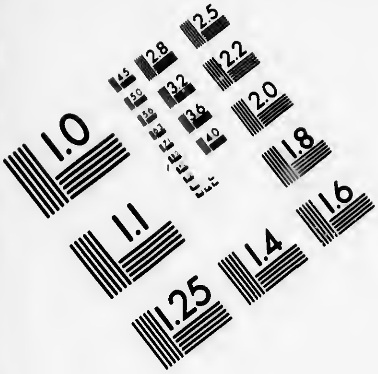

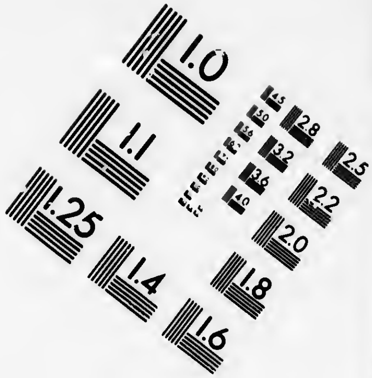

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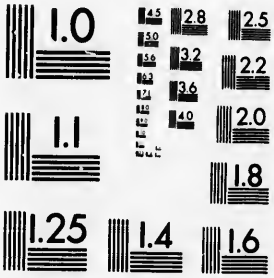

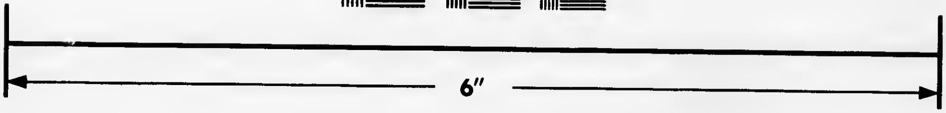

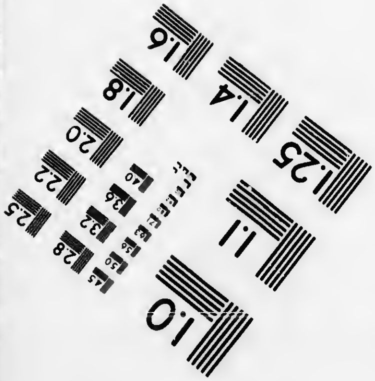

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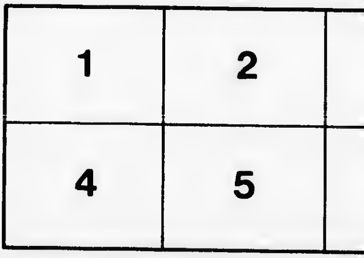

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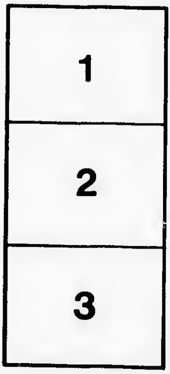

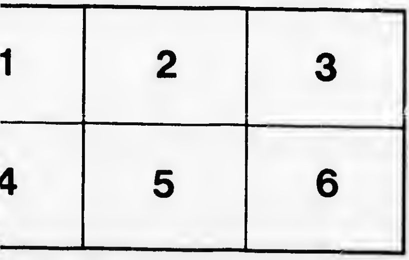


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SCIENCE PRIMERS,

Edited by PROFESSORS HUXLEY, ROSCOE, *and*
BALFOUR STEWART.

II.

CHEMISTRY.

Science Primers.

CHEMISTRY.

BY

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Author of

"The Spectrum Analysis," "Lessons in Elementary Chemistry," &c.

WITH ILLUSTRATIONS.

FOURTH EDITION.

TORONTO:
ADAM MILLER & CO.
1876.

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PREFACE.

In publishing the Science Primers on Chemistry and Physics, the object of the Authors has been to state the fundamental principles of their respective sciences in a manner suited to pupils of an early age. They feel that the thing to be aimed at is, not so much to give information, as to endeavour to discipline the mind in a way which has not hitherto been customary, by bringing it into immediate contact with Nature herself. For this purpose a series of simple experiments has been devised, leading up to the chief truths of each science. These experiments must be performed by the teacher in regular order before the class. The power of observation in the pupils will thus be awakened and strengthened; and the amount and accuracy of the knowledge gained must be tested and increased by a thorough system of questioning.

The study of the Introductory Primer will, in most cases, naturally precede that of the above-named subjects; and then it will probably be found best to take Chemistry as the second and Physics as the third stage.

Boxes containing the whole of the chemical apparatus and specimens needed for the experiments are supplied by the publishers; or by Messrs. Jas. Woolley, Sons, and Co., Market Street, Manchester; Messrs. Mottershead, Manchester; Messrs. Mawson and Swan, Newcastle-upon-Tyne; or by J. Griffin and Sons, Garrick Street, Covent Garden, W. C., for £5 10s.

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FIRE—AIR—WATER—EARTH.

1. Here are four things which we all know well; let us try to learn what Science teaches us about them.

The study of these matters constitutes a part of the study of nature; it is in nature or in the visible world around us that these things occur, it is there that we learn what they are, it is there that we can handle and examine them. This handling and examination of the objects of nature is called **Experiment**; and it is either by observation or by experiment that we learn all we know about what goes on around us. To find out and explain what goes on when the **Fire** burns, to tell how the **Air** makes the fire burn or helps the plant to grow, to find out what **Water** is made of, and to learn the many different substances which can be dug out of the **Earth**; all this belongs to the **Science of Chemistry**. Let us try to get hold of a few ideas about these interesting subjects; and first let us remember that in the Introductory Primer we have been taught the meaning of the words solid, liquid, and gas. The **earth** on which we stand is a solid, the **water** which runs about on the earth's surface is a liquid, and the **air** which surrounds the earth is a gas. You have learnt some of the common properties of earth, water, and air, you have now to learn something new about these things, what they are made up of and how their several parts can be obtained. Before we begin to study the chemistry of air, water, and earth, let us start with **Fire**, about which you have not learnt much.

FIRE. § I.

2. What happens when a candle or a taper burns.

The wax as well as the wick of the taper gradually disappears as the taper burns, and at last all is gone —wick, wax, and all. What has become of the wax? it has disappeared. Is it lost? So far as our eyes are concerned certainly it is lost, but so is the ship which sails away on the sea, and yet we know that the ship still exists though we do not see it; and so the lump of sugar appears to be lost when we put it into a cup of hot tea, and yet we know that the sugar is not really lost, because the tea is made sweet. Now we must look for the wax of our taper in another way; we must put a question to Nature for her to answer, and we shall always find that our question, if properly asked, is always clearly and certainly answered. We must make an **Experiment**, and if this is properly made we shall never fail in the end to get the information we want.

EXPERIMENT I.—Let us burn our taper in a clean glass bottle with a narrow neck; after it has burnt for a few minutes we notice that the flame grows less and less, and in a short time the taper goes out. This is the first thing we have to observe. We next have to discover **why** the taper goes out. For this purpose let us see whether the air in the bottle is now the same as it was before the candle was burnt. How can we tell this? Let us pour some clear **lime-water**[1] first into a bottle filled with air in which no candle has burnt, and then into the one in which our taper burnt. You see the difference at once! In the first bottle the lime-water remains clear, in the second it becomes at once milky. Hence we see that the air has been changed in some way by the burning of the taper. This milkiness is nothing else than **chalk,** and chalk is made up of **lime** and **carbonic acid.** Carbonic acid is, like common air, a colourless invisible gas which we cannot see, but which we find turns the lime-water milky, and puts out a burning taper. Part of the wax has been changed by burning into this carbonic acid gas; that is, the **carbon** or **charcoal** of the burnt wax is to be found again in this invisible gas. Some of this carbon you may notice going away unburnt as smoke or soot; and if you quickly press a sheet

Fig. 1.

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[1] Made by letting a piece of fresh lime stand in water, and shaking it up, and then letting the water get clear again.

of white paper on to the flame so as not to burn the paper, you will see that it becomes stained with a black ring of soot or carbon.

3. Besides carbonic acid gas there is another substance formed when the candle burns, viz., Water.

You may perhaps think it strange that water is formed in the hot flame. Still a simple experiment will show you that this is really the case. If water comes off from the flame, it will be in the state of hot steam, which you cannot see, for what we commonly call steam coming out of the boiling kettle is not steam, but fine drops of water; and if you had a glass kettle, and could look inside it, you would see nothing above the boiling water, because steam is an invisible gas like carbonic acid and common air. Now as the steam from the kettle becomes small drops of water when it cools, so the hot air coming from the burning taper, if it contains steam, must deposit the steam in the form of drops of water when it is cooled.

Fig. 2.

Experiment 2.—All we need to do to see whether steam is given off from a burning candle, is to hold a cold, dry, bright glass, such as a tumbler, over the flame of our taper. You see that the bright glass is at once dimmed, and if you look carefully you will notice the little drops of water which bedew the inside of the glass. If we went on for some time, and if we so arranged the experiment as to keep the glass always cool, we could get a wine-glass full of water by burning a candle, and the water thus got is like all other pure and good water, except that it may perhaps taste a little of soot.

Let us now look back as to what we have learnt about our candle burning; for it is most important always to get clear ideas, first, as to what we want to prove by our experiments, and secondly, as to what we have to learn from them.

We want to know what happens when a candle burns. We have learnt—

1. That the candle soon goes out if it be burnt in a bottle of air.

2. That a colourless invisible gas called **carbonic acid** is formed in the bottle after the candle has burnt.

3. That the carbonic acid gas comes from the carbon or soot contained in the wax.

4. That water is also formed when the candle burns.

We therefore have learnt that the wax of the candle has **not been destroyed** or lost, but that it **has changed its form** and has been converted into carbonic acid and water. This sort of an entire change is called a **chemical change.** No one could have foretold that the wax would have changed into two totally different substances; it is only by making these careful trials that we learn what happens in such cases as these: hence Chemistry is called an **Experimental Science.**

FIRE. § II.

4. When a candle burns nothing is lost.—Our experiment with the taper gives us at once an answer to the question, where does all the coal go to in a common fire? It goes up the chimney as carbonic acid gas. We heap on coals all day long, and take away next morning only a shovelful of ashes—the coal has burnt away. But this is not a sufficient answer. We have got next to find out what happens to the carbon of the wax or of the coal when it burns away and flies up the chimney as carbonic acid gas.

EXPERIMENT 3.—For this purpose we must make another experiment. Here we have a glass tube with a cork at the bottom, through which some holes are bored; into one of these holes I stick a piece of our taper. In the **U**-shaped tube I have placed some pieces of a white substance called caustic soda. Now I hang the tube, with he taper and caustic soda, on to one end of a pair of common apothecaries' scales, and put weights at the end until the tube is quite balanced. Next I fasten the top of the tube by a piece of india-rubber tubing to the top of an oil-can filled with water, and having a perforated cork and glass tube at the top and a tap to let the water out at the bottom. Now when I let the water run out quickly into the bucket, the air passes through the holes in the cork into the tube, to fill the space left by the water, as seen by the direction of the arrows in the drawing. I next light the taper and quickly replace it and the cork, and allow it to burn in the draught of air. After the taper has burnt for a few minutes I stop the water running, and you see that the candle goes out; and when you look at the scales you will find that they are no longer balanced, but, strange as it may seem, the tube in which the taper has been burnt is really heavier than it was before the candle was lighted, although some of the candle has disappeared. This is then what our experiment teaches us. We must try to understand how the candle, after it is burnt, weighs more than before it was burnt. In the first place, then, I put the lumps of caustic soda in the **U**-shaped

Fig. 3.

tube above the taper, in order that the two invisible gases—carbonic acid and steam—which we now know are always given off when the taper burns, shall not escape from the tube, but shall be held fast by this caustic soda (just as fish may be caught in a net). Having then caught these gases, we discover that they are heavier than that part of the original candle which has been burnt. How can this be explained? Why, only by supposing that something having weight has been joined to or has united with the substance of the taper to produce the two gases in question. This supposition turns out to be correct, and this something is another colourless gas which partly makes up common air, and is called **oxygen gas.** Now we can more clearly understand what goes on when the taper burns. Whilst the act of burning is going on, the substance of the wax (or coal) is **uniting chemically** with the oxygen of the air. The carbonic acid and steam formed are the results of that **chemical union.** These gases weigh more than the wax (or coal) which is burnt, because they contain something else besides, viz., oxygen taken up from the air. If we had weighed the air, we should have found that the air had lost exactly as much weight as the burnt wax (or coal) had gained, viz., the weight of the oxygen.

5. What we have learnt.

Now we have learnt two most important things about the burning of a candle, (1) that nothing really disappears or is really lost; (2) that the parts of the candle are uniting chemically with the oxygen of the air.

By making these three simple experiments, and by trying to find out what they teach us, we have learnt more about **Fire** than all the ancients knew, so that you now understand the use of experiments; and when you come to read the Physics Primer (Articles 48 and 75), you will learn still more about the *Nature of Heat.*

Let us, however, go on a step further, and let me tell you that in all the experiments which are given in this book, or which you will ever make for yourselves, you will always find the same truth come out —**that no substance is ever really lost. We cannot really destroy, neither can we really create any substance.** Another fact which you have learnt from the burning candle is also true in other cases, viz., that wherever chemical union is going on there **Heat** is sure to be felt, and when that union goes on quickly we see **Flame** or **Fire.**

6. Heat felt when chemical union goes on.

Let us make two experiments about this.

EXPERIMENT 4.—Take a lump of **quicklime,** put it on a tin plate, and pour over it some cold water; you will soon see that the water and the lime both begin to get hot, and the water hisses on the hot lime till at last it boils, and clouds of steam are given off. The lime remains on the plate as a fine dry white powder, called **slaked-lime.** We have only done

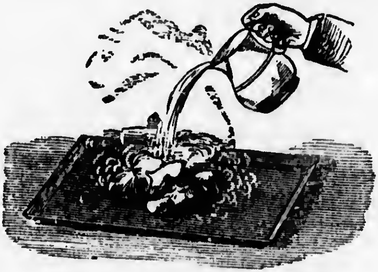

Fig. 4.

what the bricklayers do every day to make their mortar; we have slaked the lime. Why should all this heat and steam arise? It arises because the water and the quicklime have **combined together chemically,** and the result is slaked-lime.

Fig. 5.

EXPERIMENT 5.—Put some yellow powdery **flour of sulphur** on the bottom of a small glass flask, and above this put into the flask some bright **copper turnings.** Next place the flask on an iron stand, and heat it over the flame of a gas lamp for the purpose of boiling the sulphur. We will place the lamp on a common plate, to catch the sulphur if the flask should chance to crack. Now look what happens. First the yellow sulphur melts; it gets darker and darker in colour, and at last it boils. Now the boiling sulphur touches the copper turnings, and we may remove the lamp, when we see that the turnings first become red-hot and glow with a splendid lurid red light, and then melt and drop down to the bottom of the flask. When the flask is cold we break it open, and find that it contains neither bright copper nor yellow sulphur, but that a black substance is found at the bottom. What is this? It is a **chemical compound** of the two

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different things, copper and sulphur; the copper has united chemically with the sulphur, and whilst they were joining heat was given off, or the copper **took fire** and burnt.

7. What we have learnt.

Now I think you have learnt that where there is **Fire** there chemical union is going on, whether it is a taper burning, or coal burning, or a hayrick on fire, or a house on fire. In all these we have the same thing going on, viz., chemical union of the parts of the burning body with the oxygen of the air. And so from **Fire** we get to **Air.**

AIR. § III.

8. About the Air.

How do you know that there is anything between you and me in this room? What makes you say that there is **Air** out of doors? If you move your hand and arm quickly round and round, you will feel a draught of air through your fingers; if you fan yourself, you feel the air passing over your face. Out of doors you notice the **Wind** blow, you see the trees or the clouds moved by the breeze, and this breeze is only the **air in motion.** What makes the sails of a windmill go round and round? The wind, you say. Well then this wind which blows sometimes so hard as to uproot trees and wreck ships is only **air** moving. But if the air is still and quiet, how can we tell that it is present? Certainly not by seeing it, because air is invisible, but by making an experiment we at once learn something new about it.

9. What the air contains.

EXPERIMENT 6.—Here I have a bell-jar open at the bottom and furnished with a neck, and a cork at the top (an old bottle with the bottom cracked off will do very well). I will put the bell into this basin of water, but first we must float on the water a little china dish with a small bit of dry phosphorous as big as a pea on it, and light the phosphorous with a match.

Fig. 6.

Phosphorous is a very dangerous substance, and much care must be taken of it, as it is very apt to take fire by itself, and may burn your fingers badly. Now you see the bright flame of the phosphorous burning inside our bell-jar. After a while it goes out, although it is not all burnt, and we will let the bell-jar stand until it is cool. You notice that the white smoke or fumes which were made by the burning phosphorous have now disappeared, and we have a quantity of air left. But you will at once see that there is not so much air left as there was when we began; the jar was full of air to start with, now there is a good deal of water in the lower part of the jar. Let us next ask ourselves, is the air which remains the same kind of air which we took? We take out the cork of the bell-jar and plunge our burning taper into the gas; why, at once, it goes out. We light it again with a match, and repeat the experiment; again it goes out when we lower it into the bell-jar. There can be no doubt about this. Something is left after the phosphorus is burnt, which is different from what was in the bell-jar at first. So that you see there are really two different kinds of air in this room: one kind of air (called **Oxygen gas**) unites with the phosphorus forming those white fumes, and this disappears and water comes into the bell-jar in its place; the other kind of air (called **Nitrogen gas**), which is left behind, puts out the burning taper, and is therefore quite a different thing from oxygen. Thus we have learnt not only that there is something, which we call air, in this room and in this bell-jar, but that there are two separate things (both invisible gases), called oxygen and nitrogen. What a great deal so simple an experiment may teach us! Science is always simple and plain when we go carefully forward, and when we make sure to understand each step we take.

AIR. § IV.

10. What goes on when we breathe the air.

We now know that whenever a candle or other thing burns in the air a chemical union is going on between the substances composing the candle and the **Oxygen** of the air. The burning wax candle is producing carbonic acid and water, because the carbon and hydrogen contained in the wax are uniting with oxygen; we must light the candle before it will burn, or we must start this union. The candle flame is hot because this **Oxidation** is going on: when you blow the candle, the flame is cooled and goes out, the wax no longer combining with the oxygen.

The oxygen of the air is as necessary for the life of men and animals as it is for the burning of candles. You know that we must have fresh air to breathe: if we do not get enough fresh air, we shall be suffocated and die. There are many dreadful stories told of people being suffocated on board ships in storms when the hatchways had been nailed down to prevent the waves from sinking the ship, or in coal mines, or in wells where foul air had collected. Now let us ask the question, what is going on when we breathe? Do men and animals produce any chemical changes in the air which they breathe like the burning candle or phosphorus? Here a simple experiment will soon plainly answer this question.

EXPERIMENT 7.—Pour some clear lime-water into a glass, and then blow the air from your lungs through the liquid by means of a straw or a piece of glass tubing. You will soon notice that the lime-water has become milky; exactly the same effect has been produced as was noticed when you burnt a taper in a bottle (Experiment 1); the milkiness shows that chalk has been formed, and the chalk shows that carbonic acid gas has come out of your lungs. For this carbonic acid gas did not go into your lungs with the air, because if you shake up lime-water with common air it does not get milky. Hence we learn that the air you **breathe out** differs from the air which you **breathe in** by containing large quantities of carbonic acid gas.

Where does this gas come from? It is the same gas which is always formed when a candle burns. Can our bodies be really burning like candles? You will say at first, No, certainly not, for we do not feel hot like a candle flame. But then you will think, Why! I am really hotter than the table or walls or anything which is not alive. So is the dog or the cat; so are a great number of animals. But when these animals cease to live, or when they cease to breathe, then they become cold like the walls or the table. The **breathing of animals** is therefore **an act of oxidation.** The air passes through the nose and mouth down the throat into a fine network of very small tubes called the **lungs.** At one side of these thin tubes is the **air,** at the other side is the **blood,** and the oxygen of the air passes through the thin sides of these air-passages into the blood, and there it combines with the dead carbon contained in the body. You may easily convince yourself that animal bodies contain carbon, by noticing that a piece of meat becomes **charred** or converted into charcoal or carbon when it is partly burnt by placing it before a hot fire. Now this carbon of the body forms carbonic acid when it unites with oxygen, just as the carbon of a piece of wood does. And the heat which is given off in each case is exactly the same. If we were to get a bottle full of pure carbonic acid gas from a burning taper, and the same

Fig. 7.

sized bottle full of pure carbonic acid gas from our lungs, the heat which is produced in our body by the combustion of our animal carbon, in order to get this much carbonic acid gas, is the same as that given off by the burning of the candle to get the same quantity of the same gas. We do not see any flame in the animal because the heat of combustion is spread all over the body; if the oxidation took place in as small a space as the wick of a candle, then we might expect to see a flame, but as it is the blood running throughout the body simply keeps the whole warm.

Thus by another experiment we have learnt (1) that animals take in the oxygen of the air into their lungs; (2) that there the oxygen goes into the blood; and (3) that there the oxygen is used to burn up the waste carbon of the body forming carbonic acid, and thereby giving rise to **animal heat.**

AIR. § V.

11. Let us next ask what sort of action do Plants exert on the air?

Again we must have recourse to experiment, but this time one which will last some days.

Experiment 8.—If you sow some mustard or cress seeds on a piece of common flannel kept moist by a little water contained in a plate, the seeds will soon begin to sprout, and if you keep them in the light they will continue to grow until after some days you may have a fair crop of mustard and cress plants. Whence did the growing plants get the materials necessary to form their stalks and their leaves? Not from the flannel, for that remains unchanged; not wholly from the seeds, for the plants weigh much more than the seeds; not from the water alone, because the plants are building up stalks and leaves containing **Carbon,** and this substance is not present in water. Where does the plant get the **carbon** it needs? From the air, we answer. Our previous experiment showed us that animals are continually giving out **carbonic acid gas** in their breath, and we are therefore sure that this gas must be present in the air, although perhaps in small quantity. Let us see whether we can find out that there is a little carbonic acid in common air.

EXPERIMENT 9.—Pour a little clear lime-water into a shallow saucer or clean plate, and allow it to stand for a few minutes, either in a room or in the open air, then move it about and pour it into a glass. You will notice that a thin white film has been formed on the top of the lime-water. This film is chalk or carbonate of lime, derived from the union of the carbonic acid contained in the air with the lime. It takes some time to form, and then only is seen in small flakes or films, because there is only a very little carbonic acid gas in the air. **But this small quantity of carbonic acid serves as the main food of all the plants which grow on the earth.**

12. Growth of plants.

If the plant uses carbonic acid as its food, and produces therefrom wood, and fruit, and leaves, all of which need carbon to form them, what becomes of the oxygen which we know is united with carbon to form carbonic acid? We must as usual go to Nature for an answer and make an experiment.

EXPERIMENT 10.—Take a bunch of fresh green leaves—water-cresses answer well—and place them in a large bottle, then fill the bottle quite full of fresh spring water, so that no bubble of air is left in the bottle. Turn the mouth of the bottle, full of water and leaves, downwards into a basin full of water, and place the bottle and basin in the strong sunlight for an hour or two. If you then carefully examine the leaves, you will see that they are covered with small bubbles, and that more of these bubbles have collected at the top of the bottle. These bubbles consist of pure oxygen gas[1] derived from the carbonic acid contained dissolved in the spring-water.[2] **Plants have the power in presence of sunlight of decomposing the carbonic acid of the air, taking the carbon to build up their stems, leaves, &c., setting free the oxygen as a gas.**

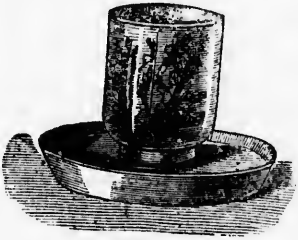

Fig. 8.

EXPERIMENT 11.—You probably know that green plants will not grow in the dark, and you may understand why this is so, if you repeat the last experiment; but instead of placing the bottle of spring-water containing the leaves in the light, put it in a dark cellar.

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[1] This may be shown if the gas is present in sufficient quantity by transferring the gas to a narrow test-tube, and exhibiting the re-ignition of a red-hot splinter of wood.

[2] By adding lime-water to the spring-water a milkiness of chalk will be produced, showing the existence of carbonic acid in the latter.

You will then not notice the formation of any bubbles of oxygen gas, even after standing for many hours, and you will learn that sunlight is necessary in order that green plants may decompose carbonic acid, and therefore necessary for their growth.

13. Action of animals and plants on the air.

Let us now reflect for a moment on the different changes which animals and plants produce in the air. We have learnt that both these sets of living beings are constantly causing important chemical alterations in the air, so that chemistry has not only to do with the changes which occur in dead or inanimate matter, but also is nearly concerned in the very life of every animal and vegetable existing on the globe. Now we have learnt that—

Animals inhale (breathe in) oxygen, and exhale (breathe out) carbonic acid—give off heat—are constantly burning.

Plants inhale carbonic acid gas, and exhale oxygen,—take up the sun's light and heat, without which they cannot grow,—are constantly forming material which will burn.

Here you see that the part played by the animal is exactly the opposite of that played by the plant: the animal renders the air **impure** by constantly breathing out carbonic acid; the plant constantly tends to purify the air again by taking up the carbonic acid, and breathing out (by means of its leaves) oxygen gas. This balance between animal and vegetable life is well illustrated by the Vivaria, now so common, in which small water-animals and water-plants grow in a globe shut off from the air; the carbon contained in the carbonic acid evolved by the animals is set free by the plants, and is just sufficient for their growth, whilst the oxygen at the same time liberated serves for the respiration of the animals.

WATER. § VI.

14. What is Water made up of?

You have learnt in the Introductory Primer that if I put a piece of ice into a glass and heat it over a lamp, the **solid ice** changes into **liquid water,** and, if I continue to heat the water, it begins after some time to **boil** and forms **gaseous steam.** This steam is an invisible gas, quite different in its properties from the liquid water which is got by cooling it. Let us see if we can get anything else from water than steam, by treating it in different ways.

EXPERIMENT 12.—Instead of sending **heat** into the water, by which I only get it to boil, I will send a stream of **electricity** through the water (to which I will add a few drops of acid to allow the electricity to pass more easily). I use four cells of a Grove's battery (a description of which is found in Article 87 in the Physics Primer), and the electricity will pass into the acidulated water by the two platinum wires passing through the cork at the bottom of the glass funnel, when I join these from the copper wires from the battery.

What do we notice the instant we join the wires? The water near the wires seems to boil, or effervesce, owing to small bubbles of gas being given off. These bubbles cannot be steam, because steam, if formed near the wire, would at once be condensed by the water near it, and these bubbles rise up through the cold water. Let us try to collect these gases, and we will see whether the bubbles from the one wire are the same as those from the other. For this purpose we will put a small test-tube filled with water over each wire, so that the bubbles as they rise round the wire must be all caught by the tubes, which are both of the same size. What do we notice as the gases collect? Why, that in one tube we are getting just twice as much gas as in the other. Now one of the tubes is quite full of a colourless invisible gas, whilst the other is just half full. Next let us see what sort of gas we have got. I take the tube which is half full of gas and lift it out of the water by placing my thumb on the mouth, and then, turning it up, I bring a red-hot bit of wood into the gas; the red-hot splinter at once bursts into flame! What must we conclude?

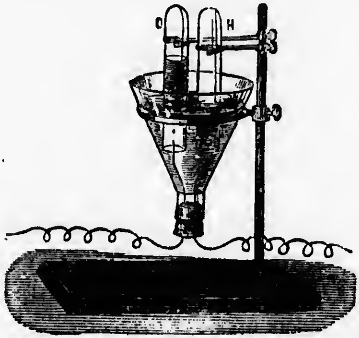

Fig. 9.

That the gas is **oxygen,** for we have learnt to recognize this substance by its re-lighting a red-hot taper.

Now we will try the same experiment with the other tube, but we will hold its mouth downwards, for a reason which we shall soon understand. The red-hot spark does not rekindle; but if we now bring the flame of a taper to the mouth of this tube, the gas itself can be lighted and is seen to burn with a pale blue flame. Here we have to do with something quite different from oxygen; this gas is called **hydrogen.**

If we repeat this experiment with the water, we shall always get the same result, and by no other treatment that we know of can we get anything else but oxygen and hydrogen from water. Hence we conclude

(1) **That by means of electricity we can split up or decompose water** into two **perfectly different** substances, **oxygen and hydrogen gases**; and into nothing else.

(2) That **water, when thus decomposed, yields twice as large a volume of hydrogen as it does of oxygen.**

15. We can get hydrogen from water in several other ways.

Experiment 13.—If I throw a small pellet of the metal potassium,[1] as large as half a pea, on to the surface of water contained in a basin, we see that the metal, being lighter than water, swims on the

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[1] This substance must be kept in rock oil, and not exposed to air or moisture. It may be cut with a penknife.

surface, but also that the moment it touches the water a flame arises round the metal. This flame is caused by the **hydrogen of the water,** which is set free and **takes fire and burns.** Now if this flame is due to burning hydrogen, what becomes of the oxygen of the water? The oxygen unites chemically with the metal potassium to form the **alkali potash**; this we can see by adding a little **red litmus** solution to the water on which the potassium has been thrown, when we notice that the red colour is changed to blue, owing to the presence of the alkali[1] potash. If I throw a small bit of the metal **Sodium** on to water, this will also swim on the surface and set free the hydrogen and form with oxygen the alkali **Soda**; but the heat is not sufficient to light the hydrogen.

Fig. 10.

16. How hydrogen can be collected.

EXPERIMENT 14.—By making the last experiment in rather a different way, we can collect the hydrogen which we saw burn on the surface of the water. For this purpose we will mix a few small pieces of sodium with a little dry mercury or quicksilver, the well-known bright shining liquid metal. If we press the bit of sodium with a pestle under the surface of

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[1] For the meaning of this word see page 65.

the mercury contained in a mortar, the two metals will unite, and we get a mixture of the metals, or an amalgam, as it is called. Now pour this liquid amalgam into a basin of water, having inverted a bell-glass or large test-tube filled with water over the centre of the basin. The sodium will gradually decompose the water, forming soda, and the hydrogen of the water will be liberated and will collect in the inverted glass. After a certain amount of the gas has been formed, the presence of hydrogen may be shown by bringing a light to it and seeing that it burns with a pale flame.

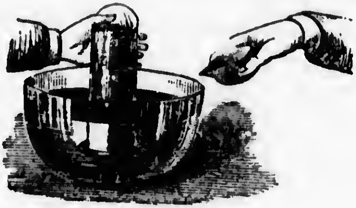

Fig. 11.

WATER. § VII.

17. Hydrogen got in other ways.

Many other metals have the power of decomposing water, taking the oxygen to form an **oxide of the metal** and setting free the hydrogen. Some metals, like potassium and sodium, are able to do this (as we have seen) in the cold;—other metals, such as iron, must be heated red-hot before they can split up water into its two constituent parts uniting with the oxygen to form **oxide of iron** or **iron-rust** and setting the hydrogen gas free. Some metals, as zinc and iron, although they do not split pure water up into oxygen and hydrogen in the cold, are able to do so if some **acid**[1] is present.

EXPERIMENT 15.—If we put a few zinc clippings into a flask containing some water, and if we then carefully pour in a little sulphuric acid (oil of vitriol), we shall soon notice an effervescence, due to the escape of gas. Then we fit tightly into the neck of the bottle a cork furnished with a bent glass tube. The hydrogen, as it is formed from the acidulated water by the zinc, will pass through the tube; and the bubbles of gas may be collected in a bottle full of water placed in the trough. Care must be taken to allow all the air to be displaced from the generating flask before the gas is collected. This is done by trying when the gas, caught in a small test-tube over the water, burns quietly on being brought mouth downwards to a flame. When the supply of gas begins to

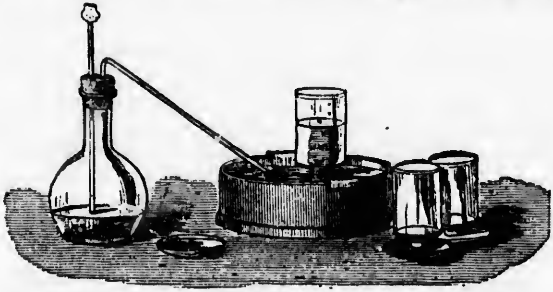

Fig. 12.

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[1] For the meaning of this word see page 65.

lessen, it can be again increased by pouring a little more acid through the tube funnel without taking out the cork.

Having thus collected three bottles full of hydrogen, which are kept by placing their mouths downwards in small saucers filled with water, let us see what experiment can tell us about the properties of this interesting gas got from water.

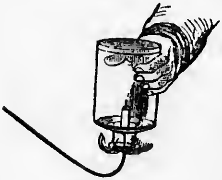


Fig. 13.

13. Hydrogen burns and is lighter than air.

Experiment 16.—Take one of the bottles full of hydrogen and hold it mouth downwards in the air, and then push a lighted taper fixed on a wire into the bottle. We shall see that the hydrogen gas takes fire and burns at the mouth of the bottle, but that the flame of taper inside the bottle has gone out. When we bring the taper out again, it will be rekindled by the flame of the burning hydrogen, but will be extinguished when plunged into the gas. What does this experiment teach us?

1. Hydrogen is inflammable, and burns with a pale blue flame.

2. Hydrogen does not support the combustion of a taper.

Experiment 17.—Turn upwards the mouth of a bottle filled with hydrogen, and then quickly bring a light to it; the hydrogen will burn with a much larger flame than when the bottle is turned mouth downwards. This is because hydrogen is **much lighter**

than air. For this reason we can pour hydrogen upwards. Take a bottle filled with air and another filled with hydrogen, and bring them together thus, and then slowly bring them into this position, when the lighter hydrogen will pass upwards, displacing the air from the lower into the upper bottle. Then bring the top bottle with its mouth downwards to a light, when the hydrogen will take fire and burn (sometimes with a slight report from admixture of air). Let the bottom bottle stand for a few moments mouth upwards on the table and then bring a light to it.. All the hydrogen has gone, and the bottle is filled with common air. This experiment shows that hydrogen is much lighter than common sir. Indeed, it is the lightest substance we know of, and is therefore used for filling balloons.

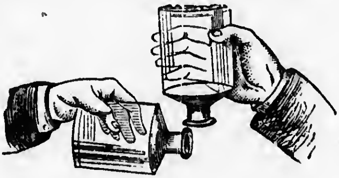


Fig. 14

19. Water formed when hydrogen burns.

Let us next try to find out what is formed when hydrogen burns in the air.

EXPERIMENT 18.—Instead of the bent tube fixed to the flask used to generate the hydrogen, attach a straight one with a pointed end to act as a jet. After you are quite sure that all the air has been driven out of the flask (and this can be

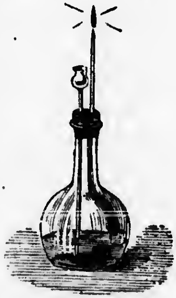


Fig. 15.

ascertained by hanging a dry test-tube on to the pointed tube and seeing that the hydrogen which then will fill the test-tube burns quietly on lighting it), bring a flame to the jet. The hydrogen will burn with a steady flame; now bring over this flame, as in Experiment 2, a dry glass, when a deposit of dew, or small drops of water, will be noticed. This shows that when **hydrogen** burns it **unites with the oxygen** in the air **to form water.**

EXPERIMENT 19.—Now let us see whether anything else is produced when the hydrogen burns. We will allow the flame to burn inside a large bottle or flask, and then add to the air in which the flame of hydrogen has burnt some clear lime-water (as in Experiment 1). No milkiness is, however, produced, and we therefore see that no carbonic acid gas is formed by the burning of hydrogen; and so, by making further experiments, chemists conclude that when hydrogen burns in the air nothing but pure water is formed. By arranging Experiment 18 so as to keep the glass cool fo some time, we may collect a glass full of water, and we find that this is perfectly pure water and quite free from soot, which was present in the water got by burning the candle. (Experiment 2.)

Now we learn where the water came from when the candle was burnt; the wax must contain hydrogen, and the water is formed by the union of the hydrogen of the wax with the oxygen of the air. So you see that in gaining knowledge about **water** we have learnt about **air**, for we have seen that water is made up of two different kinds of airs or gases, so closely are the parts of natural knowledge linked together.

WATER. § VIII.

20. Composition of water.

Next let us try to learn more about the composition of water. We have found (Experiment 3) that oxygen is contained in the air mixed with nitrogen (Experiment 6). The oxygen exists in the air in the **free state** as a colourless gas; in water the oxygen is **chemically combined** with hydrogen, and when united together these two gases form liquid water. We also know that (Experiment 12), when water is decomposed, 2 **volumes** of hydrogen gas are obtained for every **volume** of oxygen. It now becomes an important question to ask what **weight** of oxygen and hydrogen unite together to form water. How many pounds of hydrogen and how many pounds of oxygen go to form so many pounds of water? You must take care to distinguish between **volume** and **weight.** To ascertain the composition of water with accuracy is not easy, and it is so important that many chemists have devoted months or years to find out the exact weights of hydrogen and oxygen which are contained in water. We may copy their experiments by what I may call a rough model, which, if it is rather more difficult than the former experiments, is of great interest, and will be understood by all who read the description and try the experiment with care.

EXPERIMENT 20.—In the Introductory Primer the pupil has learnt the use of scales or the **balance,** and knows how the weight of a substance is determined. It may, however, be well for him to learn how to weigh for himself, and to know the number and value of the weights.

I have here a small pair of common apothecaries' scales and a set of weights. A is a tube of hard glass with a bulb blown on to it, and into this I bring about half an ounce of **black oxide of copper**; B is another tube into which the bent end of tube A can be fixed; this tube is filled with white calcium-chloride, a substance which eagerly absorbs moisture; C is a flask for generating hydrogen from water and dilute acid by means of zinc; D is a little wash-bottle containing some oil of vitriol, which will dry the hydrogen as it bubbles through; E is another tube containing calcium-chloride, through which the gas must pass, and thus get quite dry before reaching tube A. In making the experiment we must first get the weight of the tube A and the copper oxide, by taking out the corks and separating it from the tubes E and B, then carefully putting it on one pan of the scales and placing weights in the other until it is **exactly bal-**

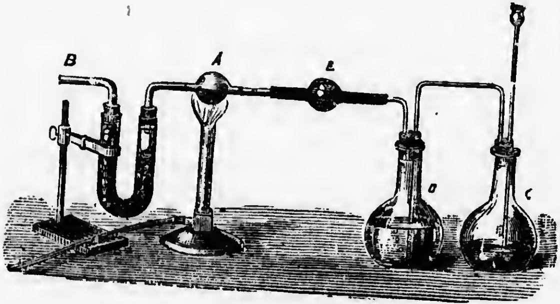


Fig. 16.

anced. The precise weight of the tube and the copper oxide must then be written down. Next carefully weigh the tube B in the same manner, and set its exact weight down on paper.

Now put the two tubes back into their places, as before, taking care not to lose any of their contents; then pour some sulphuric acid down the funnel tube on to the zinc, and allow the hydrogen to bubble through the whole apparatus and over the copper oxide. Put a dry test-tube over the turned-up end of tube B, and collect the hydrogen as it comes out; try from time to time whether the air is driven out from the apparatus by bringing this test-tube (mouth downwards) to a flame. After several trials the hydrogen in this test-tube will be found to take fire and burn quietly. As soon as this is the case, put a small gas-flame under the tube containing the oxide of copper. As long as this remains cool no difference can be observed in the black oxide, although the hydrogen passed over it; but when it is heated, a change begins at once. The black colour changes to a bright red metallic tint, and drops of water are seen to condense on the cool part of the inside of the tube. As the whole bulb gets warm the water will be carried into the tube B, and there it will be held by the calcium-chloride, a moisture-absorbing substance. Let the hydrogen pass over the heated bulb until all the black colour has disappeared, and then take the lamp away. Whilst the bulb is cooling let us find out what has happened. The hydrogen has combined with the oxygen of the copper oxide to form water which has passed on, partly as water and partly as steam, into tube B, where it all collects, none of it escaping into the air; the red powder left in the bulb is pure **metallic copper.** Now let us weigh the two tubes again. In the first place, **tube A weighs less** than it did before, because it has lost something (viz., the oxygen) which has weight. Secondly, the **tube B weighs more,** because it has gained something (viz., the water) which has weight. Now then we have:

		Grains.
1.	Weight of tube A, containing the copper oxide, before experiment	1056
2.	Ditto, after experiment	1016
	The difference between these weights is the loss due to escape of oxygen	40
3.	Weight of tube B before experiment	803
4.	,, ,, after experiment	848
	The difference between these weights is the gain of weight of tube B due to absorption of water	45

What must we conclude from this most important experiment? The answer is obvious—That 45 parts by weight of water contain 40 parts by weight of oxygen; and as water contains nothing but hydrogen and oxygen, it must contain the difference, or five parts by weight of hydrogen; or to two parts of hydrogen by weight water contains sixteen parts of oxygen.

These same proportions are always found if the experiment is carefully made. And thus we learn **the first great law of chemical combination,** that the **same chemical substance always contains the same quantities of its components.** Water is always made up of 16 parts of oxygen to 2 parts of hydrogen by weight.

WATER. § IX.

21. What is the difference between sea-water and fresh spring-water?

We know that sea-water is **salt,** or it contains salt **dissolved** in it. It is easy to make salt-water by throwing some common salt into water; the solid salt disappears or **dissolves,** and the water now tastes salt.

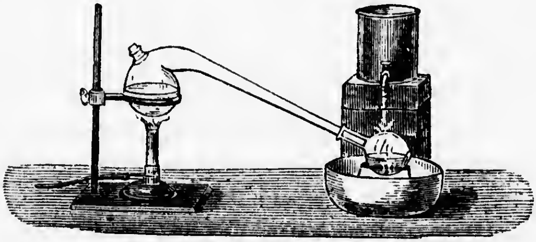


Fig. 17.

EXPERIMENT 21.—We can only get rid of this saltness by **distilling** the water; that is, by boiling the water, and collecting and cooling the steam. This we can do best in a glass retort (fig. 17). We boil the water with a lamp, the steam comes off and passes down the neck of the retort, and into the flask, over the outside of which some cold water runs to cool the steam inside the flask. The **distilled** water has no longer a salt taste; it is **pure water,** for all the solid salt remains behind in the retort, as we may see when we boil off all the water. This plan of getting fresh water from salt sea-water is much used on board ship, and the water thus got is good for drinking purposes. Sometimes spring or fresh river water contains common salt dissolved in it, but in such small quantities that it does not taste salt. The chemist, however, has a better mode of seeing whether water contains salt than judging by his tongue of the saltness: he uses a more delicate **test** than this. An experiment will show this.

22. Testing for salt.

EXPERIMENT 22.—Take two large clean glasses, full of distilled water or clean rain-water; drop into one of these a grain of common salt as big as a pin's head; stir it well up until this salt is quite dissolved. Now try whether you can taste the salt. You will not be able to do so. Now take the bottle labelled "Silver Nitrate," and carefully pour three or four drops of the liquid into the middle of each of the glasses of water. Soon a white cloud will be seen floating in the water to which the grain of salt was added, whilst the pure water remains clear and bright. Thus, then, the chemist by **his testing** and experiments can ascertain the presence of substances which the common observer overlooks or cannot see, and you will afterwards learn what happened here when this white cloud was formed. (See page 87.)

23. Solution and crystallization.

Many other solid substances dissolve readily in water—sugar, soda, alum, for instance. Others dissolve a little, such as gypsum or plaster of Paris. Others again do not dissolve at all in common water, such as flint, sand, or chalk.

EXPERIMENT 23.—If we take two ounces of soda crystals, commonly called washing soda, and add to them one ounce or about a test-tube full of hot water

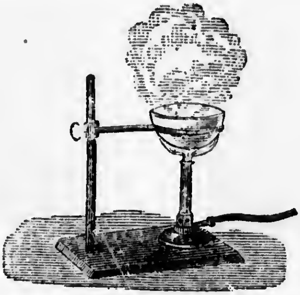
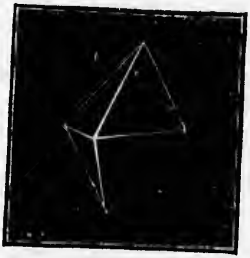


Fig. 18.

in a glass, the crystals will all dissolve on stirring. If we allow this **solution** of the soda to cool, we shall notice that particles of the solid soda begin to



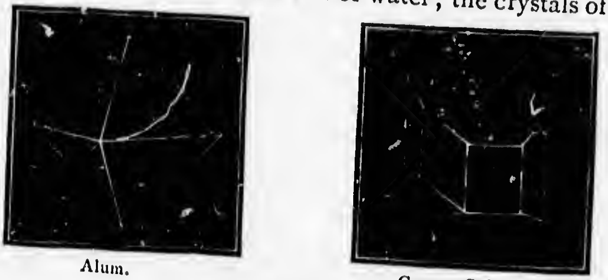
Soda.

Fig. 19.

make their appearance on the sides of the glass in bright shining little masses called **crystals**, or the solution is said to **crystallize.**

If you notice the shape of the crystals, you will find them all alike, only some larger than others.

Now try the same with one ounce of **alum** and one ounce or a test-tube full of water; the crystals of alum will make their appearance by degrees. They have quite a different shape from the crystals of soda, as you see in the drawings.



Alum.

Copper Sulphate.

Fig. 20.

EXPERIMENT 24.—You may do the same with bluestone or sulphate of copper, and the blue crystals will slowly form of the shape shown in the drawing.

Now mix up half an ounce of powdered alum and half an ounce of powdered sulphate of copper, and having mixed these powders well together with the mortar and pestle, dissolve them in one ounce of hot water, and let the solution cool. Carefully notice what separates out. You will see that the colourless crystals of alum are formed, and side by side with them blue crystals of sulphate of copper appear. The two different salts can thus be separated by crystallization; and if we took time enough, we could pick out all the alum crystals and put them on one side, leaving all the crystals of sulphate of copper. This shows how nature separates out things which are different, and we see that many rocks and minerals are formed in the earth by crystallization. Thus we find calc-spar, fluor-spar, heavy-spar, fel-spar, and quartz, all crystalline minerals which have, in different ways (and we cannot always tell exactly how) been produced in the earth by crystallization.

WATER. § X.

24. Rain is distilled Water.

If we think where rain comes from, we shall soon see that rain water is the purest kind of water which we find on the earth. Rain falls from the clouds by a condensation or liquefying of the moisture which is in the air. When the hot winds blow over the ocean, these hot winds take up much moisture from the ocean as **vapour** or **steam,** just as the steam passes over from the retort; and when this hot and moist air gets blown to a cooler place, it gets cold and cannot contain so much moisture in the form of vapour as when it was hot, **so that this moisture is deposited in drops as rain.** Hence rain-water is distilled water, and you will see that a gigantic system of distillation is going on all over the globe; and if you reflect for a little, you will understand that every drop of running water on the globe has once been distilled as rain from the ocean to which it again returns.

25. Suspended and dissolved impurities.

But does the water running from our springs, our streams, and our rivers into the ocean take anything else back with it? Why, you will at once say—Yes, certainly, it washes away sand and soil and dirt into the sea. This you can see if you take some river-water, even the clearest, and let it stand a little; some sediment will separate out and sink to the bottom. This sand and dirt which the rivers carry out into the sea can be separated by **filtration**, that is, by passing the dirty water through a piece of porous paper, blotting or filter-paper, placed in a funnel as shown in fig. 21, or by filtering through sand or through a sponge or through charcoal, as is usual in the water-filters we employ in houses.

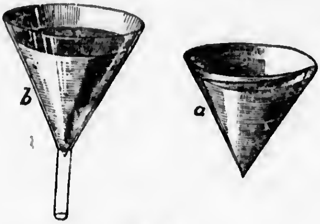


Fig. 21.

Experiment 25.—Still you will readily understand that only those substances which are **suspended** in the water as solid particles can thus be got rid of. No process of filtering, however perfect, can get rid of **dissolved** matter. Add a few drops of blue indigo solution to water, and filter this through a paper-filter; you will not be able to get rid of the colour, because the indigo is dissolved in the water. In order to get the water free from blue indigo, it must be distilled in a retort.

26. Hard and Soft Waters.

Experiment 26.—The water running back to the ocean takes, however, away with it **substances in solution.** If we boil down a pint of any clear spring or filtered river water in a clean porcelain basin, so as to drive off all the water, we shall always find that **some solid residue** is left; whereas, if we boil down a pint of distilled water, **no solid residue** will remain. This is because the rain-water, falling on the ground and trickling through the soil and over the rocks, always finds something which it can dissolve, and which it takes away with it. Thus the sea is constantly having soluble matter carried into it from the land, and it is becoming, though very slowly, more impure.

Of course the kind of substances which the rain-water takes up in solution on its road to the sea will depend upon the kind of rock or soil through which it passes, and also, you will say truly, upon the sort of dirt which people living near throw in. Some springs are even more salt than the sea itself, because the water which supplies them flows over a layer or bed of solid salt inside the earth.

Many spring and river waters are said to be **hard,** whilst rain-water is always **soft.** A water is hard when soap does not at once form a lather with it, but a sediment or curd is produced. Let us see if we can make out why this is, and for this purpose we must try an experiment.

27. What makes Hard Water.

EXPERIMENT 27.—Take a little powdered gypsum or plaster of Paris, and put a pinch of this into a large bottle full of distilled or rain (soft) water. Then shake the water and the powder well together for some time, and afterwards filter the whole through a paper-filter. The water will be quite clear, but it has become hard; this you may tell by trying to wash your hands with soap in this water, or, better, by first dissolving some soap in hot water (as is done for making soap bubbles), and then dropping a little of the clear solution of soap into the hard water, when you will find that the soap does not make the water lathery, but curdy, until after you have added more soap solution, when the froth appears.

Hence we learn that spring and river water may become **hard by containing gypsum** or sulphate of lime in solution. If you boil the water which you have thus hardened with gypsum, no change will occur; the boiled water on cooling will be as hard as before.

WATER. § XI.

28. Hard Chalk Water is softened by boiling.

There is, however, another kind of hard water about which we have to learn. We have already learnt (Experiment 7) that the air from the lungs contains carbonic acid gas, and that when you blow the air out of the lungs through some clear lime-water a white insoluble powder called chalk or carbonate of lime is formed in the water, which soon becomes quite milky.

EXPERIMENT 28.—Repeat Experiment No. 7, but blow a great deal more air through the lime-water than you did before. If you go on long enough—perhaps for five minutes—you will see that the milkiness begins to disappear, and the water becomes clearer; you may not be able to get it quite clear, but you can now filter the liquid through a paper-filter. A clear water will come through, which, however, you will find (by trying the soap experiment) is quite **hard.** What now has happened? Why, the carbonic acid from your lungs has the power of dissolving the chalk (which you know does not dissolve at all in pure water); and thus we get a clear water which is **hard,** because it contains **chalk dissolved in carbonic acid.** Now you know that carbonic acid is a gas; if we boil the water which we have just hardened, all the carbonic acid gas will be driven off, and the chalk which was dissolved in the carbonic acid will be thrown down as a white powder. This you can easily see by boiling the hardened water in a glass flask. If you filter this boiled water, you will find (by the soap test) that it is no longer hard, but has been **softened** by **boiling.** Another way in which water hard with chalk dissolved in carbonic acid can be softened, is to add clear lime-water to the hard water; the lime unites chemically with the carbonic acid, forming chalk or carbonate of lime, which precipitates or falls down as an insoluble powder together with the chalk originally present. By this latter plan hard chalk waters can be easily softened on a large scale.

29. The Water of different rivers differs in hardness.

The **hard chalk** water then differs from the **hard gypsum** water, inasmuch as we can soften the former by boiling or adding lime, whilst the latter cannot be thus softened. Now if the rain-water trickles down through rocks containing gypsum, the springs and rivers in that district (as the river Trent), are hard with gypsum. The rain, however, although purer than any other form of running water, is not quite pure, for it contains carbonic acid gas dissolved in it, which it gets from the air (see Experiment 9). Thus it happens that when rain-water passes through a limestone district, or through chalky rocks or soil, the carbonic acid dissolves some of the chalk, and we get (as in the Thames) water hard from chalk. The crust or deposit often found in kettles or boilers is generally nothing more than this chalk, which slowly separates out on boiling the water and sticks to the bottom or sides of the kettle as a hard crust.

If the rain passes through a granite district (as the Dee in Scotland), where there is no chalk or gypsum, then the water remains a soft water, because it cannot take up and dissolve any hardening substance from the soil.

30. Surface Water of towns impure.

If water flows through a town or near sewers, it becomes impure from admixture with the drainage from houses, and is rendered quite unfit for drinking purposes; indeed, it may thus become poisoned, and the cause of disease. Sometimes the most clear and sparkling water may contain **sewage-impurity**, if drawn from the neighbourhood of towns or drains. It is for this reason that most of our large towns are now supplied by **pure water collected in reservoirs** at a distance from the towns, and brought into each house by iron or lead pipes, so that it cannot become spoilt by mixing with drainage water.

31. Water dissolves Gases.

Gases will also dissolve in water, some kinds much more than others. We have seen that carbonic acid gas from the air dissolves in rain-water, and in soda-water there is so much of this gas dissolved, that when the cork is taken out the gas flies out. Even the air dissolves in water, and the dissolved oxygen gives to spring-water its pleasant fresh taste. If you boil the spring-water, the dissolved air flies off, and when cooled again you will find the water tastes flat and insipid. The dissolved oxygen in sea-water is essential to the life of fishes, for they need oxygen for their breathing as much as animals which live in the air. Where do they get the oxygen ?—not from the oxygen which is combined with hydrogen to form water, but from the oxygen gas which is dissolved in the water. Fishes pass large quantities of water through their gills, and in passing through they extract the oxygen. If you throw a live fish into cold water which has been well boiled and not exposed to air, the fish will die, because there is no dissolved oxygen in the water for it to breathe.

EARTH. § XII.

32. About Earth.

We have now learnt a little about Fire, Air, and Water: let us next see what we can learn about Earth, or the solid matter of which our globe is made up.

Fire, Air, and Water are somewhat simple things:—

Fire is the heat given off when bodies burn or combine chemically.

Air is the mixture of two gases, oxygen and nitrogen, which exists around us and which we use in breathing.

Water is the liquid which surrounds the **Earth,** and is composed of two gases, oxygen and hydrogen, chemically combined together.

Earth is a much more difficult and complicated subject, and we can only learn a very little of the Chemistry of Earth in this book.

To begin with, the solid Earth, as we call it, is only solid because it is not hot. All solid things can be melted and made liquid, if only they are made hot enough. Hard iron can be melted in a furnace and poured out like water, glass can be melted and cast into plate; so all the solid rocks and stones can be melted and made liquid, like water, and even boiled away like water, and **driven off in vapour,** if we only heat them enough. In reality, the inside of the earth is hot enough to melt rocks; and in volcanoes (or burning mountains) we often see that white-hot liquid rock (called lava) is pressed out, and sometimes runs out over a town, as at Herculaneum, near Mount Vesuvius, and burns up and buries all that comes in its course.

Let us take up some different kinds of earthy bodies, and see what they are made of and what we can get from them.

33. Preparation of Carbonic Acid Gas from Chalk.

Experiment 29.—Take a few pieces of chalk or limestone or marble (for these are all the same chemical substance); put them into a bottle fitted with a cork, bent tube, and tube funnel; pour some water into the bottle, and then add a little "hydrochloric acid." You will notice that a bubbling takes place near the chalk, and if you dip the end of the bent tube under water contained in a glass, bubbles of gas will pass through the water. Change this glass for an empty bottle, and let the gas pass from the tube into this bottle. After a few minutes plunge a burning taper into the bottle into which the gas has passed, it will be instantly extinguished. Next pour some clear lime-water into the bottle, it will be turned milky. Then put the burning taper at the bottom of another bottle containing air and **pour** the gas from the other bottle (as if it were water) on to the burning taper; soon you will see that it is put out. What is the gas we have got from chalk or marble? It is carbonic acid gas, for it puts out a flame, it makes lime-water milky, and it is so much heavier than air that we can pour it from vessel to vessel like water. This carbonic acid gas is combined in the chalk, and when we add another acid, this gas comes off. What else does the chalk contain? Let us put a piece of chalk or limestone or marble into the fire, so as to heat it gently, and then notice what happens.

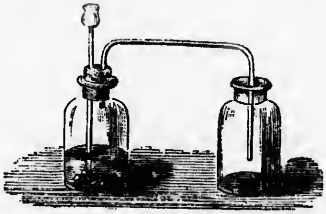


Fig. 22.

If we take the stone out of the fire, we see that it has been altered by being burnt. If we pour acid upon it, bubbles are not given off; it has therefore lost its carbonic acid by being burnt. But if we pour water on it, we notice that the solid substance falls to powder and becomes hot enough to make the water boil. Now what has happened is that, by heating, the limestone or marble has lost its carbonic acid and **quicklime** is left (and this is what happens in the lime kilns); and when we pour water on to quicklime, it is **slaked**, or combines with the water. Hence we have learnt that **chalk** or marble is a **chemical compound of lime and carbonic acid**, and also that from an earthy substance we may be able to get a gas.

EARTH. § XIII.

34. Preparation of Oxygen Gas.

Experiment 30.—Next we will take another earthy substance, not so common as chalk, but one

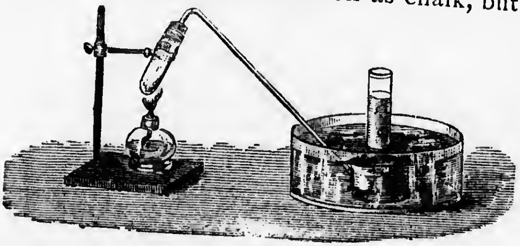


Fig. 23.

which will teach us some important lessons. We will put a little of this red powder out of the bottle labelled "Mercury Oxide" into a little tube of hard glass, and fasten to it a cork and bent glass tube, and fix this in a holder. Then heat the red powder—it will soon get dark-coloured, and then a bright white shining substance will be deposited on the cold sides of the tube. Bubbles of gas will be seen to come off at the end of the tube, and these can be collected in a tube filled with water placed in the trough. We can then test to see what this gas is, and by bringing a red-hot splinter of wood we shall see that this gas is oxygen gas, because the red-hot spark is at once rekindled. Now we may go on heating the red powder until it has all disappeared or is all converted into oxygen gas and the bright shining substance which collects in the tube. Let us find out what this substance is. When all the red powder has disappeared from the bottom of the tube, we take the tube and cork out of the water to prevent the water going back into the tube when we take away the lamp. Now when the whole is cold scrape down the shining deposit with a little piece of wood, and you will find that bright liquid drops of metal can be shaken out of the tube. This metal is **mercury** or **quicksilver.**

Now we have learnt that this red powder can be split up into two substances by heating it: (1) Oxygen gas; (2) The metal Mercury. Not only does this red powder, wherever it may be got from, always yield mercury and oxygen on heating, but the same weight of this red powder always gives the same volume of oxygen and the same quantity of mercury.

You see why this is called **oxide of mercury**

—because it is a chemical compound of oxygen and mercury. Nobody could tell that this red powder contained these two quite different substances! this is a thing which can only be found out by trial or experiment. Chemists have found by weighing the red powder, and the mercury and oxygen which it yields, that 216 pounds' weight of red oxide of mercury always yields 200 pounds of metallic mercury and 16 pounds' weight of oxygen. So here again we have proof that **the same chemical compound always possesses a fixed and unalterable composition.**

35. Metals become heavier by oxidation.

Almost all the earthy and solid rocks and bodies which we see around us contain oxygen combined with something else, forming oxides. Thus all the **metals,** such as iron, copper, silver, zinc, lead, will combine like mercury with oxygen to form oxides, and the oxide will always be heavier than the metal contained in it, because there is also the oxygen, which has weight.

EXPERIMENT 31.—To show that this is the case, take a small horseshoe magnet, and dip the ends of the magnet into fine iron filings, which will stick to the magnet, forming a kind of small brush. Then hang up the magnet, with the filings on it, on one end of the beam of the scales, and accurately balance the other pan with weights. Now place the flame of a lamp underneath the filings as they hang on the magnet; you will see that the filings take fire and burn—that is, they are combining with the oxygen of the air to form **oxide of iron,** which is the same thing as **iron rust;** and, if you get enough filings to stick to your magnet, you will see that the scales

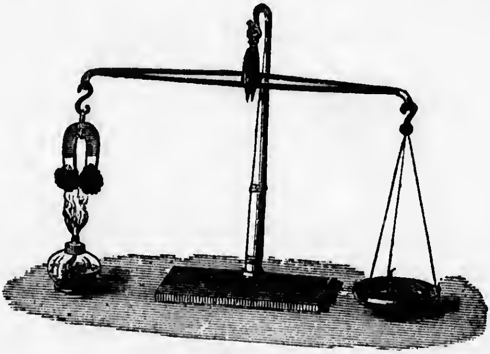


Fig. 24.

will no longer be balanced, but that the iron rust is heavier than the filings.

36. Metals contained in earthy substances.

So we learn from these two last experiments that an earthy-looking substance may contain a bright metal. Let us make one or two more experiments to show this.

EXPERIMENT 32.—Take a small crystal of "bluestone," or sulphate of copper; dissolve this in some hot water in a test-tube; then place the clean blade of a knife, or any piece of bright iron, into the blue liquid. In half a minute take out the bright iron and you will see that it is coloured red where it has dipped in the blue liquid; and if you rub this you will get the bright red colour of **metallic copper.** Put the iron back again, and leave it for some time in the blue liquid, when you will find that the blue colour will have disappeared, and much copper will be deposited as a brown powder; and on putting a piece of clean iron in the solution, no further red deposit will be formed, showing in two ways that all the copper has been thrown down from solution.

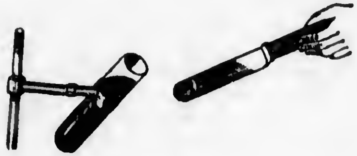


Fig. 25.

EXPERIMENT 33.—Take half an ounce of the white solid labelled "Lead Acetate," commonly called sugar of lead, and put it with some water into a small clean glass, when it will all soon dissolve; tie a small bit of zinc by a thread to a bit of wood,

Fig. 26.

so that when the wood rests on the top of the glass the zinc hangs in the liquid. Allow this to stand for some hours, when crystals of **metallic lead** will be formed on the zinc, and form a tree-like growth, showing that the white crystals contain metallic lead.

EARTH. § XIV.

37. What is Coal?

Next let us try to find out something about coal. **Coal,** we know, contains **carbon,** for we saw that it burns and yields carbonic acid gas by combining with the oxygen of the air. As you learnt in the Introductory Primer, coal is got from "pits" or "mines," and it is found sometimes deep down in the earth, and sometimes at or near the surface. A great deal might be said about coal—about how it was formed, what it contains, what we can get from it, and what we do with it.

1. How was coal formed? Though it may seem strange, it is still true, that coal is the remains of plants which grew long ago on the surface, but which have been buried down deep in the earth. When you go down a coal-pit you will see the roof and floor of the passages covered with impressions or casts of leaves and other parts of plants, showing that plants have been buried here; and if we slice a piece of coal very thin indeed, we see in the coal itself marks which show us that it has all been vegetable matter.

2. What does coal contain, and what can we get

from it? Coal contains carbon: if it burns with a clear flame we know that carbonic acid gas is formed; and if it burns with a smoky flame we can get black **soot**, or carbon, from the coal. The coal contains, however, other things besides carbon; it contains hydrogen as well.

38. Manufacture of Coal Gas.

EXPERIMENT 34.—Powder a little coal and put it into the bowl of a common long tobacco-pipe; then cover the top well with a stopper of moist clay (made by mixing the powdered Stourbridge clay with a little water), and let the clay dry well. After it is well dried, fasten the bowl of the pipe over the flame of the gas-lamp. Soon a yellow smoke will come out at the end of the pipe, and this yellow smoke will burn with a bright flame when a light is brought to it. This smoke is **coal gas**, but not purified like that which we burn in our houses. Now push the end of the pipe under water; you will see that bubbles of gas come off, and if you place a test-tube full of water with mouth downwards over the end of the pipe, the

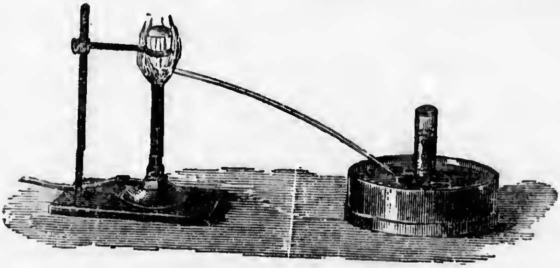


Fig. 27.

bubbles of coal gas will collect, and the tube may be filled with gas, which will burn when you bring a light to it. This coal gas contains **carbon,** for you may get black soot from the flame of this gas when it is burning, and because **carbonic acid gas** is formed when the gas burns, as you may show with the lime-water test: it also contains **hydrogen,** because if you hold a dry clean glass over a flame of coal gas, drops of water will collect in the inside of the glass, showing that the hydrogen of the coal gas has united with the oxygen of the air to form **water.**

You have already learnt in the Introductory Primer that coal gas is colourless and invisible, that it is lighter than air, and that it is inflammable. Try to think what experiments you can make with coal gas to prove that this is the case.

All the coal gas which we use in our towns is made in this way. Instead of tobacco-pipes, large ovens made of brick or sometimes of iron are used and these are called **retorts;** instead of a pinch of coal, many thousands of tons are made into gas; instead of a test-tube to collect the gas in, enormous **gas-holders** made of iron-plate are used.

Now when the pipe is cold take off the clay, and you will find some grey **coke** in the bowl; this is some of the **pure carbon** of the coal which is left behind. Some of the carbon and all the hydrogen of the coal has gone off as **gas,** or **water,** or **tar,** for all these things are formed when coal is **distilled** or heated as we have done.

There are many different kinds of coal, some of which are not so good for gas-making as others, because some contain more carbon and less hydrogen than others, and therefore give less gas and more coke.

Besides coal gas we can get many other things from coal. Thus we get the **tar** which is used to tar ropes, sails, and fishermen's nets, to prevent them from rotting in the salt water; also **pitch,** which is used for **asphalting** pavements; and, what is more wonderful, we get from coal those splendid bright violet and crimson colours, mauve and magenta, which you see in the shop windows. How these colours can be got from coal you cannot at present understand.

39. Uses of Coal.

Of the importance of coal it is difficult to give you an idea in a few words. Try to think what England would be without coal! Almost all our manufactures depend on our having cheap coal. Our comfort, or rather our very existence, in the winter, depends on our supply of this essential article. Where should we be without railroads or steamboats? and yet these both depend on our having coal. Coal is not found everywhere in Great Britain. In those districts where coal is found great industries have sprung up; where no coal is found the country is purely agricultural. Thus in Lancashire we have **coal** and the **cotton trade**; in South Wales we have **coal** and the **iron trade**; in Yorkshire we have **coal** and the **wollen trade**; but in Kent, and Essex, and Sussex, where there is no coal, we do not find great centres of manufacture; in these counties the people chiefly live by farming.

EARTH. § XV.

40. Coal Cas and Flame.

Let us now try a few experiments with coal gas and see what we can learn about **Flame.**

Experiment 35.—Why does the flame of hydrogen (see Experiment 18) give off so little light, whilst the flame of coal gas gives off so much? A simple experiment with the **Bunsen gas-burner** will soon explain this. If you stop up the holes at the bottom of the lamp with your fingers, you will see that the gas burns with a **luminous** flame; if you remove your fingers, the flame loses its brightness and burns blue. This is because **carbon** or soot in a finely-divided state is present in the bright flame, but not present in the blue flame. Hold a piece of white paper for a few seconds over the bright flame, it will be smoked; but when held over the blue flame there will be no smoke. In the bright flame the combustion (or burning) is incomplete, and solid particles of carbon are separated out in the flame and cause the flame to be bright; in the blue flame all the carbon is at once burnt by the air which rushes through the round holes and mixes with the coal gas before the mixture burns at the top of the lamp.

Fig. 28.

Experiment 36.—The different parts of a common candle flame are well worth study and teach us much. If you carefully look at the flame of a candle burning steadily you will see that the flame consists of three parts:—

1. A blue scarcely visible outer zone, or mantle, where the combustion is complete.

2. An inner bright or luminous zone, where soot is separated out and the light is given off, and where the combustion is incomplete.

Fig. 29.

3. A black cone in the inside, consisting of the unburnt gas given off by the wick.

The candle is in fact a small gas-works, the wax or tallow is the material which is distilled, the wick is the retort where the distillation goes on, and higher up and outside of this the gas burns.

You can show that this black cone consists of unburnt gas by taking a small bent piece of glass tube and putting the end into the black centre of the flame. the unburnt gases will pass up the tube and may be lighted at the other end. (See fig 29.)

41. Explosions in Coal Pits—how caused and how prevented.

You have all heard of the dreadful accidents which sometimes happen in coal pits from explosions of **fire-damp**, or a kind of coal gas, which, when it is mixed with air, explodes or burns suddenly and kills the miners. As the pits are dark the miners are obliged to take lights with them to see to do their work and get the coal, and when the gas or fire-damp rushes out from the coal it mixes with the air, and the mixture takes fire at the miners candles, and it explodes and does great damage. These horrible explosions can be prevented by using **Davy's Safety-Lamp.** Let us try if we can learn why this is.

EXPERIMENT 37.—Take a piece of common iron wire gauze, and bring it close over a gas-burner or the Bunsen's lamp; then turn on the gas, and light it on the top of the gauze; next remove the gauze several inches above the burner; the flame does not pass through the wire gauze (fig. 30). Why is this? **Because the metallic gauze so quickly takes away the heat that the gas will no longer burn.**

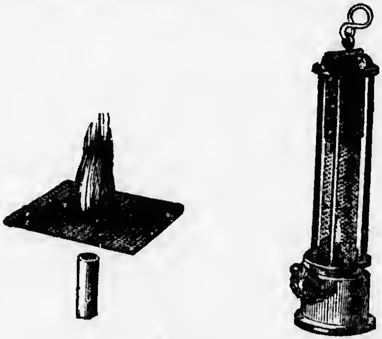


Fig. 30.

Suppose now we were to place such wire gauze quite round a flame; we should see the flame burning inside the gauze; it would give light, and it would get air to burn through the meshes of the gauze; but **no flame can pass through** the gauze, and therefore if we take such a **safety-lamp,** like the one drawn in fig. 30, into a mine where there is fire-damp, the gas in the mine cannot become lighted, because the flame cannot pass through the wire gauze. This is the reason why Davy's safety-lamp has saved so many lives.

In fig. 30 you have a picture of the lamp; you see the flame burning inside the wire-gauze case, which is screwed tight on to the brass oil-can at the bottom. You learn how such a simple scientific principle as the one I have just explained may be made the means of saving thousands of lives, and render it safe to get the coal which we need so much.

ELEMENTS AND COMPOUNDS. § XVI.

42. The preceding experiments have taught us much respecting some of the common kinds of earthy substances which we meet with. These are, however, only a very small portion of the experiments which chemists have made, and by which they have learnt all that they know about the composition of the earth. It is only by examining and experimenting that we can learn anything in chemistry, and it is the business of the chemist to **try** and **test** the properties of every kind of substance which comes within his reach, to see what it is made of, and what kind of substances it contains.

In this way testing all bodies, whether they come out of the air or out of the sea or out of the inside of the earth, or whether they are of mineral or of vegetable or of animal origin, chemists have found that all substances they meet with may be divided into two great classes:—

1. **Simple bodies, or Elements; substances out of which nothing different can be got.**
2. **Compound bodies; substances out of which two or more different things can be got.**

43. Let us look for some examples of simple and

compound bodies; first among the **gases.** Oxygen gas is a **simple body,** or an element; nothing else can be got from oxygen. Hydrogen gas is also an element for the same reason. But coal gas is not an element, it is a **compound,** for we can split it up into or get out of it two quite different substances, viz., carbon or soot, and hydrogen gas. Carbonic acid gas, too, we have learnt is a compound of carbon and oxygen gas. So for liquids; the metal mercury is an **element;** we cannot get out of it anything different but the bright shining liquid metal: water, however, is a **compound,** for, as we have seen, we can in many ways prove that water contains the two elements oxygen and hydrogen. In like manner, many **solids** are elements or simple bodies, whilst many are compounds; thus, red oxide of mercury is a compound, for we can get from it metallic mercury and oxygen gas; chalk is a compound, for we can get from it carbonic acid and lime; common salt is a compound, for we can get the yellow gas chlorine from it, and likewise a metal; so is "bluestone," because we can get bright red copper and also sulphuric acid from it. But **sulphur, carbon, phosphorus, copper, iron, silver, gold,** and many others, are all solid **elements** or simple bodies, for out of these chemists have not been able to get anything different. Nor have chemists ever been able to change any one of these elements into any other one.

44. By continually making experiments on the substances they see around them, chemists have found that everything which exists above, or on, or below the earth's surface, is made up of one or more of **sixty-three elementary bodies.** Some of these are met with as gases, as oxygen; some as liquids, like mercury; most, however, occur as solids, like sulphur and iron. Many of these elements are very common, and are found in enormous quantities, both as elements, or in the **free state,** and also **combined**; thus, for instance, oxygen is contained in the free state as a gas in the air, but combined with hydrogen to form water, and with the other elements to form oxides. Many of the elements are however found very seldom, and only in very few places, and these are generally not used in the arts or manufactures. Still we have no right to consider these elements unimportant and useless, although we cannot in these lessons do more than speak of those which are found in larger quantity.

For the sake of simplicity we divide the elements themselves into two classes; those which are **metals,** such as **iron, copper, gold, silver**; and those which are **non-metals,** such as **oxygen, sulphur, carbon.** The difference in appearance between things which are metals and things which are not metals will be seen at once by looking at specimens of the above elements.

There are only fifteen non-metals, whilst we know altogether of forty-eight metals.

Here is a table containing the names of **the most important elements**:—

Non-metallic Elements	*Metallic Elements.*
Oxygen.	**Iron.**
Hydrogen.	**Aluminium.**
Nitrogen.	**Calcium.**
Carbon.	**Magnesium.**
Chlorine.	**Sodium.**

Non-Metallic Elements.	*Metallic Elements.*
Sulphur,	**Potassium,**
Phosphorus,	**Copper,**
Silicon	**Zinc,**
	Tin,
	Lead,
	Mercury,
	Silver,
	Gold.

These sixty-three elements all possess different properties, by means of which they can be recognized and separated one from the other. Some, however, resemble one another more than others; thus, tin and lead are more like each other in their properties than are oxygen and hydrogen. Now when we examine the way in which these elements unite together to form compounds, we find that **the most unlike elements combine** together Thus, tin and lead do not form any compound differing in essential properties from either of the two metals; but, oxygen and hydrogen being unlike, unite to form water, a body quite different from either of the component elements It is true throughout that **chemical combination takes place most readily between those bodies which least resemble one another.**

NON-METALLIC ELEMENTS. §XVII.

45. Now let us learn about the properties of these commoner elements in the order in which they are written in the table.

Oxygen is a colourless, invisible, tasteless gas. It exists in the **free state** in the air, mixed with about four times its bulk of nitrogen gas. It combines with all the elements (with one exception) to form **oxides.** When oxygen combines with other elements **heat** is evolved, and often **light,** and the substance is said to **burn.** Oxygen is contained in all rocks, sand, soil, and minerals. More than half the weight of our whole earth consists of oxygen. Oxygen is necessary for the life of animals; they breathe it, and use it to oxidize and purify the blood and to keep up the animal heat.

We can get pure oxygen gas by heating many compounds which contain it; thus by heating red oxide of mercury in a tube, or by heating chlorate of potash in a flask, we can test for oxygen by plunging a red-hot splinter of wood into the gas: if oxygen be present, the splinter will burst into flame.

To make oxygen gas on rather a larger scale than is described in Experiment 30, we may take half an ounce of powdered chlorate of potash, and mix it with enough black oxide of manganese to make it black. Then place the powder in a flask furnished with a perforated cork and long bent tube, placing the flask on a ring of the retort stand so that you can gently heat the mixture, and then collect the gas as it comes over in bottles placed in the pneumatic trough, as shown in fig. 22.

You may show—

1. That a taper stuck on a wire having a red-hot wick will be rekindled when plunged into the bottle of oxygen, and then prove that carbonic acid is formed by pouring in lime-water.

2. That a piece of red-hot charcoal burns brightly in oxygen, likewise forming carbonic acid.
3 That a small bit of sulphur melted and allowed to burn on the spoon burns with a brilliant blue flame when plunged into oxygen.
4. That a very small bit of dry phosphorus put in the spoon and lighted burns with dazzling splendour in oxygen gas.

You may also show that the colourless gas formed by burning the sulphur, and the white fumes formed by burning the phosphorus, are both **acid** substances, because if you pour a little blue litmus solution into each of the bottles used, you will see that the blue solution will turn red.

46. **Hydrogen** is also a colourless, invisible, tasteless gas. It does not occur in the **free state** in the air, but exists combined with oxygen to form **water.** By several ways we can get the hydrogen from water (Experiments 12 and 14), and also show that when hydrogen burns in the air pure water is formed. Hydrogen combines with many other elements—with carbon it forms marsh-gas (or fire-damp), a substance found in coal gas: hydrogen also is found in all acids; thus, in nitric acid, sulphuric acid, hydrochloric acid. Hydrogen gas is the lightest substance we know of, being 14½ times lighter than air, and it has, therefore, been used for filling balloons.

47. **Nitrogen** is likewise a colourless, invisible. tasteless gas. It exists in the **free state** in the air,

We can separate the oxygen in the air from the nitrogen by burning a piece of phosphorus (Experiment 6). Nitrogen also is found in many compounds, in **nitric acid** and **nitre** or **saltpetre,** and in **ammonia** or **spirits** of **hartshorn.** It is also found combined in the flesh of animals. Nitrogen does not unite readily with bodies, and is a very inert substance: it does not burn itself, nor support combustion nor animal life. It is, however, not poisonous, and animals die when placed in nitrogen simply from want of oxygen, that is, they are suffocated.

Nitrogen can be made to combine with hydrogen to form **ammonia,** and with hydrogen and oxygen to form **nitric acid.**

EXPERIMENT 38.—**Nitric acid** can be easily obtained by putting half an ounce of powdered nitre into a retort and pouring on it half an ounce of sulphuric acid. Then put a lamp under the retort, and a flask, kept cool in a basin of water, to catch the acid which comes over. Soon a yellow liquid will collect in the

Fig. 31.

flask. This is nitric acid. It is very sour and corrosive; strong nitric acid will make yellow stains and wounds if it touches the skin. It will turn **blue** litmus solution **red**, because it is an **acid**; and if mixed with an **alkali**, like caustic potash (which has the power of turning **red** litmus **blue**) it loses its acid properties. Take a little **caustic potash** solution and add litmus to it, then gently pour some **nitric acid** in; the blue litmus will soon turn red, because the acid **neutralizes** the alkali. If the water be now boiled away in a small porcelain basin, a white salt will be left, which is **nitre or saltpetre**, made by the chemical combination of nitric acid and potash, the substance which we originally used to make the nitric acid; and if after heating it strongly you dissolve a little of this salt in water, the solution will neither turn red litmus blue, nor blue litmus red: this shows that the salt is neutral.

Acids, Alkalies, and Salts.

From this experiment you learn—

1. That a substance is called an **acid** when it is sour and corrosive, and when it turns blue litmus solution red.
2. That an **alkali** is a substance which turns red litmus solution blue, and has the power of neutralizing acids.
3. That a **salt** is the substance formed when an acid combines with an alkali and forms a neutral body.

Here again we see that **unlike** substances combine chemically with each other. No two bodies can be more unlike one another than nitric acid and potash, and these two unite to produce the well-known saltpetre, totally differing in its properties from either of the two things of which it is made up.

43. **Carbon.**—This is a solid element; we know it in the free state as charcoal, coke or coal. Carbon also exists free as two other quite different sorts of bodies, viz., the colourless hard gem called **diamond,** and the soft body, used for making pencils, called **blacklead** or **graphite.** How can we show that three such different substances as these are **chemically** the same element? Suppose we were to burn a bit of **charcoal** in oxygen gas, we get carbonic acid gas formed; if we burn a bit of **graphite,** we also get carbonic acid gas formed; and if, instead, we take a bit of **diamond** and burn it, we also find that carbonic acid gas is formed. From this we conclude that each of these three things—charcoal, graphite, and diamond—contains carbon. But do they contain anything else besides carbon? No, because if we take the same weight of each—12 grains of charcoal, 12 grains of graphite, and 12 grains of diamond—and burn them separately, we find that we get exactly the **same weight** of carbonic acid, viz., 44 grains, **in each case.** So that, although they look to be such very different substances—the precious gem and common coal—yet they are identically the same chemical element, carbon.

Carbon forms a necessary part of all vegetables and animals. In a piece of wood charcoal you can see the form and texture of the original wood; if a piece of flesh is charred, you soon see the black carbon; if, however, the wood or the flesh is completely burnt, then the carbon all disappears as carbonic acid gas, and only a small quantity of a white ash is left.

Experiment 39.—To show that vegetable matter contains carbon, take a few lumps of white sugar in a glass, and pour on these a little hot water to form a thick syrup. Then pour into the syrup some strong sulphuric acid. You will soon see that the syrup gets dark coloured, and then froths up, and all the white sugar is converted into black charcoal. This is because the sugar contains carbon, which has thus been made visible.

What would be the result if this single element, carbon, had not existed on the earth? Why, then no animal or vegetable being could have existed. So great a change can the absence of a single element produce.

Carbon, however, exists combined not only in the bodies of plants and animals, but also in the air as carbonic acid gas; and from what has been learnt (from Experiment 9), you will understand that this carbonic acid in the air serves as food for all plants. Carbon also exists in many rocks—as carbonic acid in chalk rocks, limestone rocks, and marble.

NON-METALLIC ELEMENTS. § XVIII.

49. **Chlorine** is an element very different in its properties from any of those we have mentioned. It is a yellowish gas, possessing a very strong smell, and if breathed acts as a poison. Chlorine is not found in the free state in nature, but we can get it from a useful compound which contains it—viz., **common salt.** This body, which we use to

flavour our food, and which gives the saltness to sea-water, is made up of chlorine and metal sodium, and common salt is therefore called **chloride of sodium,** or **sodium chloride.**

EXPERIMENT 40.—We can get chlorine from common salt by mixing a little salt with a little powdered black manganese oxide, putting the mixture into a flask, and pouring on to the mixture some sulphuric acid diluted with the same quantity of water. By adapting a bent tube as shown in fig. 32, and by slightly heating the flask, a heavy yellow very strongly smelling gas is given off, and may be collected in the dry bottle.

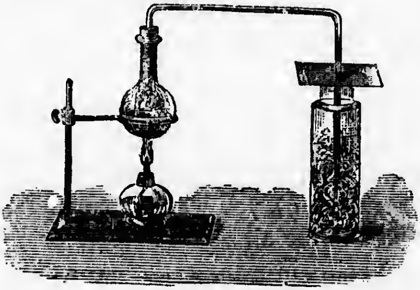


Fig. 32.

This is the chlorine which was combined with the metal sodium in the rock salt: care must be taken not to breathe it, as it causes coughing and inflammation of the throat. This gas combines at once with metals to form **chlorides**; if we throw a little powdered metallic antimony into the bottle containing the chlorine gas, we see sparks of fire, and a white cloud of antimony chloride is formed. Thus we learn that substances can burn not only in oxygen, but also in chlorine gas, and that **heat** is given out whenever chemical combination occurs.

Chlorine also has a strong **bleaching** power, and it is largely used for taking the colour out of cotton and linen cloth. This you can easily experiment by throwing in a bit of wet coloured cotton rag into a bottle of the yellow gas—after a few minutes' shaking the rag will have lost its colour.

Bleaching powder, which is sold in the shops for this purpose, contains chlorine, as you may see by taking a little of this white powder at the bottom of a bottle, and pouring on to it a little dilute sulphuric acid, when yellow chlorine gas will at once be seen above the white powder, and this gas will be found to bleach.

EXPERIMENT 41.—If we mix a little bleaching powder with water, and put a piece of coloured cotton rag into it, the colour will not be discharged; but if we then dip the rag into water containing (or rendered sour with) a little sulphuric acid, the dye will begin to disappear; and if we repeat this once or twice, the rag will become white. This is the plan used by bleachers. The acid in the "souring" sets free the chlorine from the bleaching liquor, and this takes away the colour by destroying it.

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50. **Sulphur** or brimstone is a yellow solid element; we know it in fine yellow powder, flour of sulphur, and in sticks or rolls. If we heat a little bit of sulphur in a spoon over a flame, it first **melts,**

then **boils,** and then takes fire and burns away entirely, giving off a pale blue flame, having the well-known smell of burning sulphur.

In this burning it is uniting with the oxygen of the air to form an oxide of sulphur, which is a colourless gas. Sulphur is used for putting on the ends of lucifer matches, because it easily takes fire and lights the wood. It is also used for making gunpowder, which is a mixture of sulphur, charcoal, and nitre.

Free sulphur is found in the earth in volcanic districts, and comes chiefly from the island of Sicily. Sulphur is found also in combination chiefly with metals, forming **sulphides** of the metals. These sulphides are generally the **ores** of the metals, that is, the substances from which the metals are obtained. Thus the ore of lead, a mineral called **galena,** is sulphide of lead. Sulphur also combines with oxygen and hydrogen to form **sulphuric acid,** a very important chemical compound. This acid is a heavy oily liquid, and is commonly called **oil of vitriol,** and it is made in enormous quantities (many thousand tons every week), and used for a great number of processes—for making alkali, for soap-making, and dyeing, and calico printing and bleaching, and for the preparation of almost every other acid. Sulphuric acid unites with metals to form **sulphates**—thus we have **sodium sulphate,** or Glauber salts; **iron sulphate,** or green vitriol; **copper sulphate,** or blue vitriol; and many others.

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51. **Phosphorus** is an element which does not occur in the free state in nature, but is contained in the **bones of animals** in combination with oxygen,

and the metal calcium forming **calcium phosphate.** When a bone is burnt, a white porous mass is left called bone-ash, and from this phosphorus can be prepared.

Phosphorus, like carbon, exists in two different forms: one is known as yellow or common phosphorus; the other as red phosphorus. These two sorts of phosphorus differ very much in their properties.

EXPERIMENT 42.—Take a small iron tray, placed on a tripod, and carefully cut off a bit of yellow phosphorus as large as a quarter of a pea; this must be done under water, as the phosphorus is a very inflammable and dangerous substance, because it takes fire of itself in the air, and produces serious burns if it takes fire whilst in the fingers. Then quickly dry the bit of phosphorus on a cloth or blotting-paper, and put the dried bit with a pair of tongs or a knife-blade on to the iron tray. Next take a bit of red phosphorus (or the powder) of the same size, and put it also on the iron tray. You will see that the red phosphorus is not kept, like the yellow, under water. The reason of this you will soon understand. Now put the flame of a lamp under the tray; in a few instants the yellow phosphorus (*b*, fig. 33) will take fire and burn with a bright flame, and give off dense white fumes. The bit of red phosphorus (*a*), however, does not take fire, and we have to continue the heat for some time before this red substance catches fire; this it does, however, at length, and then burns

Fig. 33.

exactly like the yellow phosphorus. Thus we see that yellow phosphorus is very inflammable, and must be kept under water to prevent it taking fire with the oxygen of the air, whilst the red variety does not burn at all easily, and can therefore be kept in the air.

EXPERIMENT 43.—Yellow phosphorus takes fire by rubbing it. Take another very small bit, and wrap it in a piece of blotting-paper; then rub it with your boot on the floor, or with a hammer on a piece of wood. You will see that the rubbing causes the phosphorus to take fire and burn. This is the reason that common **lucifer matches** light when they are rubbed. The brown or red tip of the match contains phosphorus; when you rub or strike the match on a rough surface, the varnish which covers the **phosphorus paste** is scratched off, and the phosphorus takes fire and the match burns.

Lately **safety** lucifer matches have been made, which light only on the box. How is this? A little thought and examination will soon teach us. Take one of these safety matches, and try to light it on the sandpaper outside a common match-box, it will not light; but rub it on the brown or reddish-brown paper on the outside of the safety match-box, and it takes fire at once. The explanation is easy: the tip of the safety match contains no phosphorus, but only some substance which will easily cause phosphorus to burn, and therefore it cannot light by rubbing on any rough surface; the paper on the box is covered with some powdered red (or non-inflammable) phosphorus; when you strike the safety match on this red paper, a little of the red phosphorus sticks to the end, and then takes fire with the mixture on the tip.

52. **Silicon** is an element which (like phosphorus) we do not meet with in the free state in nature, although it is contained in enormous quantities in combination with oxygen. Silicon oxide, or **Silica,** is known as **quartz** or **rock crystal,** and it is found in almost all rocks. Sand, sandstone, and flint are also more or less pure silica. Silica forms, with metals, compounds called **Silicates. Clay** is a silicate, so therefore are bricks, pottery and china, which are made from clay. **Glass** is also a silicate; it is made by heating together in a hot fire or furnace a mixture of white sand (silica), lime, and soda, or of sand, oxide of lead, and potash.

The first mixture forms what we know as **plate-glass** or **window-glass**; the second produces **flint-glass.** Silicon itself is a black crystalline substance, and is got by taking away the oxygen from silica.

All the rocks and stones of which the solid earth is made, contain either silicon or some metallic elements, or both combined with oxygen. So you see that the earth is made up of **burnt** or **oxidized substances.** Now let us learn a little about the chief metals which the earth contains.

METALS. § XIX.

53. **Iron.**—We may well begin an account of the more important **metals** with iron, because of all of them iron is the most useful to man. Without iron we should almost be savages; we could have no railroads, nor engines nor machines; no gas-pipes or water-pipes, no tools or knives. There was once a time when men

had no iron, because this most useful substance is not found as a metal, but as an earthy **ore,** from which the metal can only be got with difficulty. In those old days men used tools made of **bronze** or **copper,** and in still earlier times they only used **stone** hatchets and knives. One most useful ore of iron is red iron oxide, called **hæmatite** iron ore. By heating this with charcoal the oxygen is got rid of, and the metal iron remains, and this can be hammered into **bar-iron,** from which we can make horseshoes or spades; and it can be flattened by rolling into flat plates for making ships or boilers. This is called **wrought-iron,** because it can be hammered and wrought, or made, when it is red-hot, into anything which is wanted. This is the kind of iron which we see the blacksmith uses to make nails or horseshoes, or the tyres of wheels; and it is very useful, because when hot it can be **welded,** that is, two pieces of hot iron when hammered together stick firmly together so that they cannot be separated. But there is another kind of iron also very useful; this is called **cast-iron,** because it can be melted, and poured when melted into moulds, and castings then got. Cast-iron is used for making gas and water pipes, for lamp-posts and railings, and large wheels, and the heavy stands for machines, and a great number of other things. Cast-iron is made from **iron ore** and **coal,** and **limestone,** by putting these into large high furnaces, called **blast furnaces,** because the air is blown in to burn the coal and melt the iron by a powerful **blast.**

Cast-iron cannot be hammered when hot, like wrought-iron, into bars or rolled into plates; it is

brittle, or breaks, like glass, into pieces under the hammer. **Cast-iron** is not pure iron, but **contains carbon,** which it gets from the coal; we can burn the carbon away (by a process called puddling), and we thus can get wrought-iron from cast-iron. A third kind of iron is called **steel**; this is used for making razors, knives and tools, because it is both hard and tough, and can be ground so as to have a sharp edge. Steel also contains a little carbon, and can be made either from wrought or from cast-iron.

If we burn iron in the air (Experiment 31) or in oxygen, we get oxide of iron. The same thing is formed when any piece of bright iron is left exposed to air and wet; it becomes **rusty,** and at last will all change to **rust.** Iron-mould on linen is also oxide of iron, or rust.

EXPERIMENT 44.—If you pour a little dilute sulphuric acid on a few iron filings in a test-tube, gas

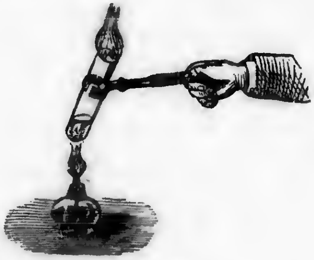

Fig. 34.

will at first be slowly given off; if the test-tube be warmed, the gas will escape more quickly, and it may be lighted at the mouth of the glass. This gas is hydrogen; the iron dissolves in the acid, forming a salt, called sulphate of iron or green vitriol, and the hydrogen of the sulphuric acid is given off. If you fill the test-tube with water, and then filter the liquor through a paper filter, you will get a nearly colourless solution; and if this be **evaporated** or boiled down (fig. 35), crystals of green vitriol will be formed on cooling.

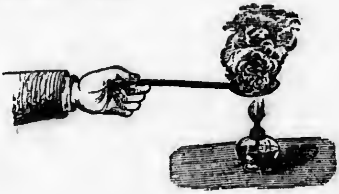

Fig. 35.

We can tell that iron is present if we add a little of this solution mixed with a few drops of nitric acid to a pint of water, by pouring in a few drops of the bottle labelled "potassium ferro-cyanide," or yellow prussiate of potash, when a dark blue colour (of Prussian blue) will be formed.

54. **Aluminium.**—We take this metal next because it is the metal got from **clay**, and therefore is contained in large quantities in many rocks. No one would suppose that a bright, silver-white metal can be got out of common clay, and yet chemists can do so. It is a pity that it is not easy to get rid of the oxygen in the clay, for then we might use the bright metal aluminium for very many purposes. It costs too much to make the metal, although clay is so cheap

and common. When this bright metal is heated in the air, it burns and forms an oxide called **alumina,** the earth of clay.

The white crystals of **alum** contain this metal.

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55. **Calcium** too is a metal which it is very difficult to get in the pure state, although its compounds are very common. Quicklime is calcium oxide; chalk and marble and limestone and coral are all calcium carbonate; gypsum is calcium sulphate; and bone earth is calcium phosphate. So you see that there is plenty of this metal in the earth.

EXPERIMENT 45.—In making carbonic acid from chalk and hydrochloric acid (Experiment 29), the liquid remaining in the bottle is a solution of calcium chloride. If you filter the liquid and boil down the clear solution to dryness, you will find a white dry powder left. This is a **salt** called calcium chloride. We used it in Experiment 20 for drying the hydrogen and collecting the water, as it takes up moisture with great ease. Let a little of the dry powder remain exposed to the air for a few hours; you will then find that it has become liquid, because it has absorbed, or taken up, the moisture which is always present in the air.

If you add some of the clear solution labelled "sodium carbonate," to a little bit of the dry powder of calcium chloride, which you have dissolved in some water in a test-tube, you will see that the two clear liquids at once become milky or turbid. This is because calcium carbonate, or chalk, is produced, and this chalk is insoluble, or does not dissolve in water, as the calcium chloride does, and it is therefore thrown down, or precipitated. This represents what happens:—

We take—

Calcium chloride (soluble in water) and Sodium carbonate (soluble in water);

and we get, on mixing the solutions—

Calcium carbonate, or chalk (insoluble in water) and Sodium chloride, or common salt (soluble in water).

This shows you that some salts of the same metal may be not soluble in water (like chalk), whilst others (like calcium chloride) readily dissolve in water. But you must take care not to fancy that any substance is afterwards present which was not there before; we have here to do only with a **difference of arrangement.** An exchange takes place by which the chalk is formed but the materials of the chalk were present in the original substances.

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56. **Magnesium** is a soft, silver-white metal, which can be made into wire and ribbon.

Experiment 46.—If you hold the end of a bit of magnesium ribbon about six or eight inches long in the flame, the metal will take fire, and burn with a dazzling white light, and a white powder will fall on the ground. This white powder is **magnesia**, the oxide of the metal. Black as well as white fumes will be seen whilst the magnesium is burning. The black fume is not soot, for there is no carbon present; it consists of some of the metal, which is not burnt, but is sent off as a cloud having a black colour; the white fume is the solid oxide magnesia going off in fine dust.

EXPERIMENT 47.—If you collect some of this white powder and warm it in a test-tube, with a few drops of sulphuric acid, the white powder will dissolve; then pour the clear solution into a porcelain basin, and boil off the greater part of the water. On cooling, some long needle-shaped crystals will be found in the basin. These crystals are **Magnesium Sulphate,** or **Epsom Salts**; a compound of magnesia and sulphuric acid.

There are many other compounds of magnesium, some of which are found in minerals and rocks. The metal is never found uncombined, and the process for making it from magnesia is rather a costly one; still it is now used for burning, and for making fireworks and signals, where a very bright light is needed. It keeps bright in dry air, and might be used for many purposes if it could be got cheaply.

METALS. § XX.

57. **Sodium** is the metal which we used (Experiment 13) for getting hydrogen from water. It is very unlike any metal which we see used in the arts; not only cannot we keep sodium in the air, because it at once oxidizes and forms a white powder, but we must not allow water to come near it, as it at once will combine with the oxygen of the water, and set free the hydrogen; but the metal must be kept under **rock oil,** which contains no oxygen. We have seen (Experiment 13) that a bit of this curious metal, thrown on

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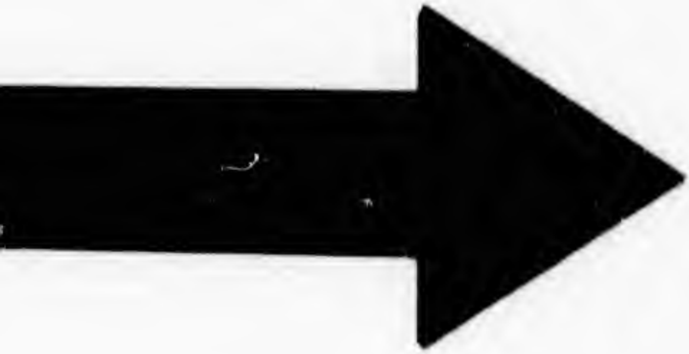

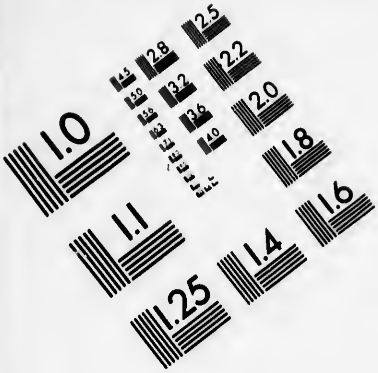

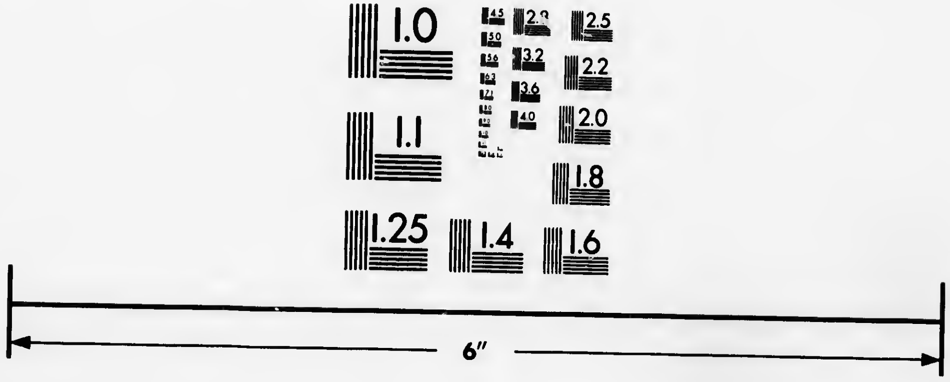
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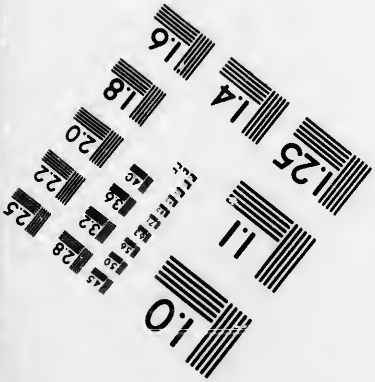

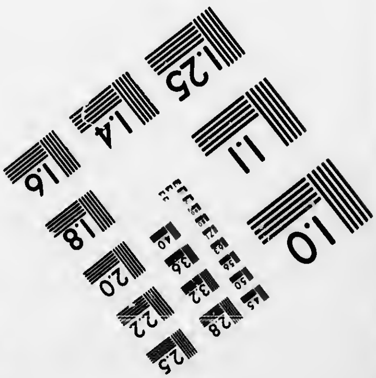

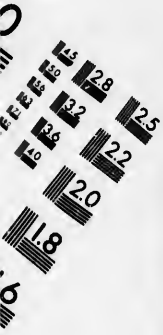
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4.0
2.0
1.8
1.6


1.1
1.0

to water, swims on the surface, and hydrogen is given off; if the water has been turned red with a little red acid litmus, the colour will change to blue after the sodium has disappeared. This is because the **alkali soda** has been produced.

EXPERIMENT 48.—Sodium is a very useful metal to the chemist, for he can by using it get the two preceding metals, magnesium and aluminium. Sodium, as you may be sure, does not occur in the free state in nature; it is made by taking away the oxygen from soda (the oxide of sodium). If you heat a small bit of sodium in a spoon over the flame of the lamp, it will first melt, and then take fire and burn with a bright yellow-coloured flame; white fumes of the oxide (soda) will be given off.

Sodium is the metal of the **soda salts**, a great many of which are very useful and common substances.

The following is a list of a few of the most important:—

Common Name.	*Chemical Name.*	*What it contains.*
Sea, table, or rock-salt.	Sodium chloride.	Sodium and chlorine.
Glauber salts.	Sodium sulphate.	Sodium and sulph. acid.
Washing-soda crystals.	Sodium carbonate.	Sodium and carb. acid.
Chili saltpetre.	Sodium nitrate.	Sodium and nitric acid.

Of these, **rock-salt** is found in largest quantity: it is got from mines, in Cheshire and elsewhere, and many hundreds of thousands of tons are used every year. It can also be got from sea-water by evaporation. From it all the other sodium salts can be got. Thus, if you want to get sodium sulphate or Glauber's salts, you have only to pour sulphuric acid on to common salt; a dense fume of **hydrochloric acid** gas comes off, and sodium sulphate is left; what here happens is this:

We take

Sodium chloride (common salt) and sulphuric acid,

We get

Sodium sulphate (Glauber's salts) and hydrochloric acid gas.

You may easily show that the fumes are strongly acid, by holding a little bit of wet **blue litmus paper** in the midst of the fume, when it will at once go red.

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58. **Potassium** is the metal contained in the alkali potash, and in the potash salts. A small bit of potassium, as large as half a pea, thrown on to water, combines so violently with the oxygen, that the hydrogen at once catches fire and burns, the flame being coloured violet by the **alkali potash** which is formed.

Potash salts are found in many places in the earth, and also in the ashes of plants; and this alkali derives its name because it can be got by boiling out wood **ashes** in **pots.** There are many useful potash salts: soda and potash are called the **alkalies.**

Common Name.	*Chemical Name.*	*What it contains.*
Potashes.	Potassium carbonate.	Potassium and carbonic acid.
Nitre or saltpetre.	Potassium nitrate.	Potassium and nitric acid.
Chlorate of potash.	Potassium chlorate.	Potassium, chlorine & oxygen.

EXPERIMENT 49.—**Soap** is made by boiling animal or vegetable oils or fats with alkali. Soaps containing soda are **hard soaps**; potash gives **soft soaps.** Common fat is boiled with alkali, and thus soap is got. You can easily make soap by pouring half an ounce of castor oil into a thin porcelain

basin with some hot water, and adding some caustic soda; then on boiling the liquor the oil will all disappear, and soap will be formed which dissolves in the water. When it has boiled for a little, throw in a handful of common salt; this will dissolve in the water, and will drive out the soap, which will swim on the surface. When cool, this soap will become a white, hard solid, and may be used for washing your hands. Common oils or fats are generally used; we have taken castor oil, because it is made into soap more easily than ordinary fats.

We next have to speak of several metals which are useful substances, some more valuable than others, but all used for a variety of purposes.

METALS. § XXI.

59. **Copper** is a reddish-coloured metal, used for making kettles, and pans, and boilers; copper wire is very useful, because it is both soft and tough. Metallic copper is sometimes met with in nature; it is then called **native copper**; it is, however, more commonly got from **copper ores**, of which there are several kinds. The most important ore of copper is the compound of copper and sulphur, which we made in Experiment 5. By taking away the sulphur the pure metal copper can be got.

Copper is much used to mix with other metals, and yields useful alloys or mixtures of metal, such as **brass** and **bronze.** When copper is heated in the air, it **tarnishes,** and then becomes covered with a black coating of oxide; and if the heating be continued, all the copper combines with the oxygen of the air, and we get **copper scales** or black oxide of copper, which we used in Experiment 20.

EXPERIMENT 50.—If you take one or two copper turnings in a test-tube, and pour on to them a few drops of nitric acid, dense brownish red fumes will be given off from the nitric acid, and a **blue solution of copper nitrate** will be formed. The copper has combined with oxygen and with nitric acid. One drop of this blue solution, poured into a test-tube full of water, will still give a blue colour when we add ammonia, and thus we can easily test for the salts of copper. Bluestone (Experiment 32), **or copper sulphate,** is a compound of copper and sulphuric acid. You may try the ammonia test with a drop or two of a solution of this substance, and show that it gives the same deep blue colour as the copper nitrate did.

60. **Zinc** is a useful white metal. It is used for covering iron plate, which is then said to be **galvanized iron.** This covering of zinc prevents the iron from rusting in damp air. The chief ore of the metal is **zinc sulphide,** a compound of zinc and sulphur, called **Blende.** Zinc is also used to mix with other metals to form useful alloys; thus brass is an alloy of zinc and copper, and it is, therefore, not a simple or elementary body.

EXPERIMENT 51.—If we dissolve zinc in dilute sulphuric acid (Experiment 15), we get **hydrogen gas** given off and **zinc sulphate** left. Let us filter some of the liquid got in making hydrogen, and then evaporate it down. On allowing it to cool, white crystals of zinc sulphate will be formed. Zinc will burn when thin turnings are strongly heated in the air, and a white powder of zinc oxide is formed: in this respect zinc resembles magnesium.

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61. Tin is a bright white metal much used for "plating" iron. Common tin-plate is really iron-plate, which is covered with tin by dipping the iron into melted tin. This coating of tin preserves the iron from rust. Tin is also used for making several useful alloys, such as pewter, Britannia metal, plumber's solder. The most important ore of tin is an **Oxide of Tin,** known as **Tin Stone,** and is found in Cornwall. Metallic tin is got from this by heating it with charcoal, which takes away the oxygen, and the pure metal melts and can be drawn off.

Fig. 36.

Experiment 52.—Take a little powdered oxide of Tin, and mix it with about the same quantity of carbonate of soda, and then put this mixture in a hole made in a bit of charcoal. Now heat this with the flame of a blow-pipe, got by blowing into a luminous gas-flame, made by stopping up the holes at the bottom of the Bunsen burner, as shown in the figure. Soon the mixture will melt, and after heating for some time you then cut that part of the charcoal out with a knife, and rub the whole to fine powder in the mortar. Next wash away all the light particles of charcoal with water, and you will find some heavy bright round grains or globules of white metallic tin remaining at the bottom. In this experiment the oxygen of the tin oxide has united with the carbon of the charcoal to form carbonic oxide gas, which goes off, and the metal tin remains behind and melts with the heat.

62. **Lead** is a heavy metal with a bluish colour; it can be easily melted and cut, and does not rust or oxidize in the air; so that it is very useful for making pipes for gas and water, and for rolling into sheets for covering the roofs and gutters of houses. It is also used for making shot and bullets, because it can be easily melted and cast. Lead ore is found in Wales; it is called **Galena,** and is lead sulphide. The process for getting the metals from the ores is called **smelting**; and the branch of science which has to do with the getting of metals is called **metallurgy.**

There are several very useful compounds of lead.

Common Name	*Chemical Name.*	*What it contains.*
White lead.	Lead carbonate.	Lead and carbonic acid.
Red lead.	Red lead oxide.	Lead and oxygen.
Litharge.	Yellow lead oxide.	Lead and oxygen.
Sugar of lead.	Lead acetate.	Lead and acetic acid.
Chrome yellow.	Lead chromate.	Lead and chromic acid.

White lead, red lead, and chrome yellow are used as paints. You must remember that black lead is the common name for graphite, and that it contains no lead whatever; it is pure carbon.

EXPERIMENT 53.—Add a little solution of potassium chromate to a glass filled with water, to which you have added some lead acetate solution. A splendid yellow precipitate of lead chromate, or chrome yellow, will be produced. This is what happens:—

Before Mixing.		*After Mixing.*
Potassium chromate and lead acetate (both soluble salts)	give	Chromate of lead (insoluble yellow powder) and potassium acetate (soluble).

63. **Mercury** or **quicksilver** is the only simple metal liquid at the ordinary temperature, and it is very valuable for this reason, especially for making **thermometers** (instruments for measuring heat) and **barometers** (instruments for measuring the pressure of the air), about which you will learn in the Physics Primer, and for silvering mirrors. Mercury does not **tarnish** in the air, but it oxidizes when heated, forming **red oxide** of mercury, from which the oxygen can be driven off again by heating it more strongly (Experiment 30). Mercury can be boiled, and, like water, it may be distilled. Like many other metals, mercury and its compounds are very poisonous, but taken in small quantities some of them are used as medicines.

64. **Silver** is a highly prized and valuable metal. It is found in Mexico, Peru, and elsewhere. The

property which makes silver so useful is that it never tarnishes from oxidation, but it goes black when brought near sulphur, as a black sulphide is formed. Silver has been used since the earliest times for making valuable and beautiful articles, and especially as an article of exchange as **silver coin.** English silver coin contains a little copper, added for the purpose of hardening the silver.

EXPERIMENT 54.—Let us see if we can find both copper and silver in a sixpence. Cut a piece of a sixpence, put it into a test-tube, and pour on it some nitric acid. Soon dense red fumes will come off from the nitric acid, and on warming gently the whole of the silver will be quickly dissolved. We have seen (Experiment 22) that silver can be used to detect the presence of sodium chloride, or common salt. Now add some solution of common salt to the solution of silver in nitric acid; a dense **white precipitate** of insoluble **silver chloride** will be thrown down. What happens is this:—

We take	*We get*
Silver nitrate and sodium chloride (both soluble salts),	Silver chloride (a white curdy powder insoluble in water) and sodium nitrate (soluble in water).

Now filter through paper. The clear solution has a bluish-green colour, and contains the whole of the copper. Put a bit of bright iron into the liquid, and a red deposit of metallic copper will soon be seen on iron.

65. **Gold** is a still more valuable metal than silver. It has a beautiful yellow colour, and is found always as **metallic gold.** Lately much gold has been got from California and Australia. Gold is one of the heaviest

metals we know of, and it can be drawn out into very thin wire and beaten out into very thin plates called **gold leaf,** which is much used for gilding. Pure gold is too soft to make coins of, so in England a little copper is added to the gold to make sovereigns, which has the effect of hardening the metal.

EXPERIMENT 55.—Gold does not dissolve in any one acid. Take a leaf of gold and divide it into two pieces; put one piece into one test-tube and one into another; pour upon one a little nitric acid, and into the other a little hydrochloric acid. The gold in neither glass will dissolve; now pour the two together and the metal rapidly disappears, showing that although neither acid by itself can dissolve gold, a mixture of both can do so. Gold never tarnishes in the air or gets stained with sulphur, like silver, so that it has been much used for ornaments as well as for coin from the earliest times.

RESULTS. XXII.

66. Combination in definite proportions.—It will be useful to consider some of the most important results to which the study of fire, air, water, and earth has led us. You have now a distinct idea of some of the different kinds of matter of which the world is made up. You have learnt that all the various things—whether solid, liquid, or gaseous; whether animal, vegetable, or mineral—are composed of one or more of sixty-three elementary or simple substances. No one of these can be converted into any other one, nor has any one of these ever been split up into two different new things.

You have also learnt that these elements unite together to form compound bodies which differ altogether in properties from the original elements, but from which these original elements can again be obtained in various ways. You have learnt that the weight of the compound is always exactly the sum of the weights of the elements, and that in all the chemical changes which take place, no loss of weight ever occurs. We cannot either create or destroy matter.

The use of the **balance** for weighing bodies and for determining the composition of chemical substances has also been made clear to you. Chemists have to weigh everything they wish to examine, and thus to find out—as we did in the case of water in Experiment 20—what weight of each element is contained in the compound.

We found that—

Sixteen parts by weight of oxygen . .	16
and Two parts by weight of hydrogen . .	2
make up eighteen parts by weight of water .	18

and I told you that water always contains its elements in these fixed proportions. The same thing is true for all other chemical compounds—they all contain their elements in fixed proportions. Thus, for instance, chemists have found, by careful weighing, that the red oxide of mercury which we used in Experiment 30, **always contains**

Oxygen . .	16	parts by weight.
and Mercury . .	200	" "
making Oxide of mercury	216	" "

So if I want to get 16 lbs. of oxygen, I must take at least 216 lbs. of the red powder, and if I do not lose any by accident, I shall get exactly the quantity of oxygen I want. And you will understand that by a simple proportion I can calculate the weight of the red oxide which I must take to get any other weight of oxygen.

This great fact of the constancy of chemical combination runs through all the changes we have noticed. If we want to get all the nitric acid we can from the least weight of nitre and sulphuric acid (Experiment 38), we must take 98 parts of sulphuric acid and 101 parts of nitre, and we shall always get 63 parts of nitric acid. And if I burn 24 parts of magnesium wire (Experiment 46), I shall always get exactly 40 parts of magnesia, provided I lose none.

Thus you learn that all the elements combine with each other in fixed proportions by weight, and the numbers representing these proportions are called the

67. Combining weights of the elements.

Here is a list of the most important elements—

Non-Metallic Elements.

Oxygen	O	= 16
Hydrogen	H	= 1
Nitrogen	N	= 14
Carbon	C	= 12
Chlorine	Cl	= 35
Sulphur	S	= 32
Phosphorus	P	= 31
Silicon	Si	= 28

Metallic Elements.

Iron	Fe	= 56
Aluminium	Al	= 27
Calcium	Ca	= 40
Magnesium	Mg	= 24
Sodium	Na	= 23
Potassium	K	= 39
Copper	Cu	= 63
Zinc	Zn	= 65
Tin	Sn	= 118
Lead	Pb	= 207
Mercury	Hg	= 200
Silver	Ag	= 108
Gold	Au	= 197

with their **combining weights** and their **symbols** attached to them. The letter placed after the name of each element is the symbol or short way of writing the name; thus, instead of writing the word phosphorus, I may write the letter P. For these symbols, the first letters of the words are generally taken; but in some cases the Latin and not the English word is used; thus Fe stands for iron, from the Latin **ferrum**, Ag for silver, from the Latin **argentum**. The numbers placed after the symbol of each element represents the **fixed proportion**, by **weight**, in which that element combines with others. Each of these numbers has been found by experiment, that is, by the **analysis** of the compounds which that one element forms with others. Thus we find, when we analyse the red oxide of mercury, that it contains 16 parts by weight of oxygen to 200 parts by weight of mercury, to form 216 parts by weight of the oxide; or when we heat sulphur and copper together (Experiment 5) until they combine, we find that exactly 63 parts by weight of copper unite with 32 parts by weight of sulphur to form 95 parts by weight of copper sulphide; and if more than this quantity of one of these elements had been taken, it remains uncombined. Now the same weight of oxygen (16 parts) unites with other metals to form oxides, and the weight of metal with which it unites is either the combining weight of the metal, or some weight bearing a close relation to the combining weight. Thus 16 parts by weight of oxygen unite with 56 parts by weight of iron to form an oxide of iron; with 40 parts of calcium to form an oxide of calcium, called common lime; with 65 of zinc, 118 of tin, 207 of lead, to form oxides of these metals.

Our chemical short-hand means, however, more than I have yet told you. If I write the symbol O, or the symbol Hg, I signify thereby not any weight of oxygen or of mercury, but exactly the combining weights of these two elements. O means 16 parts by weight of oxygen, and no other weight; Hg means 200 parts by weight of mercury, and no other weight; and therefore I have written $O = 16$ and $Hg = 200$ in the table.

Now supposing I want to write the chemical symbol for a compound, I have only to put the symbols of the elements it contains alongside of one another. Thus HgO signifies oxide of mercury; and this symbol not only tells me that the compound contains oxygen and mercury, but it tells me **how much** oxygen and **how much** mercury the body contains, because I remember that O means 16, and Hg means 200; so that the chemical symbol, or formula, is most useful as expressing not only the **qualitative** composition (or what the body contains), but also the **quantitative** composition (or how much of each thing the body contains). Thus, again, CaO means calcium oxide, or lime, and exactly 40 and 16, or 56 parts by weight of lime; ZnO means zinc oxide, but 65 and 16 or 81 parts by weight; whilst H_2O signifies water, being twice H, or two parts by weight of hydrogen combined with 16 parts by weight of oxygen to form 18 parts by weight of water.

68. Some of the elements combine together in different fixed proportions, forming several compounds.

Thus nitrogen and oxygen unite to form five different compounds, as follows:—

The first compound, called nitrogen mon-oxide, contains 28 parts by weight of nitrogen, to 16 parts by weight of oxygen.

The second compound, called nitrogen di-oxide, contains 28 parts by weight of nitrogen, to twice 16, or 32 parts, by weight of oxygen.

The third compound, called nitrogen tri-oxide, contains 28 parts by weight of nitrogen, to three times 16, or 48 parts, by weight of oxygen.

The fourth compound, called nitrogen tetroxide, contains 28 parts by weight of nitrogen, to four times 16, or 64 parts, by weight of oxygen.

The fifth and last compound, called nitrogen pentoxide, contains 28 parts by weight of nitrogen, to five times 16, or 80 parts, by weight of oxygen.

Now remembering that N means 14, and that O means 16, we can easily write the symbols for the above compounds.

The first compound contains 28 parts, or two combining weights of nitrogen, to 16 parts, or one combining weight of oxygen. Hence we write the symbol of this compound N_2O.[1]

For a like reason we write the formula

Of the second compound N_2O_2
„ third „ N_2O_3
„ fourth „ N_2O_4
„ fifth „ N_2O_5

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[1] The small figure written below the symbol means that the weight is to be taken more than once. O_3 means Oxygen=16 taken three times, or 3 × 16=48.

From this we see that the weight of oxygen contained in the four last of these compounds is twice, three times, four times, and five times that contained in the first compound. And, moreover, we find that it is not possible for us to prepare a compound containing any intermediate quantity of oxygen. If, for instance, we try to combine 28 parts by weight of nitrogen, with 20 parts by weight of oxygen, we get the whole of this nitrogen combined with only 16 of the oxygen, the other 4 parts of oxygen remaining uncombined. Here, then, we have arrived at the two most important laws of chemical combination:—

1. The law of combination of the elements in fixed proportions, called the combining weights.
2. The law of combination in multiple proportions of these combining weights, when several compounds of the same two elements exist.

69. Meaning of a Chemical Equation.

You will now be able to understand that all the chemical changes which I have spoken of, and which you have seen, or ever will see, can be written down **in symbols.** Every one of these changes is definite, and in every case we can get to know not only what has taken place, but also how much of each substance has been formed. Let us take one or two examples. If I want to prepare nitric acid (Experiment 38), I take nitre (potassium nitrate) and sulphuric acid, then nitric acid distils over, leaving potassium sulphate in the retort. Now what happens in this change; and how much sulphuric acid and how much nitre am I to take, so as not to waste either? In order to find this out, I must write down the formula for nitre, and for sulphuric acid. Nitre is written KNO_3;[1] that is, it contains three elements—potassium, $K=39$; nitrogen, $N=14$; oxygen, $O_3=3$ times 16, or 48. Sulphuric acid is written H_2SO_4; that is, it contains hydrogen $H_2=$twice 1, or 2; sulphur, $S=32$; oxygen, $O_4=$ 4 times 16, or 64. When we mix these two compounds together, a change occurs; half the hydrogen (H) in the sulphuric acid changes place with the whole of the potassium (K) in the nitre, and two new substances are formed, viz., HNO_3, nitric acid (which distils off as a yellow liquid), and $KHSO_4$, sulphate of potassium, which remains in the retort as a white solid salt. This change we can therefore express in an equation, thus—

Before the change.		*After the change.*
Nitre and Sulphuric Acid	yield	Nitric Acid and Potassium Sulphate.
$KNO_3+H_2SO_4$	$=$	HNO_3+KHSO_4

This shows us, then, exactly what takes place; nothing is lost; the nitric acid and potassium sulphate which we get, weigh, taken together, as much as the nitre and the sulphuric acid which we took. We see this clearly if we write down the numbers which these symbols represent.

$$39+14+48 \text{ and } 2+32+64 = 1+14+48 \text{ and } 39+1+32+64$$

$$101 \quad + \quad 98 \quad = \quad 63 \quad + \quad 136$$

The equation then tells us that if I take 101 parts by weight of nitre, and 98 parts by weight of sulpuric

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[1] The number below the letter applies to that letter only.

acid, I shall get exactly 63 parts by weight of nitric acid, and that no nitre or sulphuric acid will be wasted; and you will easily understand that these numbers enable you to calculate the quantity of the materials you must take, to get any given weight of the acid. Suppose you wanted 10 pounds of nitric acid, how much sulphuric acid and nitre would you need to employ? Well, if you wanted to get 63 pounds of nitric acid, you would need 98 pounds of sulphuric acid, and 101 pounds of nitre; and, of course, in order to get 10 pounds you will need $\frac{10}{63}$ of 98 pounds of sulphuric acid, and $\frac{10}{63}$ of 101 pounds of nitre. So that all calculations of this kind are matters of simple proportion.

Let us take one other example. We made hydrogen by acting upon zinc with sulphuric acid and water (Experiment 15). The change which here takes place is represented by the equation—

$Zn + H_2SO_4 = H_2 + ZnSO_4$ or

Zinc and Sulphuric Acid yield Hydrogen and Zinc Sulphate.

65 and 2 + 32 + 64 yield 2 and 65 + 32 + 64 or

65 and 98 yield 2 and 161

parts of Zinc, parts of Sulphuric Acid, parts of Hydrogen, parts of Zinc Sulphate.

This means that if I take 65 pounds of zinc, and 98 pounds of sulphuric acid, I must always get 2 pounds of hydrogen gas, and 161 pounds of zinc sulphate. If I ask you how much zinc and sulphuric acid must you take in order to get 40 pounds of hydrogen, I am sure you will all be able to tell me.

In like manner every chemical change, as soon as we understand it, can be represented by a formula, or set of symbols, which tells us exactly what happens, and how much of each of the various materials must be taken, and how much of each of the several products are formed.

It is the business of the chemist to seek out and determine the nature of all new chemicals which may be observed, and he does this with zeal and confidence, because he knows that if he has once determined, with care, the nature of the change, and if he has once ascertained the proportions by weight in which the elements, or compounds, take part in it, he has settled this particular question for ever, as the same chemical combination always takes place according to the same unchanging laws.

HINTS FOR THE USE OF THE APPARATUS AND FOR THE EXPERIMENTS.

1. TRY every experiment over carefully before it is shown in class, and observe *exactly* the description given in the text.
2. Cleanliness and neatness in manipulation are as necessary in doing experiments as clearness of exposition is in teaching.
3. Place *everything* needed for the experiments of the day in order upon the table, so that there may be no confusion or delay.[1]

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[1] Faraday, our great master in experimental lectures, always devoted many hours to the preparation of the experiments for each lecture. No point, however trifling, bearing upon the success of the experiment was considered unimportant; he used to try the stoppers of all the bottles he had to use to see that they had not become fixed, and thus would cause delay by requiring forcible opening.

4. When the lesson is over carefully clean all the apparatus, and remove it and the specimens to a locked box or cupboard. Many of the acids, especially sulphuric and nitric, are dangerously corrosive, phosphorus is dangerous from its inflammable nature, whilst these and others of the reagents are poisonous, so that all must be completely removed from the pupils, and had better be kept in the teacher's private room.

5. The elder and more advanced pupils, having once seen the teacher go through the course of experiments, may with great advantage be permitted to perform the experiments for themselves under his superintendence.

Notes for the Experiments:—

EXPERIMENT 1.—If the neck of the bottle be very wide, the top must be covered by a piece of card, otherwise sufficient fresh air will get in to permit the continued combustion of the candle.

EXPERIMENT 3.—The U-tube containing the caustic soda should be carefully removed and corked up after each experiment, to prevent the caustic soda absorbing carbonic acid and moisture from the air. After the same caustic soda has been used for the experiment several times, the tube must be cleaned out, and a fresh supply of lumps of caustic soda obtained.

EXPERIMENT 5.—This may also be done in a test-tube; take care to have the copper turnings well heated before the sulphur boils, otherwise the glow is not well seen.

EXPERIMENT 6.—Take great care how you cut phosphorus; do so always under water. Then carefully and lightly dry the bit of phosphorus with blotting paper, and put it, with a dry knife or small pliers, on to the small floating dish.

EXPERIMENT 10.—This cannot be easily shown in winter, as the light is not intense enough.

EXPERIMENT 12.—How to charge the Grove's battery. Measure one pint of water into a basin, and gradually pour into this three fluid ounces of strong sulphuric acid or oil of vitriol, and let the liquid, after well mixing, be allowed to stand till it is cool. See that all the clamps and metal connections are bright, using sandpaper to clean them. Set up the battery with the porous cells and platinums inside the pot cells, and clamp all tight. Pour the dilute sulphuric acid into the pot cells so as nearly to fill each; then by means of a funnel carefully nearly fill each of the porous cells with strong nitric acid. The battery is now ready for action. When done with, the sulphuric acid may be returned to a bottle kept for the purpose, and the nitric acid poured into another bottle, unless the battery have been long in use, when both acids may be thrown away. The porous cells and zincs must be allowed to soak in water over-night and then placed back in their places. Should any of the zincs begin to effervesce in the acid when the wires of the battery are not in contact, they must be amalgamated afresh. This is done by washing the surface of the zinc with some hydrochloric acid, and then pouring some mercury, together with the acid, over the metal. After repeating this several times, the metal will possess a uniform bright colour, and will not dissolve in dilute sulphuric acid unless the wires be joined.

EXPERIMENT 16.—The union of sodium and mercury is always accompanied by a slight explosion, but quite free from danger. Always take five times by bulk as much mercury as sodium.

EXPERIMENT 17.—It is best to mix the sulphuric acid and water (one to six by volume) beforehand; pour the acid into the water in a thin stream, and stir the mixture round.

EXPERIMENT 20.—A piece of hard wide glass tube without a bulb, fitted with a cork to the tube E, and drawn out at the other end, as shown in the figure, may serve instead of the bulb-tube A. Unless nearly half an ounce of copper oxide is taken the height of water formed will be too small. After the experiment is finished, the reduced metallic copper must again be oxidized by drawing air over it (by means of the oil-can used in Experiment 3) whilst it is heated with the lamp. The oxide thus formed will have gained its original weight, and can be used again for a repetition of the same experiment.

EXPERIMENT 31.—In order that this increase of weight by oxidation should be rendered evident, the magnet must be a good one, the filings very fine, and the balance delicate. Another mode of showing the increase of weight by absorption of oxygen is that mentioned above, when the reduced copper is heated in a current of air.

EXPERIMENT 36.—It requires a little practice to get the gas to burn permanently at the end of the tube.

EXPERIMENT 40.—In a close room the evolution of chlorine gas should be avoided.

EXPERIMENT 52.—When using the blow-pipe the breath must be sent out from the cheeks and not from the lungs ; it is thus possible to inflate the cheeks when required breathing through the nose.

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LIST OF APPARATUS REQUIRED FOR EACH EXPERIMENT,

WITH APPROXIMATE PRICES OF THE ARTICLES,

As quoted by Messrs. J. Woolley, Sons & Co., and Messrs. Mottershead & Co., of Manchester.

No. of Expt.		Price.		
		£	*s.*	*d.*
1.—	Taper with wire holder	0	0	2
3.—	Glass tube containing a taper, with U-tube for holding the caustic soda, and caoutchouc tubing to connect to the aspirator	0	1	6
	Pair of hand-scales with glass pans, and weights from 2 oz. downwards, in oak box	0	3	9
5.—	A 2-oz. glass flask, 3*d*., iron tripod stand, 10*d*.	0	1	1
	Bunsen's burner, with one yard of caoutchouc tubing	0	2	2
	(This will be replaced by a spirit-lamp and one pint of methylated spirit when desired.)			
6.—	A bell jar, 1*s*., capsule to contain the phosphorus, 5*d*.	0	1	5
12.—	Apparatus for decomposing water by electricity, with two collecting tubes and wire to suspend them	0	2	0
	A 4-cell Grove's battery, in wooden tray, with wires	1	16	0
14.—	Glass mortar and pestle, 10*d*., gas eprouvette, 6*d*.	0	1	4
15.—	Flask, &c., for generating hydrogen	0	1	6
	Stoneware pneumatic trough, with beehive shelf	0	2	8
	Four wide-mouthed gas-collecting bottles, pint size	0	1	4
	Three stoneware gas trays	0	0	9

No. of Expt.		Price. £	s.	d.
20.	—A pint flask, wash-bottle, two **U**-shaped calcium-chloride tubes, and hard glass tube to contain the copper oxide	0	4	0
21.	—Two 8-oz. stoppered glass retorts	0	1	6
	A retort stand, with three rings, and clamp for test tubes, &c.	0	5	6
23.	—A 16-ox. porcelain evaporating dish, 1*s.* 6*d.*, 4-oz. ditto, 8*d.*	0	2	2
25.	—Two 3-inch glass funnels, 6*d.*, 100 filter-papers, 9*d.*	0	1	3
31.	—A horseshoe magnet	0	0	4
32.	—A palette-knife	0	0	6
37.	—A piece of iron wire gauze, six inches square	0	0	3
42.	—Iron tray or sand bath	0	0	5
44.	—One dozen 5-inch test-tubes, 1*s.*, test-tube holder, 6*d.*	0	1	6
	Test-tube stand for twelve tubes	0	1	3
	One blow-pipe 1*s.*, two files (round and triangular), 1*s.* 4*d.*	0	2	4
	Half a pound of glass tubing, 6*d.*, two dozen spare corks, 6*d.*	0	1	0

CHEMICALS, &c.

Sulphuric acid	4 lbs.
Nitric acid	3 ,,
Hydrochloride acid	2 ,,
Lime-water,	1 pint.
Ammonia (solution)	4 oz.
Caustic potash ,,	4 ,,
Sodium carbonate ,,	4 ,,
Potassium chromate ,,	4 ,,
Potassium ferrocyanide	4 ,,
Silver nitrate (solution)	4 oz.
Litmus ,,	4 ,,
Indigo ,,	4 ,,
Calcium chloride	8 ,,
Marble	8 ,,
Iron filings	8 ,,
Lime	4 ,,
Gypsum	4 ,,
Stourbridge clay	4 ,,
Bleaching powder	4 ,,
Manganese dioxide	1 lb.
Soda crystals	4 oz.

Alum	4 oz.
Sulphur roll	4 „
„ flour	4 „
Potassium nitrate	4 „
Zinc	2 „
Copper turnings	2 „
„ oxide	2 „
„ sulphate	2 „
Antimony	2 „
Mercury	2 „
Lead acetate	2 „
Castor oil	2 „
Caustic soda (solid)	2 „
Sodium carbonate andydrous	1 oz.
Phosphorus, yellow	1 „
„ red	¼ „
Tin oxide	½ „
Mercury oxide	½ „
Potassium	1 dram
Sodium	1 „
Gold leaf	6 leaves
Magnesium ribbon	½ yard
Litmus paper	1 book
Charcoal	1 piece

	£	s.	d.
Amounting to	0	14	6
43 bottles (various) containing the above chemicals and preparations	0	7	6
Set of 33 specimens in one-ounce specimen bottles	0	7	0

LIST OF SPECIMENS.

Aluminium.
Tin.
Lead.
Silver.
Bar iron.
Cast iron.
Steel.
Galvanized iron.
Iron ore.
Iron oxide.
Iron sulphate.
Bronze.
Brass.
Limestone.
Clay.
Tin stone.
Galena.
Zinc blende.
White sand.
Red "
Flint.
Quartz.
Graphite.
Rock salt.
Sodium sulphate.
Sodium nitrate.
Bone ash
Potassium chlorate.

Magnesium sulphate.
Potassium carbonate.
White lead, Red lead.
Litharge.

Messrs. J. WOOLLEY, SONS, & CO., and Messrs. MOTTERSHEAD & CO., both of Manchester, will supply the above-enumerated apparatus, chemicals, preparations, and specimens, packed in a box with lock and key, for the sum of £5 10*s*.

THE END.

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d, Red lead.

srs. MOTTERS-
ly the above-
and specimens,
of £5 10s.