MANCHESTER SCIENCE LECTURES FOR THE PEOPLE.

EIGHTH SERIES. WINTER SESSION, 1876.

WHAT THE EARTH IS COMPOSED OF.

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LECTURE I.

THE question as to the composition of the terrestrial matter, or what the earth is composed of, is one which has interested men from very early times; but it is also one the solution of which has only been even partially found within a comparatively recent period. The ideas of the ancients on this subject were vague and unsatisfactory; and it is difficult for us at the present day, when our knowledge, so far as it goes, is clear and precise, to put ourselves in the position of those who lived in past ages, or clearly to see the difficulties which those great minds had to encounter who broke through the thraldom of the Aristotelian philosophy, and prepared the way for truer views of the constitution of the earth upon which we live. From remote years, throughout the dark ages, and even down to recent times, the prestige of Aristotle altogether prevented the establishment of anything like a true view of the great phenomena of Nature. The doctrine of the existence of the four elemental states of matter—fire, air, water, earth—was generally accepted; and the possibility, nay, the proved fact, of the conversion of one kind of substance into another kind, and especially the "transmutation," as it was termed, of the metals, was universally acknowledged; so that the strivings of the alchemists to obtain the "philosopher's stone"—which should enable them to convert the base into the noble metals—followed as a matter of course. Next came the assumption of the existence of three principles, of which the material universe was alleged to be composed, namely, mercury, salt, and spirit, which, "mingle as mingle may," were thought, somehow or other, to produce all the different forms of matter which we see around us.

The man who, more than any other, stands conspicuous as having first distinctly opposed the prevailing views respecting the essential constitution of matter, and to whom we are indebted for the overthrow of the Aristotelian as well as the Paracelsian philosophy, is the Hon. Robert Boyle, who was born in 1627 and died in 1691. Robert Boyle was a very extraordinary man. He left behind him an extensive series of works, in which we find not only the description of a large number of important physical experiments and discoveries, but treatises upon almost every other branch of inquiry, including even theology. In his curious and interesting chapter entitled *The Sceptical Chemist*, published in 1661, he upholds the view that it is not possible, as had hitherto been supposed, to state at once the exact number of the principles or essential constituents of matter; but that, on the contrary, all those forms of matter which were not themselves capable of further separation must be regarded as simple or elementary bodies. Thus, in his introduction to the *Sceptical Chemist; or, Critical Chemico-Physical Doubts and Paradoxes touching the Experiment, whereby Vulgar Chemists are wont to endeavour to evince their Salt, Sulphur, and Mercury to be the true Principles of Things*, he uses the following expression:—

"It may as yet be doubted whether or no there be any determined number of elements; or, if you please, whether or no all compound bodies do consist of the same number of elementary ingredients or material principles."

Boyle was the first to point out the great fact—which is now the corner-stone of our science of chemistry—that a grand distinction must be drawn between compound and elementary bodies. He held, as indeed all chemists do at the present day, that chemical combination consists of an approximation of the smallest particles of matter, and that decomposition takes place when a third body is present capable of exerting on the particles of the one element a greater attraction than is possessed by the particles of the other element with which it is combined. We have in the works of Robert Boyle, then, the first instance of the recognition of the important fact in the world of science, that there is an essential distinction between substances which the chemist is able to split up into different bodies, and those substances which the chemist is unable to divide thus; and to this latter class is given the name of *chemical elements.* I will endeavour to elucidate this difference in the essential properties of matter by an historical illustration. The year before last Professor Thorpe gave us a lecture in this hall upon the life and labours of Joseph Priestley. Those who were present on that occasion will remember that Professor Thorpe pointed out how Priestley discovered oxygen on the 1st August, 1774. They will remember that Priestley took some of this red powder, which he termed calx of mercury, and found that when it was heated by the rays of the sun it underwent a peculiar change. We cannot heat the powder at this moment by the direct rays of the sun, but we will do so by indirect solar rays, for the heat of this gas-lamp is in fact nothing but solar heat derived by a roundabout process. If I heat this red powder, as Priestley did, we find that it disappears, and that whilst the red particles disappear, certain bright globules become visible on the side of the tube; and these globules prove to be shining metallic liquid, mercury, or quicksilver. Moreover, a gas is given off which has the power of re-igniting this bit of red-hot chip of wood, as you may see, when I plunge the red-hot wood into the colourless gas contained in the tube. Here then we have a very distinct and remarkable change taking place, a change which no one could foresee, and which was not observed until about the year 1774, when Priestley made the experiment you have seen, bringing about a creation of two distinct things out of this red powder, namely, the bright metallic liquid mercury which you see here; and the colourless oxygen which we have in this globe.

The news of this discovery of Priestley's was at once conveyed to Paris, and became known to the French chemist, Lavoisier, and he then made an experiment which is of great historical interest, as not only illustrating the point upon which we are engaged, but at the same time proving the fact that the air is not a simple or elementary substance, but contains two different gases, viz., oxygen and nitrogen. For this purpose he introduced into this globular retort (Fig. 1.), the long neck of which was bent down as you see, about four ounces of pure mercury or quicksilver, and he measured carefully the exact volume of air contained in the retort and in the bell-jar, the side of which was marked with a graduated scale. By means of a furnace he heated the mercury nearly to its boiling point. The total volume of air before he began his experiment, was exactly fifty cubic inches, at a temperature of ten degrees, and the barometer at twenty-eight inches. At first no apparent change was brought about by the action of the heat, but after a while, little red specks began to appear upon the surface of the mercury, and these specks grew larger and more numerous as the heat continued. At last, after heating it for twelve days and twelve nights, no further increase in the number and size of these

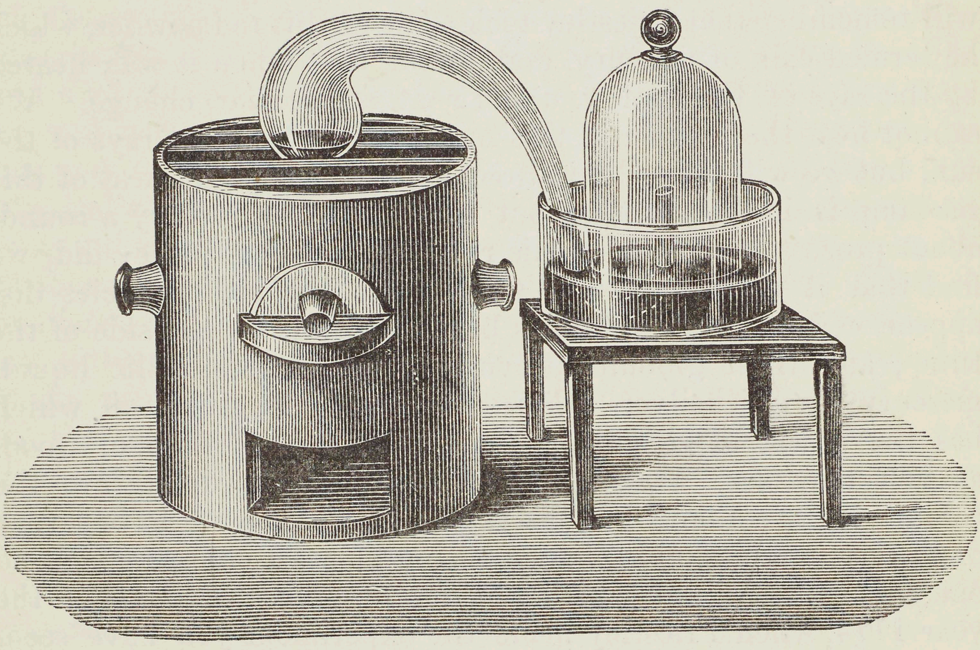


Fig. 1.

red specks was observed, and so Lavoisier allowed the whole apparatus to cool down again to ten degrees. He then once more measured the volume of air, and he found that instead of having fifty cubic inches of residual air, the volume was reduced to between forty-two and forty-three cubic inches; so that it appeared that from seven to eight cubic inches of air had disappeared. Lavoisier next took his apparatus to pieces, and collected carefully all the red powder, which he found to weigh exactly forty-five grains. The next part of his experiment is illustrated. He took the forty-five grains and placed them in the small tube-retort (Fig. 2), and proceeded to heat the powder by means of a lamp, having a gas delivery tube so arranged that he could collect and measure any gas which might be given off in a graduated cylinder. After he had heated these forty-five grains of powder for some time, he found that a gas made its appearance, whilst at the same time mercury was deposited on the sides of the tube. When the operation was completed, and the whole of the powder had undergone this change, Lavoisier observed that between seven and eight cubic inches of a peculiar gas had come over into his cylinder, and this gas had the property of re-igniting a red-hot splinter of wood; it was, in fact, oxygen gas, or "vital air" as it was then termed, which Priestley had previously discovered.

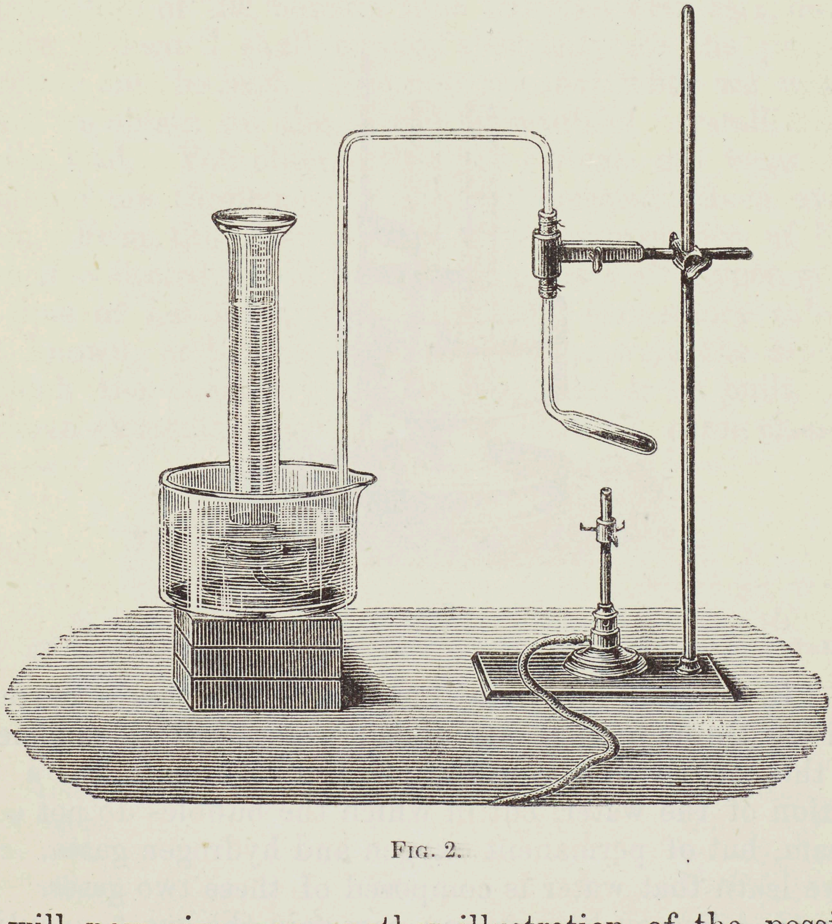


Fig. 2.

I will now give you another illustration of the possibility of splitting up some kinds of matter into different constituents. In the year 1783, some time, as you will observe, after the discovery of oxygen gas, a man of whom you have also heard, and whose discoveries were pointed out to you last year by Dr. Thorpe, I mean the great Henry Cavendish, proved that water is not an elementary substance, but that it may be produced by bringing together two quite different kinds of matter, that is, these two colourless gases, which we term oxygen and hydrogen. Cavendish showed that when these two gases, the first of which was then termed dephlogisticated air, and the latter inflammable air, were united in the right proportion, namely, one volume of oxygen and two volumes of hydrogen, they produced water, and nothing besides. In the year 1800, some seventeen years after this discovery by Cavendish, the action of electricity upon water was discovered by Nicholson and Carlisle ; and it was found that by sending a current of electricity through acidulated water, we can actually separate the constituent parts of water, and obtain an evolution of the two permanent

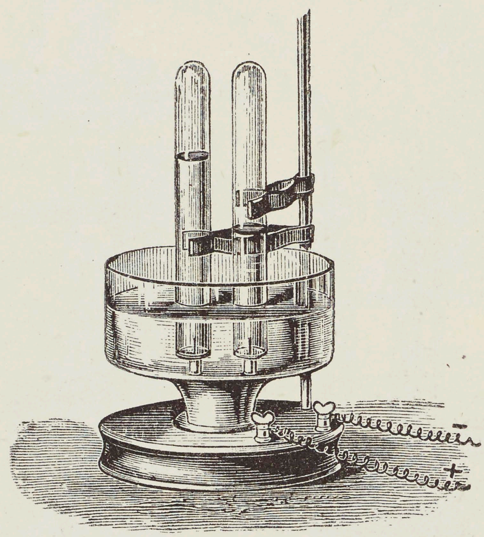


Fig. 3.

gases. In order to illustrate this fact, I will pass a current o electricity through some acidulated water, and the moment I make the contact of the wires, you see on the screen a rapid ebullition of the water, but in which the bubbles do not consist of steam, but of permanent oxygen and hydrogen gases. From this we learn that water is composed of these two gases. Next I have to show you how we can ascertain the exact quantity of the two gases necessary to be combined to form water. Instead of allowing the bubbles to escape, as in the previous experiment, I will collect from the one wire the oxygen, and from the other the hydrogen, gas. You see now that bubbles are rising from both wires, and you will notice in a short time that the two gases will collect in their separate tubes ; you will likewise observe

(Fig. 3) that the volume of gas in one tube is larger than the other; and when we make the experiment with care, we find that the volume in the one case is exactly double that in the other, the oxygen being always exactly half the volume of the hydrogen. Here then we have another instance that such an apparently simple substance as water can be split up into two totally different substances—oxygen and hydrogen.

As a third instance of the decomposition of substances into two or more essentially different bodies, I may take this white salt, called sugar of lead, and I show you that it contains the well-known metal lead. This metal I can obtain from the white powder by a similar kind of process to that which I adopted for the extraction of the mercury from Priestley's red calx, only that in place of heat I shall employ electricity for the purpose of separating out the lead. You now see that when we make the contact we obtain on the screen a beautiful crystallization of metallic lead. You observe that the crystals are beginning to grow, and are throwing out their arborescent shoots over the screen. From the other wire we have the evolution of bubbles which if collected would turn out to consist of oxygen gas. In the time of Lavoisier, only seventeen elementary substances were known, and these seventeen bodies were the bricks out of which the chemistry of that time had to be built. These seventeen elementary bodies were divided into three classes : we have :—

ELEMENTS KNOWN TO LAVOISIER.

Class I. The Non-Metals,	Class II. The True Metals,	Class III. The Semi-Metals,
Oxygen, or vital air.	Gold.	Arsenic.
Hydrogen, or inflammable air.	Silver.	Antimony.
Nitrogen.	Copper.	Bismuth.
Chlorine.	Lead.	Zinc.
Carbon.	Iron.	Cobalt.
	Tin.	Nickel.

Since the time of Lavoisier, thanks to the labours of several generations of chemists, we have now become acquainted with sixty-four elementary substances, existing in varying proportions in the air, the water, and the solid crust of the earth. Here is a list of these elements, some of which are widely distributed;

others are marked "common and useful;" while a long list at the bottom is marked "rare elements":—

TABLE OF THE ELEMENTS KNOWN AT THE PRESENT TIME.

MOST WIDELY DISTRIBUTED.

Aluminium.	*Hydrogen.	Oxygen.
*Bromine.	*Iodine.	*Phosphorus.
Calcium.	Iron.	Potassium.
*Carbon.	Magnesium.	*Silicon.
*Chlorine.	Manganese.	Sodium.
*Fluorine.	*Nitrogen.	*Sulphur.

COMMON AND USEFUL.

Antimony.	Copper.	Silver.
Arsenic.	Gold.	Strontium.
Barium.	Lead.	Tin
Bismuth.	Mercury.	Tungsten.
*Boron.	Nickel.	Uranium.
Chromium.	Platinum.	Zinc.
Cobalt.		

RARE.

Cadmium.	Lanthanum.	*Selenium.
Cæsium.	Lithium.	Tantalum.
Cerium.	Molybdenum.	*Tellurium.
Didymium.	Niobium.	Thallium.
Erbium.	Osmium.	Thorium.
Gallium.	Palladium.	Titanium.
Glucinum.	Rhodium.	Vanadium.
Indium.	Rubidium.	Yttrium.
Iridium.	Ruthenium.	Zirconium.

Many of the substances named in the third division are but slightly known, and have been experimented on by only a few chemists, and most of these have as yet not been applied to any useful purposes in the arts or manufactures; still we cannot tell what a day may bring forth, and even the rarest of these elements may at any time prove to be a useful and important body in ways not dreamt of before.

The next important fact which I wish to bring before you is the fixedness of the composition of chemical compounds. How would it be possible to have a science of chemistry if the composition of chemical substances varied from time to time? We know that if we once make an accurate determination of the quantity of lead which can be got out of a certain weight of this white sugar of lead, or of the mercury which we can obtain from this red calx, we need not trouble ourselves to make a second determination. By one accurate experiment we can be certain as to the result, for experience has shown us that the same chemical compound always contains its constituent elements in the same unvarying proportion; and this important conclusion is one which can be arrived at by experiment alone.

It is only by experiment, or by putting questions to nature, that she divulges her choicest secrets. Of all the means which have assisted chemists in arriving at these conclusions, the help afforded by the *balance* is the most important. The first man who employed the balance for the purposes of research appears to have been Joseph Black, professor of chemistry, first in Glasgow and then in Edinburgh. Black's balance is now to be seen in the valuable and interesting exhibition of scientific instruments at South Kensington; and although Black's instrument was not a delicate one, simply consisting of a rough pair of scales, nevertheless, with it he made investigations and determinations which have an undying interest.[1] After Black came Lavoisier, and it is generally stated that Lavoisier was the first to introduce the balance. This, however, was clearly not the case; for although he employed the balance largely, we are indebted to Black for its first introduction. In writing to Black in 1790, Lavoisier acknowledges the claims of the Scotch chemist in the following remarkable words:—

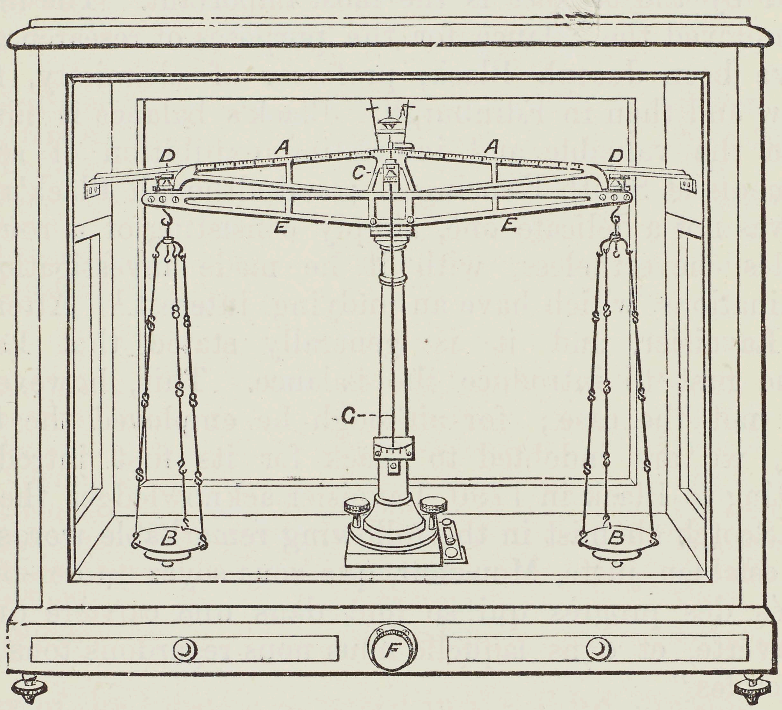
"Il est bien juste, Monsieur, que vous soyez un des premiers informés des progrès qui se font dans une carrière que vous avez ouverte, et dans laquelle nous nous regardons tous comme vos disciples."

This is a clear recognition of Black's claim to the merit of discovering the method of investigation which Lavoisier afterwards employed.

From what I have said, the necessity for experimentation—in order that we should attain a knowledge of the chemical properties of the substances of which the earth is made up—will be evident to you all. I may illustrate this in a very simple way. Suppose, for instance, that we have here—as is indeed the case—a series of jars filled with colourless, invisible gas, which, so far as we can tell, by merely looking at them seems to be of one kind. If, however, we interrogate Nature, that is, if we

[1] *Experiments upon Magnesia, Alba, Quicklime, and other Alkaline Substances.* Edinburgh, 1755.

make an experiment, as to the nature of the gas contained in these jars, we shall find that, although apparently the same, these gases are in fact very different substances. If I take this taper and insert it into the jars, this difference will soon become visible. When I dip the taper into the first jar, we do not notice any apparent change, for the flame of the candle burns much as it did before. If I put the taper into the next bottle there is a distinct change, for the taper is at once extinguished. When I place the extinguished taper, having, however, its wick still red-hot, into the third jar, you will see another change, for



Here you have (FIG. 4) a figure of a chemical balance.

the taper is instantly rekindled, indicating by the brilliancy of the combustion the existence of a totally different gas. Again, I will drop the burning taper into the fourth jar, and you see that the colourless gas itself takes fire and burns, although it extinguishes the flame of the candle. I can show you in other ways, by weight as well as by sight, that these gases differ from one another. For here I can pour one gas like water from one vessel to another; whilst in another case I can pour the gas upwards, because it is lighter than air. These are properties of gases, then, which can only be learned by experiment.

Understanding, then, that bodies always have a fixed composition, let us proceed a step further, and ask ourselves whether there is such a thing possible in Nature as a loss of matter. If I take this piece of watch-spring, kindle the string tied to one end, and then plunge it into a jar filled with oxygen, you see that the watch-spring burns, and in burning it will deposit a quantity of red-hot oxide. Observe the brilliancy with which the iron is now consumed, but also notice that the white-hot molten globules which fall down indicate what has become of the watch-spring, which no longer exists as such, but instead of it we have some quantity of a brown deposit, which we know as "rust of iron." If we next take as an example of chemical change that which occurs when a common candle burns, we cannot so readily observe what becomes of the materials of the candle. That the wax and the wick, the materials of which the candle is composed, disappear is certain. The question is, have they been destroyed, or have they only undergone a change and become invisible to our eyes? By this very simple arrangement we have the means of answering this question, for we can collect all the products of the combustion of the candle, the carbonic acid and the water, and we can show that these products weigh more than the candle does, just as the iron-rust produced in our last experiment weighs more than the watch-spring did. I have here a little taper, which is placed in a tube (Fig. 5), and this tube is placed at the end of the beam of a balance, which is arranged to be in exact equilibrium. Now I am about to burn the candle, and I shall collect the products of its combustion in the white caustic soda contained in the upper part of the tube (Fig. 5), so that nothing will escape but the air which has passed through the flame in the burning of the candle. I must have a current of air passing through in order to make the candle burn, and this I obtain by allowing the water to run out of this oil-can, the top of which is connected with the tube. The candle is now burning, and the question is—What has become of the wax and the wick? I want you to see that the materials of the candle, instead of having been destroyed, exist under another form—that of carbonic acid and water, which products have been laid hold of by the caustic soda and prevented from escaping. At the end of our experiment we shall find that the candle has lost half its weight, and that the other end of the balance is heavier by the oxygen of the air which the component parts of the atmosphere have taken up. You observe that this side of the apparatus is heavier than it was before, showing that in the case of a burning candle there is no such thing as a loss of matter. And this conclusion as regards this one case of chemical change has been proved by thousands of careful experiments to apply to every other case which has come under the eyes and hands of the chemist.

Let us next consider for a moment the distribution of the elementary bodies. In the first place we find that while only

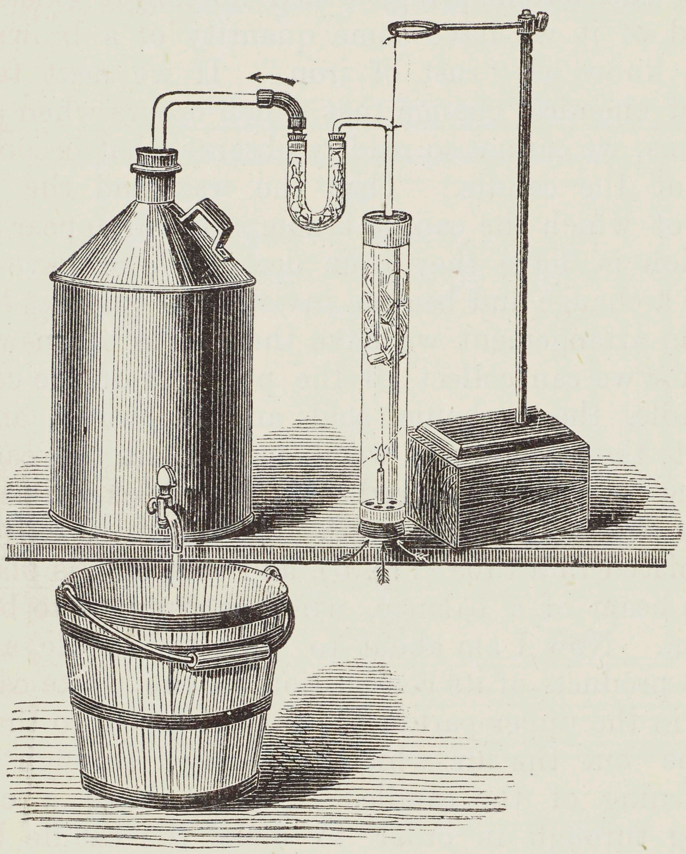


FIG. 5.

about four elements are found in the air, about thirty exist in the water of the ocean, whilst the rest are found in the solid earth. We are, however, quite unacquainted with any law regulating their distribution, but we find that certain elements are universally distributed whilst others occur most rarely. Thus, oxygen is found in almost every solid as well as in water and air, constituting (as is seen from the following table) about one-half of the solid crust of the earth.

Here you have a table giving the average composition of the solid earth's crust so far as the primary rocks are concerned. It shows that the bulk of the earth's solid body is made up of only eight elements, the remainder existing in the earth in much smaller quantity.

COMPOSITION OF THE EARTH'S SOLID CRUST IN 100 PARTS BY WEIGHT.

Oxygen . . .	44·0 to 48·7	Calcium . . .	6·6 to 0·9
Silicon . . .	22·8 to 36·2	Magnesium . .	2·7 to 0·1
Aluminium .	9·9 to 6·1	Sodium . . .	2·4 to 2·5
Iron	9·9 to 2.4	Potassium . . .	1·7 to 3·1

Respecting the composition of the whole mass of the earth we are as yet, as I have said, to a great extent ignorant, and a little consideration will show why this is the case. Imagine, if you please, that C (Fig. 6) represents the centre of the earth, and that the lines AC, and BC, are radii to the surface of the earth. Then the black line, AB, represents the portion of the earth's crust known to man. The greatest height to which man has ascended by means of a balloon, and the greatest depth to which he has descended by means of a mine, are included in the breadth of that dark line, so that all beyond this black line towards the centre of the earth is to us, so far as man's penetrating power is concerned, terra incognita. But although we cannot get there, yet we have means of learning something about the composition of these internal parts, because we can examine the chemical nature of the lava which is thrown up by volcanoes, and we can also examine the salts held in solution by spring water which comes from a great depth below the earth's surface.

Many of the hot deep mineral springs, such as those at Bath and Buxton, bring up to the surface various compounds and elements in a state of solution, the nature and properties of which can be examined by chemical means. But beyond these two means, we have at present no direct way of ascertaining what kind of elements or compounds exist at a great depth below the surface of the earth.

In the year 1772 a very interesting series of measurements was made in Scotland on a mountain known to many of you, called Schehallion. This mountain possesses very steep sides, and it occurred to several mathematicians, Maskelyne especially, that by making plumb-line observations on each side of this steep mountain it might be possible to determine the mean density of the earth, which might in turn guide us to a knowlege of the nature of the portions of the earth to which we cannot get access. It was found that the plumb-lines hung on each side of the mountain were deviated a little (11″·7) out of the perpendicular by the weight of the mountain. Now if we know the size of the mountain, which can be obtained by a trigonometrical survey, and if we know the specific gravity of the rocks composing the mountain, such as this I hold in my

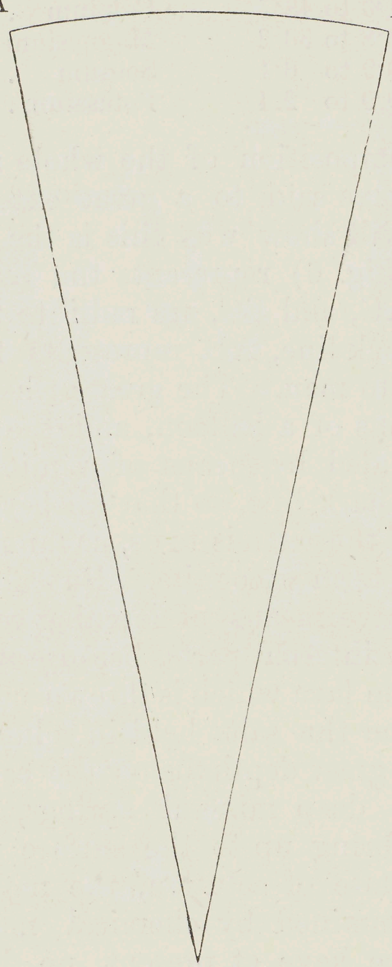


Fig. 6.

hand, and which is two and a half times heavier than water, we can discover the ratio of the attraction of the mountain to that of the earth. And then, we can get the absolute mass of the earth, and knowing its volume, we can get the mean density of the earth, that is to say, we can tell how many times the earth is heavier than an equal bulk of water. This was the first experiment made on this very interesting subject; and the calculations of Hutton and Playfair from the observations of Maskelyne made the mean density of the earth to be 4·713, that is to say, they came to the conclusion that the earth is, roughly speaking, $4\frac{3}{4}$ times heavier than an equal bulk of water.

Afterwards, another method was employed to determine this fact, namely, by means of a torsion balance, an instrument used by Cavendish, by means of which he found that the density of the earth was 5·48, or about $5\frac{1}{2}$ times heavier than water. Other observations have been made on this subject, the best of them being the result of a Commission appointed by the Government in 1838, in which the astronomer Baily was concerned. His investigations extended from October, 1838, to May, 1842, and he came to the conclusion, which we may regard as the most accurate one which has yet been obtained, that the mean density of the earth was 5·66, or rather more than $5\frac{1}{2}$ times heavier than water. It is worth remembering that Newton, in his great work, the *Principia*, predicted with a most remarkable degree of accuracy that the earth would be found to be between five and six times as heavy as its bulk of water.

You may ask—What has all this to do with the composition of the earth? Well, it has to do with it in this way: that when we descend to the greatest possible depth into the earth and bring up its solid contents, we find that the highest mean specific gravity of the rocks is 2·5, so hence the question arises—What is it that makes the earth so heavy at its centre? It cannot be all made up of granite, because even the enormous pressure of the surrounding parts would not double or treble the density of granite at the earth's centre, and yet we find that the density of the earth is between five and six. Here we come pretty nearly to the boundary of our knowledge, and at this point chemical science cannot help us further; and it is well we should see that there is here for the present a limit to our exact knowledge, and that all beyond must remain more or less conjectured until we are in possession of further experimental data.

As I shall show you in my next lecture, there are a number of elementary bodies whose specific gravity is very much greater than that of granite. Many of the metals, for instance, are much heavier than granite; and we can suppose, if we like, that the interior portions of the earth are composed of metals.

Perhaps Mr. Lockyer may continue these considerations, and he may inform you that there are other grounds for believing that the interior of the earth may be largely composed of unoxidized and heavy metals.

Then you may ask—Is the inside of the earth fluid or solid? Even in such an apparently simple question as this we are still in some degree of doubt. You may think this is strange, because we find volcanoes throwing out lava, which is liquid rock, and because we find much other geological evidence to show that solid rocks, such as basalt and trap, have been protruded as molten masses within recent geological epochs; but it has recently been shown by Mr. Mallet that the fact of volcanoes throwing out liquid rock may not be inconsistent with the view that the earth as a whole is solid. Mr. Mallet's investigations go to prove that this liquefaction of the rocks which we observe may be produced at no very great depth from the earth's surface by the shifting and rubbing together of the rocks, owing to cracking due to the alteration of the temperature, just as boys at school rub a button on the bench until it is hot, when they often place it on to their neighbour's cheek. Applying the laws of the Mechanical Theory of Heat to this problem, Mr. Mallet believes that the friction of the rocks, caused by the secular cooling of the earth and the consequent shrinkage, is a sufficient and a satisfactory explanation of the occurrence of the high temperature of volcanic action.

Sir Wm. Thomson,[1] also, than whom no one is more capable of expressing an opinion, decides in favour of the earth's solidity. He tells us in his address to the Physical Section at Glasgow, that the conclusion concerning the solidity of the earth originally arrived at by Hopkins is borne out by a more rigorous mathematical treatment than this physicist was able to apply, so that the idea of geologists, who were in the habit of explaining underground heat, ancient upheavals, or modern volcanoes, by the existence of a comparatively thin solid shell resting on an interior liquid mass, must now be given up as untenable.

[1] See *Nature*, Sept. 14, 1876.