apparently, the chief, or leading, or, in a sense, the most important element of those compounds—the ammoniacal compounds. United with carbon it gives the poisonous cyanic substances. With oxygen it gives quite a large group of bodies, amongst which are the common and important class of salts termed nitrates. With carbon as well as hydrogen and some oxygen it affords powerful agents termed alkaloids—near relatives of ammonia—while the same elements otherwise grouped, with sometimes a little sulphur or phosphorus, form the various albumenoid and gelatinoid matters characteristic of the tissues of animals and vegetables. In a perfect structure we should perhaps scarcely regard any one element or member as more important than another, still such a conclusion almost forces itself upon us as we become acquainted with the chemical history of combined nitrogen.

CHLORINE.

Source.—This element is, in the free state, a gas. Its chief source is common salt, more than half of which is chlorine.

Preparation.—About a quarter of an ounce of salt and the same amount of black oxide of manganese are mixed, and placed in a test-tube with sufficient water to cover them; on adding a small quantity of sulphuric acid, the evolution of chlorine gas commences. For the mode of collection see the following paragraphs.

Fig. 10.

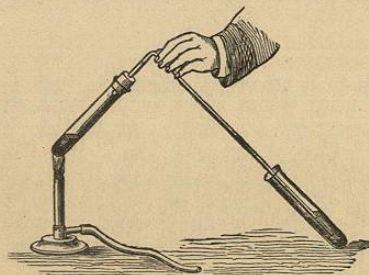
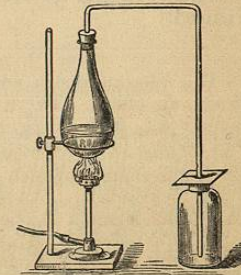


Fig. 11.



Preparation of Chlorine.

Another Process.—As the action of the sulphuric acid on the salt in the above process is mainly to give hydrochloric acid, the latter

acid (about 4 parts) and the black oxide of manganese (about 1 part) may be used in making the gas, instead of salt, sulphuric acid, and black oxide of manganese. This, the usual process, is that adopted in the British and United States Pharmacopœias.

Collection and Properties.—Free chlorine is a suffocating gas. Care must consequently be observed in experimenting with this element. As soon as its penetrating odor indicates that it is escaping from the test-tube, the cork and delivery-tube (similar to that used in making oxygen) should be fitted on, and the gas passed to the bottom of another test-tube containing water (Fig. 10). When thirty or forty small bubbles have passed, their evolution being assisted by slightly heating the generating-tube, the latter should be removed to the cupboard usually provided in laboratories for performing operations with noxious gases, or dismantled, and the contents carefully and rapidly washed away. The water in the collecting-tube will now be found to smell of the gas, chlorine, being, in fact, soluble in about half its bulk of water. Chlorine-water is official* in the United States Pharmacopœia (*Aqua Chlori*, U. S. P.).

Larger quantities may be made from the hydrochloric acid and black oxide of manganese (4 to 1) in a Florence flask, fitted with a delivery-tube, the flask being supported over a flame by the ring of a retort-stand or any similar mechanical contrivance (Fig. 11). A piece of cardboard on the neck of the collecting-bottle, as indicated in the figure, retards diffusion of the gas from the bottle during collection of the gas.

Mem.—Flasks and similar glass vessels are less liable to fracture if protected from the direct action of the flame by being placed on a piece of wire gauze 3 to 4 inches square, or on a *sand-bath*, that is, a saucer-shaped tray of sheet iron, on which a *thin* layer of sand is placed.

* The Pharmacopœia and all in it are official (*office*, Fr., from L. *officium*, an office). There are many things which in pharmacy are officinal (Fr., from L. *officina*, a shop) but not official. To restrict the word *officinal* to the contents of a pharmacist's shop, and to that portion of the contents which is Pharmacopœial, is radically wrong, and should be avoided. "An *official* formula is one given under authority. An *officinal* formula is one made in obedience to the customary usage of the shop (*officina*). To state that any preparation under the sanction of the Pharmacopœia is officinal, is a misapprehension of the meaning of the word."—J. Brough.

That is *official* which emanates from a recognized authority. That is *officinal* which is issued from an *officina* or workshop.—Joseph Ince.

Official writings and orders are those issued by official persons. *Officinal* articles are such as are found in a shop.—J. F. Stamford, M.A., F.R.S.

The *Vapor Chlori*, B. P., or Inhalation of Chlorine, is simply moist chlorinated lime so placed that some of the chlorine given off may be inhaled.

During these manipulations the operator will have noticed that chlorine is of a light-green color. That tint is readily observed when the gas is collected in large vessels. As it is soluble in water (2½ vols. in 1 vol. at 60° F.), it cannot be economically stored over that liquid. Being, however, nearly twice and a half as heavy as air, the gas may be collected by simply allowing the delivery-tube to pass to the bottom of the test-tube or dry bottle (Fig. 11).

The distinctive property of free chlorine is its bleaching power. Prepare some colored liquid by placing a few chips of logwood or other dyeing material in a test-tube half full of hot water. Pour off some of this red decoction into another tube and add a few drops of the chlorine-water; the red color is rapidly destroyed.

Free chlorine readily decomposes offensive effluvia; it is one of the most powerful of the *deodorizers*. It also decomposes putrid and infectious matter; it is one of the best of *disinfectants*. (*Antiseptics* are substances which *prevent* putrefaction. See Index.)

Combination of Hydrogen with Chlorine, forming Hydrochloric Acid.—If an opportunity occurs of generating the gas in a closed chamber or in the open air, a test-tube, of the same size as one of those in which hydrogen has been retained from a previous operation, is filled with the gas. The hydrogen tube is then inverted over that containing the chlorine, the mouths being kept together by encircling them with a finger. After the gases have mixed, the mouths of the tubes are quickly in succession brought near a flame, when explosion occurs, and fumes of a compound of hydrochloric acid with the moisture of the air are formed. The Hydrochloric Acid of Pharmacy (*Acidum Hydrochloricum*, U. S. P.) is a solution of the gas (made in a more economical way) in water.

The foregoing experiment affords evidence of the powerful affinity of chlorine and hydrogen for each other. Chlorine dissolved in water will, in sunlight, slowly remove hydrogen from some of the water and liberate oxygen. The bleaching power of chlorine is generally referred to this oxidizing effect which it produces in presence of water; for dry chlorine does not bleach.

Density.—Chlorine gas is thirty-five and a half times as heavy as hydrogen gas. A wine bottle would hold about 35½ grains.

SULPHUR, CARBON, IODINE.

The *physical properties* (color, hardness, weight, etc.) possessed by these elements when they are in the free state are familiar. Their leading chemical characters in the free state will also be understood when a few facts concerning each are made the subject of experiment.

SULPHUR.—Burn a small piece of sulphur; a penetrating odor is produced, due to the formation of a colorless gas, the same as that formed on igniting a sulphur-tipped lucifer match.

This product is a perfectly definite chemical compound of the oxygen, from the air, with the sulphur. It is termed sulphurous anhydride or sulphurous acid gas.

CARBON, free, is familiar in the forms of soot, coke, charcoal, graphite (or plumbago, popularly termed blacklead), and diamond. The presence of combined carbon in wood and in other vegetable and animal matter is at once rendered evident by heat. Place a little tartaric acid on the end of a knife in a flame; the blackening that occurs is due to the separation of carbon. The black matter at the extremity of a piece of half-burned wood is also free carbon.

Carbon, like hydrogen, phosphorus, and sulphur, has a great affinity for oxygen at high temperatures. A striking evidence of that affinity is the evolution of sufficient heat to make the materials concerned red or even white hot. When ignited in the dilute oxygen of the air, carbon simply burns with a moderate glow, as seen in an ordinary coke or charcoal fire, but when ignited in pure oxygen, the intensity of its combination is greatly exalted. The product of the combination of the two elements, if the oxygen be in excess, is an invisible gaseous body termed carbonic acid gas; if the carbon be in excess, another invisible gas termed carbonic oxide results.

IODINE.—A prominent chemical characteristic of free iodine is its great affinity for metals. Place a piece of iodine, about the size of a pea, in a test-tube with a small quantity of water, and add a few iron-filings or small nails. On gently warming this *mechanical mixture*, or even shaking if longer time be allowed, the color and odor of the iodine disappear: it has *chemically* combined with the iron: a *chemical compound* has been produced. If the solution be filtered, a clear aqueous solution of the compound of the two elements is obtained.

This compound is an iodide of iron. Its solution, made as above, and mixed with sugar, forms, when of a strength of 10 per cent., the ordinary Syrup of Iodide of Iron of pharmacy (*Syrupus Ferri Iodidi*, U. S. P.). A strong solution mixed with sugar, glycyrrhiza, gum,

etc., constitutes the corresponding Pill (*Pilula Ferri Iodidi*, U. S. P.). The solid iodide (*Ferri Iodidum*, B. P.) is obtained on removing the water of the above solution by evaporation.

Sulphur and *Iron*, also, when very strongly heated, *chemically combine* to form a substance which has none of the properties of a *mixture* of sulphur and iron—that is, has none of the characters of sulphur and none of iron, but new properties altogether. The product is termed Sulphide of Iron. Its manufacture and uses will be alluded to in treating of the compounds of iron; it is mentioned here as a simple but striking illustration of the difference between a *chemical compound* and a *mechanical mixture*.

THE ELEMENTS, THEIR SYMBOLS, Etc.

From the foregoing statements a general idea will have been obtained of the nature of several of the more frequently occurring free elements. Some additional facts concerning them may be gathered from the following Table, which gives the name in full, the symbol (or short-hand character)* of the name, and its origin.

For the purposes of study the elements may be divided into three classes—viz., those frequently used in pharmacy, those seldom, and those never used.

Name.	Symbol.	Derivation of Name.
Oxygen	O	From ὀξύς (oxūs), <i>acid</i> , and γένεσις (genesis), <i>generation</i> , i. e., generator of acids. It was supposed to enter into the composition of all acids when first discovered.
Hydrogen . . .	H	From ὑδὼρ (hudōr), <i>water</i> , and γένεσις (genesis), <i>generation</i> , in allusion to the product of its combination in air.
Nitrogen	N	From νίτρον (nitron), and γένεσις (genesis), <i>generator of nitre</i> .
Carbon	C	From carbo, <i>coal</i> , which is chiefly carbon.
Chlorine	Cl	From χλωρός (chlōros), <i>green</i> , the color of this element.
Iodine	I	From ἰὼν (ion), <i>a violet</i> , and εἶδος (eidos), <i>likeness</i> , in reference to the color of its vapor.
Sulphur	S	From sal, <i>a salt</i> , and πῦρ (pūr), <i>fire</i> , indicating its combustible qualities. Its common name, <i>brimstone</i> , has the same meaning, being the slightly altered Saxon word <i>brynstone</i> , i. e., <i>burnstone</i> .
Phosphorus . . .	P	φῶς (phōs), <i>light</i> , and φέρειν (pherein), <i>to bear</i> . The light it emits may be seen on exposing it in a dark room.

* The symbol is also much more than the short-hand character, as will be presently apparent.

Name.	Symbol.	Derivation of Name.
Potassium (Kalium.)	K	<i>Kalium</i> , from <i>kali</i> , Arabic for <i>ashes</i> . Manufactories in which certain compounds of potassium and allied sodium salts are made are called <i>alkali-works</i> to this day. <i>Potassium</i> , from <i>pot-ash</i> ; so called because obtained by evaporating the lixivium of wood-ashes in pots. From such ashes the element was first obtained, hence the name.
Sodium (Natrium.)	Na	<i>Natrium</i> , from <i>natron</i> , the old name for certain natural deposits of carbonate of sodium. <i>Sodium</i> , from <i>soda-ash</i> or <i>sod-ash</i> , the residue of the combustion of masses or <i>sods</i> of marine plants. These were the sources of the metal.
Ammonium	NH ₄	This body is not an element; but its components exist in all ammoniacal salts, and apparently play the part of such elements as potassium and sodium. Sal ammoniac (chloride of ammonium) was first obtained from near the temple of Jupiter Ammon in Libya; hence the name.
Barium	Ba	From <i>βαρύς</i> (<i>barūs</i>), <i>heavy</i> , in allusion to the high specific gravity of "heavy spar," the most common of the barium minerals.
Calcium	Ca	<i>Calx</i> , lime, the oxide of calcium.
Magnesium	Mg	From <i>Magnesia</i> , the name of the town (in Asia Minor) near which the substance now called "native carbonate of magnesia" was first discovered.
Iron (Ferrum.)	Fe	<i>Prehistoric</i> .—The spelling may be from the Saxon <i>iren</i> , the pronunciation probably from the kindred Gothic " <i>iarn</i> ," the derivation is perhaps Aryan; it probably originally meant <i>metal</i> .
Aluminium	Al	The metallic basis of alum was at first confounded with that of sulphate of iron, which was the alum of the Romans, and was so called in allusion to its tonic properties, from <i>alo</i> , to <i>nourish</i> .
Zinc	Zn	From Ger. <i>zinn</i> , <i>tin</i> , with which zinc seems at first to have been confounded.
Arsenium	As	'Αρσενικόν (<i>arsenikon</i>), the Greek name for orpiment, a sulphide of arsenium. Common white arsenic is an oxide of arsenium.
Arsenicum or arsenic.		
Antimony	Sb	Στίβι (<i>stibi</i>), or στίμμι (<i>stimmi</i>), was the Greek name for the native sulphide of antimony. The word <i>antimony</i> is said to be derived from <i>anti</i> (<i>anti</i> , <i>against</i>), and <i>moine</i> , French for <i>monk</i> , from the fact that certain monks were poisoned by it.
Copper (Cuprum.)	Cu	From <i>Cyprus</i> , the Mediterranean island where this metal was first worked.

Name.	Symbol.	Derivation of Name.
Lead (Plumbum.)	Pb	The Latin word is expressive of "something heavy," and the Saxon <i>læd</i> has a similar signification.
Mercury (Hydrargyrum.)	Hg	<i>Hydrargyrum</i> , from <i>ὕδωρ</i> (<i>hudōr</i>), <i>water</i> , and <i>ἀργυρός</i> (<i>argyros</i>), <i>silver</i> , in allusion to its liquid and lustrous characters. <i>Mercury</i> , after the messenger of the gods, on account of its susceptibility of motion. The old name <i>quicksilver</i> also indicates its ready mobility and argentine appearance.
Silver (Argentum.)	Ag	Ἀργυρός (<i>argyros</i>), <i>silver</i> , from ἀργός (<i>argos</i>), <i>white</i> . Words resembling the term <i>silver</i> occur in several languages, and indicate a white appearance.

The following are the names of some of the less frequently occurring elements, compounds of which, however, are alluded to in the British and U. S. Pharmacopœias, or met with in pharmacy.

Name.	Symbol.	Derivation of Name.
Bromine	Br	From <i>βρόμος</i> (<i>brōmos</i>), a <i>stink</i> . It has an intolerable odor.
Fluorine	Fl	From <i>fluo</i> , to <i>flow</i> . Fluoride of calcium, its source, is commonly used as a flux in metallurgic operations.
Boron	B	From <i>borax</i> , or <i>baurak</i> , the Arabic name of <i>borax</i> , the substance from which the element was first obtained.
Silicon	Si	From <i>silex</i> , Latin for <i>flint</i> , which is nearly all silica (an oxide of silicon).
Lithium	L	From <i>λίθος</i> (<i>litheios</i>), <i>stony</i> , in allusion to its supposed existence in the mineral kingdom only.
Strontium	Sr	This name is commemorative of <i>Strontian</i> , a mining village in Argyleshire, Scotland, in the neighborhood of which the mineral known as <i>strontianite</i> or carbonate of strontium was first found.
Cerium	Ce	Discovered in 1803, and named after the planet <i>Ceres</i> , which was discovered on Jan. 1, 1801. The oxalate of cerium is official, but seldom used.
Chromium	Cr	From <i>χρῶμα</i> (<i>chrōma</i>), <i>color</i> , in allusion to the characteristic appearance of its salts.

Name.	Symbol.	Derivation of Name.
Manganese . . .	Mn	Probably a mere transposition and repetition of most of the letters of the word <i>magnesia</i> , with whose compounds those of manganese were confounded till the year 1740.
Cobalt	Co	<i>Cobalus</i> or <i>Kobold</i> was the name of a demon supposed to inhabit the mines of Germany. The ores of cobalt were formerly troublesome to the German miners, and hence received the name their metallic radical now bears.
Nickel	Ni	<i>Nickel</i> , from <i>nil</i> , is a popular German term for <i>worthless</i> . The mineral now known as nickel ore was formerly called by the Germans <i>Kupfernickel</i> , <i>false copper</i> , on account of its resemblance to copper (<i>Kupfer</i>) ore. When a new metallic element was found in the ore, the name nickel was retained.
Tin (Stannum) .	Sn	Both words are possibly corruptions of the old British word <i>staen</i> , or the Saxon word <i>stan</i> , a stone. Tin was first discovered in Cornwall, and the ore (an oxide) is called <i>tinestone</i> to the present day.
Gold (Aurum) . .	Au	<i>Aurum</i> (Latin), from a Hebrew word signifying the color of fire. <i>Gold</i> . A similar word is expressive of <i>bright yellow</i> in several old languages.
Platinum	Pt	From <i>platina</i> (Spanish), diminutive of <i>plata</i> , <i>silver</i> . It somewhat resembles silver in appearance, but is less white and lustrous.
Bismuth	Bi	Slightly altered from the German <i>Wismuth</i> , derived from <i>Wiesematte</i> , "a beautiful meadow," a name given to it originally by the old miners in allusion to the prettily variegated tints presented by the freshly exposed surface of this crystalline metal.
Cadmium	Cd	<i>Kadmeia</i> (Kadmeia), was the ancient name of calamine (carbonate of zinc), with which carbonate of cadmium was long confounded, the two often occurring together.

Gold, Platinum, Tin, and Silicon are classed with the less important elements, because their salts are seldom used in pharmacy.

It will be noticed that the symbol of an element is simply the first letter of its Latin name, which is generally the same as in the English. Where two names begin with the same letter, the less important has an additional letter added.

QUESTIONS AND EXERCISES.

1. Of how many elements is terrestrial matter composed? *70*
2. In what state do the elements occur in nature? *3 s. 2 g.*
3. Distinguish between the *art* and the *science* of chemistry.
4. What is the difference between an element and a compound? *8 is 1 C. is 2 g.*
5. Enumerate the chief non-metallic elements.
6. Describe a process for the preparation of oxygen.
7. How are gases usually stored? *in bottles under bags &c.*
8. Mention the chief properties of oxygen.
9. What is the source of animal warmth? *oxygen*
10. State the proportion of oxygen in air. *1/5*
11. Is the proportion constant, and why? *no*
12. Give a method for the elimination of hydrogen from water.
13. State the properties of hydrogen. *is colorless, tasteless odorless*
14. Why is a mixture of hydrogen and air explosive? *because it will burn*
15. Explain the effects producible by the ignition of large quantities of coal-gas and air.
16. What is the nature of combustion?
17. Define a *combustible* and a *supporter of combustion*.
18. Describe the structure of flame.
19. State the principle of the Davy safety-lamp.
20. To what extent is hydrogen lighter than oxygen? *O is 16 times H. 1 of H*
21. What do you mean by *diffusion* of gases?
22. State Graham's law concerning diffusion.
23. Name the source of phosphorus, and give its characters.
24. Why does phosphorus burn in air?
25. What remains when ignited phosphorus has removed all the oxygen from a confined portion of air?
26. Mention the properties of nitrogen.
27. What office is fulfilled by the nitrogen of air?
28. State the proportions of the chief constituents of air.
29. Mention the minor or occasional constituents of air.
30. What is the proportion by weight of nitrogen to oxygen in the atmosphere?
31. Give the specific gravity of nitrogen.
32. How is chlorine prepared?
33. Enumerate the properties of chlorine.
34. Define the terms *deodorizer* and *disinfectant*.
35. Explain the bleaching effect of chlorine.
36. What proportion of hydrogen to chlorine is necessary for the formation of hydrochloric acid gas? *1 atom of H. to 1 of Cl*
37. State the prominent physical and chemical characters of sulphur.
38. State the prominent characters of carbon.
39. State the prominent characters of iodine.
40. Give the derivations of the names of some of the elements.
41. What are the symbols of oxygen, hydrogen, nitrogen, carbon, chlorine, iodine, sulphur, phosphorus?

THE LEARNER IS RECOMMENDED TO READ THE FOLLOWING PARAGRAPHS ON THE GENERAL PRINCIPLES OF CHEMICAL PHILOSOPHY CAREFULLY ONCE OR TWICE, THEN TO STUDY (EXPERIMENTALLY, IF POSSIBLE) THE SUCCEEDING PAGES, RETURNING TO AND READING OVER THE GENERAL PRINCIPLES FROM TIME TO TIME UNTIL THEY ARE THOROUGHLY COMPREHENDED.

THE GENERAL PRINCIPLES OF CHEMICAL PHILOSOPHY.

DEFINITION OF CHEMICAL ACTION.

The learner may now proceed to study the manner in which substances act chemically on each other. By acting *chemically* it will be obvious, from the preceding experiments, that what is meant is *so affecting each other that the substances are greatly altered in properties*. A mixture of free oxygen gas and hydrogen gas is still a gas; a chemical compound of oxygen and hydrogen is a liquid—namely, water; here is a great alteration in leading properties. Iodine is only slightly soluble in water, and forms a brown-colored solution, and iron is insoluble; but when iodine and iron are *chemically* combined, the product is very soluble in water, forming a light-green solution in which the eye can detect neither iodine nor iron, and which is utterly unlike iron or iodine in any one of their properties. Sand, sugar, and butter rubbed together form a mere mixture, from which water would extract the sugar, and ether dissolve out the butter, leaving the sand. Tartaric acid, carbonate of sodium, and water added to each other, form a chemical compound, containing neither tartaric acid nor carbonate of sodium, these bodies having attacked each other and formed fresh combinations. These illustrations show that *chemical action* is distinguished from all other actions by (*a*) producing an entire change of properties in the bodies on which it is exerted. Chemical action is further distinguished by the fact that it (*b*) only takes place between definite weights and volumes of matter. This (*a* and *b*) cannot be said of any other action—the action of any of the other great forces of nature (gravitation, heat, light, electricity, etc.); hence the statements (*a* and *b*) furnish a sharp and precise definition of *chemical action* or the chemical force, the force whose manifestations the reader is studying. Further (*c*), it is only exerted when the substances are close together.

ATOMS.

In a chemical compound, what has become of the constituents? Let the reader place before him specimens of sulphur, iron, and sulphide of iron; or iodine, iron, solid iodide of iron and its solution in water or syrup (*Syrupus Ferri Iodidi*, U. S. P.). In the sulphide of iron what has become of the sulphur and of the iron from which it was made? The mixture of sulphur and iron in combining to form sulphide of iron has not lost weight, and, indeed, by certain processes it is possible to recover its sulphur as sulphur, and its iron

as iron; so that we are compelled to believe, we cannot avoid the conclusion, that sulphide of iron contains particles of sulphur and of iron. But how small must be those particles! Rub a minute fragment to dust in a mortar and place a trace of the powder under the highest power of the best microscope; no yellow particle is visible, not the minutest portion of lustrous metal, but dull-brown miniature fragments of the original mass. The elementary particles of sulphur and iron, or of the elements in any other compound (the chlorine and sodium in common salt or the iodine and iron in solution of iodide of iron), are, in short, too small to be seen. Can they be imagined? Again, no. The mind cannot conceive of a particle of anything (sulphur, iron, sulphide of iron, or what not) so small but what the next instant the imagination has divided it. Yet learner and teacher must have some common platform on which to reason and converse. The difficulty is met by speaking of these inconceivably small particles as *atoms* (*ἄτομος*, *atomos*, invisible; from the privative *a* and *τεμνω*, *temnō*, to cut—that which is not cut or divided), an expedient suggested by our countryman Dalton at the commencement of the present century. It is an expedient not perhaps altogether satisfactory, but is the only one possible to the majority of minds in the present state of knowledge and education. We cannot speak of iodine and iron uniting lump to lump, as two bricks are cemented together or blocks of wood glued together, for such is not the kind of action. We cannot select a minute fragment of each to regard as the combining portions, for the minutest fragment we could obtain is visible, and iodide of iron contains neither visible iodine nor visible iron. And yet iodide of iron contains both iodine and iron, or, at least, a given weight of the compound is obtained from the same weight of the constituents, and the same weight of constituents is obtainable from an equal weight of the compound. We might say that molecules are concerned in the operation, but molecules means little masses of—of what? there is positively no work left with which to carry on conversation and description but *atoms*. Any other mode of treating the matter is too subjective for general employment. Moreover, any difficulty in forming a definite conception of an atom is met by regarding an atom, not necessarily as something which *cannot* be divided, but as “a particle of matter which undergoes no further division in *chemical metamorphoses*” (Kekulé). Even physicists regard atoms from much the same point of view; indeed they often speak of still larger portions of matter (molecules) as atoms, meaning thereby “something which is not divided in certain cases that we are considering” (Clifford).

THE CHEMICAL FORCE.

What power binds the atoms of a chemical compound together in such marvellous closeness of union that in the couple or group they lose all individuality? Clearly an attractive force of enormous power, a force remotely resembling, perhaps, that which attracts a piece of iron to a magnet. Only by such an assumption can we conceive that common salt contains chlorine and a metal (sodium), or that wood contains carbon, hydrogen, and oxygen. Were not

this force thus all-powerful, the carbon in wood would show its blackness and other qualities, and the hydrogen and oxygen give indications of their gaseous and other characters. This attractive force is commonly termed the *chemical force*, sometimes *chemical affinity*. The word *chemism* has also been proposed for it, just as the magnetic force is termed magnetism, but has not been generally adopted.

MOLECULES.

A free, uncombined atom probably cannot exist in a state of isolation, at common temperatures, for any appreciable length of time. For we must regard an atom as the home of an attractive force of great intensity, and the moment such an atom is liberated from a state of combination (say hydrogen from water, or chlorine from salt)—it finds itself in proximity to another atom having similar desires for union, so to speak; the result is an impetuous rushing together and formation of either couples, trios, or groups, according to the nature of the atoms. It would be as difficult to conceive of separate atoms as to imagine that a strong magnet and a piece of steel could be suspended close to each other without being drawn together. It is, doubtless, possible to keep some pairs of atoms apart by the aid of heat, just as the magnet and steel may be parted by a superior amount of force, but such a condition of things is probably abnormal. These pairs and other groups of atoms are conveniently designated by the one word *molecule*, the diminutive of *mole*, a mass; literally little masses. Dissimilar kinds of atoms seem to have greater attraction for each other than similar kinds; for, first, the masses of matter met with in nature in the great majority of cases contain two or more dissimilar elements; and, secondly, at the moment certain elements are liberated from their combination, they are very specially active in combining with other, different, elements; that is to say, the chances are not equal that the liberated elements will either retain their elementary condition or combine to form compounds, but the cases in which compounds are formed are actually in great majority.

MOLECULES AND ATOMS.

The study of the chemistry of molecules, *quâ* molecules, is of great interest; but the study of the chemistry of the atoms or groups of atoms within molecules is of enormously greater interest. A molecule of nitrogen, for instance, is most inactive; an atom of nitrogen has activity which even the most advanced chemist finds difficult of realization.

RECAPITULATION.

It is desirable that the learner should here make some experiment which will serve to bring again under notice in an applied or concrete form what has just been stated respecting the substances termed *chemical compounds*, and concerning the character of that *chemical force* which resides in the *atoms* of *molecules*. The following will usefully serve this purpose; it is the process for detecting a trace of sulphurous acid in common liquid hydrochloric acid.

As already proved, hydrogen gas and chlorine gas, when inter-united in a manner presently explained, form hydrochloric acid gas: the latter dissolved in water is the ordinary liquid of the shops termed *Hydrochloric Acid*, the *Acidum Hydrochloricum* or *Muriaticum* of Pharmacopœias. Commercial samples of this liquid not unfrequently contain as an impurity a trace of sulphurous acid gas, a body also already mentioned and experimentally prepared—a trace too small to be detected by its odor. Obtain a specimen of common liquid hydrochloric acid containing as an impurity a trace of sulphurous acid, or adopt the more simple course of purposely adding a few drops of aqueous solution of sulphurous acid (*Acidum Sulphurosum*,* U. S. P.) to some hydrochloric acid. (If no sulphurous acid is at hand, the object may be accomplished by pouring a quarter or a half an ounce of liquid hydrochloric acid into a wide-mouthed bottle, then burning a fragment of sulphur on a wire or strip of wood inside the bottle for a few seconds, and shaking the gas and liquid together.) Pour some of the impure liquid hydrochloric acid into a test-tube, add about an equal bulk of water, and then drop in some fragments of the metal zinc. Effervescence will occur, due to the escape of inodorous hydrogen gas, together with a small quantity of badly-smelling gas, termed sulphuretted hydrogen gas. Bring the mouth of the tube under the nose; the presence of sulphuretted hydrogen will at once be recognized.

The hydrochloric acid has now been *tested* for sulphurous acid. If the experiment be performed on any commercial specimen of the acid, and a smell of sulphuretted hydrogen be observed, the operator will at once be able to state that the specimen contains sulphurous acid as an impurity.

Using Dalton's theory of the atomic constitution of matter, the explanation of what occurs in the successive steps of the foregoing experiment is as follows:—

Hydrochloric acid is a *chemical compound* of hydrogen and chlorine. That it is a chemical compound, and not a mere mechanical mixture of hydrogen and chlorine, is shown by the fact that its properties are altogether different from the properties of its constituents. The attractive power or *chemical force* resident in the *atoms* of chlorine and of hydrogen has caused them to combine in the closest manner imaginable and form pairs of atoms or *molecules* of the chemical compound—hydrochloric acid. Zinc being introduced into the acid, and the atoms of zinc and chlorine having even still greater attraction for each other than the hydrogen for the chlorine, the zinc and chlorine atoms combine and form a new

* These aqueous solutions of acids are generally, for the sake of brevity, simply termed acids.

molecule (termed chloride of zinc) which remains in the liquid, while the hydrogen atoms, having the atoms of no other element to combine with if the acid is pure, unite to form pairs or molecules of hydrogen, and in that state escape from the vessel. If the acid be impure from the presence of sulphurous acid (sulphurous acid gas, it will be remembered, is a compound of sulphur and oxygen), some of the hydrogen atoms, at the moment of their birth, their *nascent* state (from *nascor*, to be born)—the specially active state—finding the atoms of other elements present, namely, the atoms of sulphur and oxygen of the sulphurous acid molecules, combine by preference with these atoms and form new molecules, the sulphur and hydrogen forming sulphuretted hydrogen, and the oxygen and hydrogen producing water: the former escapes with the great bulk of the hydrogen, while the water remains with the water already in the vessels.

Note.—Ordinary hydrogen gas, that is, hydrogen in the molecular, not in the atomic or nascent condition, will not thus attack sulphurous acid. Doubtless the amount or extent of attraction of two atoms of hydrogen for one atom of, say, the sulphur in the sulphurous acid molecule is a constant amount but the uncombined nascent atoms can, it is only fair to suppose, get much nearer to the attacked molecule than they can after they have themselves combined to form a molecule, molecules (but scarcely atoms) having an appreciable amount of space between them, as will be further shown almost immediately. In other words, it is probably distance which prevents an attack which would be inevitable at close quarters. These remarks apply to all similar reactions of other elements. The activity of nitrogen in what the student will now see is its atomic rather than merely nascent condition, as compared with its inactivity in what now may be termed its molecular condition, has already been alluded to (page 27).

CONDITIONS AND NATURE OF THE MANIFESTATION OF THE CHEMICAL FORCE.

The exertion of chemical affinity is only possible when the masses of the bodies touch. Thus it was necessary to bring the oxygen, hydrogen, phosphorus, chlorine, sulphur, carbon, iodine, and iron into ordinary contact, in the respective experiments with those elements, before the various reactions occurred. The exact nature of these actions, as indeed of all in which substances act chemically, would seem to be an interchange, most generally a mutual one, of the atoms of which the molecules consist—a change of partners, so to speak. Thus, in the experiment in which hydrogen and chlorine gases united to form hydrochloric acid gas, a pair of atoms in a hydrogen molecule, and a pair of atoms in a chlorine molecule, finding themselves opposite to each other, change places, the atoms of each of the old molecules unlinking, so to say, and pairing off in fresh couples—as two brothers who for many years have been close companions, and two sisters similarly united, thrown freshly into each other's society, soon accept new and still more congenial complement.

{ Hydrogen } and { Chlorine } become { Hydrogen } and { Hydrogen }
 { Hydrogen } { Chlorine } { Chlorine }

Or, using the symbols of these elements instead of the full names,

H H and Cl Cl become H Cl and H Cl.

Still further economizing space and trouble, the same statement may be made in the following form:—

H₂ and Cl₂ become 2HCl.

Once more, by using the *plus* (+) instead of the words “and” or “added to,” and the sign or symbol = or *equal* instead of the words “become” or “are equal to,” we reach the shortest method of expressing this chemical action:—

H₂ + Cl₂ = 2HCl.

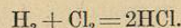
This is the form in which such an action may be expressed in the student's note-book. It is the shortest and most convenient form, and is instructive and suggestive to the mind.

CHEMICAL NOTATION.

We have thus gradually arrived at a spot in the path of chemical philosophy at which we must halt to more fully discuss the usual method of recording chemical travels. We have arrived at the subject of *chemical notation* (from *noto*, I mark), the art or practice of recording chemical facts by short marks, letters, numbers, or other signs. Already the first capital letter, or the first and one of the following small letters of the Latin names of the elements have been employed as contractions, or short-hand expressions, or *symbols* of the whole *name*. Thus H has been used for the word “hydrogen,” and Cl for “chlorine.” A *second function* of such a symbol is that of indicating one *atom*. Thus H stands not only for the word or substance “hydrogen,” but for one atom of hydrogen. Large and small figures (2 or ₂) indicate a corresponding number of atoms, the small figure only multiplying the one particular symbol to which it is attached, while a larger figure multiplies all the symbols it precedes. Thus H₂ means two atoms of hydrogen, and Cl₂ two atoms of chlorine; while 2HCl means two atoms of hydrogen and two atoms of chlorine, or, in one word, two molecules of hydrochloric acid gas. A *third function* of such a symbol as H or Cl is that of indicating one *volume* of the element in the gaseous state. Thus H, Cl, and O stand, first, for the substances named hydrogen, chlorine, and oxygen; secondly, for single atoms of hydrogen, chlorine, and oxygen. Thirdly, they represent single and equal volumes of chlorine, hydrogen, and oxygen. It will be remembered that one test-tubeful of hydrogen and an equal sized test-tubeful of chlorine were employed in a previous experiment in forming hydrochloric acid gas, HCl.

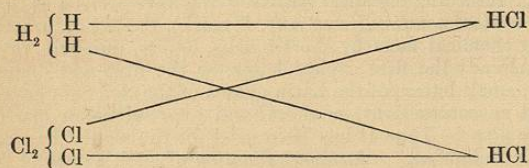
The *position* of symbols counts for something. Thus HCl indicates not only the substances hydrogen and chlorine, single atoms of each of the substances, and equal volumes of each, but also that

the two substances are *joined together by the chemical force*. If the two letters were placed one under the other, or at some distance apart, or were separated by a comma or a plus sign (+), they would be understood to mean a mere mixture of the elements; but placed as close as the printer's types will conveniently and consistently allow, they must be considered to stand for a compound of the elements, that is to say, hydrochloric acid gas (HCl). The collection of symbols representing a molecule is termed a *formula*. H_2 , Cl_2 , and HCl are the *formulae* of hydrogen, chlorine, and hydrochloric acid gas.



Such a set of letters, figures, and marks as that on the preceding line is collectively termed an *equation*, because it indicates the equality of the number and nature of the atoms before and after chemical action. On the left hand of the sign of equality are shown two molecules, and on the right hand two molecules; but, of the molecules on the left, one contains two atoms of hydrogen and the other two atoms of chlorine, while of the molecules on the right each contains one atom of hydrogen and one of chlorine. The equation forms a short and convenient plan of recording the facts of experiment.

Instead of an equation, a *diagram* may be employed to exhibit the same fact. Thus:—



PHYSICAL AND CHEMICAL CONSTITUTION OF MATTER.

RELATIONS OF GASES, LIQUIDS, AND SOLIDS.

Molecules of gases are not in absolute contact, for a volume of gas may be compressed with very little force to half or one-fourth its bulk—in short, to such an extent that in many cases the molecules sufficiently approximate to form a liquid. In a liquid the molecules are still free to glide about with ease amongst each other; and though in solids they exhibit less mobility, still even solids may be compressed by powerful pressure, so that probably in *no* instance are molecules in absolute contact. (Moreover, from the researches of Caignard de la Tour and of Andrews there would seem to be no sharp lines of demarcation between the gaseous, liquid, and solid conditions of substances.) One's mental picture of the relative position of the molecules of gaseous, vaporous, liquid, or solid matter must be such a picture as that of the moving particles of dust in the air of a room, or such a relation to each other as that of the planets and stars suspended in space. There is abundant experimental evidence to warrant such a conception. A

clear transparent fluid appears perfectly homogeneous, but is not so. Its particles are not in contact. Every one who has mixed 5 pints of rectified spirit with 3 pints of water knows that the 100 fluid-ounces of spirit and 60 fluidounces of water do not when mixed give 160 ounces of "proof" spirit, but only 156 ounces; the molecules of the liquids have gone closer together, having probably a little attraction for each other. Why a gas under pressure should immediately return to its original bulk when the pressure is removed, while a liquefied or solidified gas only slowly resumes the gaseous or vaporous state, is a question which requires for discussion a knowledge of the nature of forces other than the chemical. For it must be remembered that the study of the chemical force is mainly the study of the internal constitution of molecules, the study of the properties of entire molecules forming the domain of *Physics*—sometimes termed *Natural Philosophy*. (Physics, from *physis*, nature, that is, visible and material nature; the study of actions and reactions which do not involve entire and permanent change in the properties of bodies—the study of the action of heat, light, electricity, magnetism, gravitation, etc., on matter.)

It is necessary, however, to state something more about the physical as well as the chemical conditions of the molecules of a *gas* in order that the learner may be prepared for the fact, that mixtures of certain gaseous elements, in combining to form gaseous compounds, diminish considerably in volume. Thus, while a pint of hydrogen and a pint of chlorine give a quart of hydrochloric acid gas,

Hydrogen.	Chlorine.
Hydrochloric acid gas.	

two pints of hydrogen and one of oxygen are necessary to produce a quart of gaseous water (steam). It will be remembered that two volumes of hydrogen and one of oxygen were necessary in a previous experiment in which water was formed.

Hydrogen.	Hydrogen.	Oxygen.
Gaseous water (steam).		

Now, that a pint of hydrogen gas and a pint of chlorine gas should, after chemical reaction or rearrangement of the atoms of the molecules has taken place, form two pints of hydrochloric acid gas, is quite what we should expect. For, first, the reader, by this time, is not astonished that the chemical combination is attended by entire