JOHN DALTON AND HIS ATOMIC THEORY.

A LECTURE, delivered in the Hulme Town Hall, Manchester, on Wednesday, November 4th, 1874.

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LADIES AND GENTLEMEN,—In the eloquent lecture which we heard last week from our friend Professor Tyndall you learnt that the old Greek philosophers established what they called an atomic theory of matter; that is to say, they supposed that matter was composed of very small indivisible particles, and these particles, they imagined, flew about amongst one another in an erratic kind of way, sometimes knocking against one another, and sometimes passing one another; and they further supposed that these atoms were armed with certain claws or hooks by which they occasionally stuck together. Professor Tyndall then informed you that long afterwards Sir Isaac Newton showed that, instead of moving at random amongst one another, these atoms were attracted one towards another according to fixed and inevitable laws. On this principle he was not only able to explain the motions of the heavenly bodies, but he thereby laid the foundation of the idea of molecular force.

I have this evening to bring before you a further step in this great question. I have to tell you—and I am afraid I shall be able to tell you but very imperfectly as compared with the eloquence of my predecessor—how our great townsman, John Dalton, applied this theory of atoms to chemistry, thereby giving a precision and exactitude to this science which had previously been altogether wanting. The science of chemistry has to do with those changes of matter which not only affect the smallest particles of matter, but which at the same time are of such a permanent character as to produce from two or more unlike bodies a third body differing altogether from its components. Let me, by an example, make this clear to you. I have here a substance, bright, shining, and black, known as iodine. I have here another body, soft, wax-like, and inflammable, termed phosphorus. If I bring together a small piece of phosphorus and a small piece of iodine, a chemical change will take place. You observe, when I bring these two substances together, that an evolution of light and heat occurs, and the substance which is produced is altogether different from either the iodine or the phosphorus.

Now you may very well ask how it was that Sir Isaac Newton did not apply the atomic theory to chemistry, and how it came to be left for so long a period as up to the year 1803—almost within the memory of living men—before the atomic theory of chemistry was established. The reason of this lies in the fact that chemistry is a very new science, so much so indeed that chemistry as a science scarcely existed at the time of Newton. In old days, you will remember, I dare say, that four elementary bodies were said to exist, namely, earth, fire, air and water; but in later years this has been found to be an erroneous supposition; and it is now well known, as indeed it was known to Dalton, that instead of those four conditions of matter, there exist a much larger number of distinct substances with which the men of Newton's time were unacquainted, and which we now term the chemical elements. These are essentially different substances, which cannot be transformed one into the other, and out of each of which no different kind of substance can be got.

What, now, is the fundamental idea which lies at the foundation of Dalton's chemical theory of atoms? How does his theory differ from those of his predecessors? and what did he add to their theories in order to fit them for application to the science of chemistry? *The idea introduced by Dalton was the idea of weight.*

Up to his time no one had troubled himself to ask what is the weight of the atoms? or do the atoms of all these 63 elementary bodies weigh alike? These questions were, however, asked by Dalton, and the answers to these apparently simple questions are to be found in his celebrated *Atomic Theory.* In asking these questions, and in obtaining the requisite answers, John Dalton exhibited in a striking degree that power of spiritual insight into the secrets of nature which Professor Tyndall so truly describes as an essential condition of the true philosopher. It was no slight matter first to find the material which should give him an opportunity of putting such questions, and it required a mind of the highest powers and wonderful clearness of vision to penetrate beyond the domain of sense and give a satisfactory explanation of observed phenomena by reference to atoms so minute as to be infinitely removed from our powers of observation.

Let us endeavour, if we can, to acquaint ourselves with the process by which Dalton arrived at this great idea; let us try to trace its rise from visible and experimental evidence to that hidden source from which it sprung into full and perfect stature. But before we do this, it may be well, perhaps, for me to give you some idea, however slight, of the character of the man who made this great advance in our science. Coming from a humble but thrifty north-country Quaker stock, John Dalton, like many of the greatest men of this and other countries and ages, was entirely self-made. His chief characteristics were independence of spirit, fearlessness of inquiry, clearness and straightforwardness of vision, indomitable perseverance, and entire, unselfish, and life-long devotion to the prosecution of scientific truth. Bred up amongst prosaic people, and devoid of care for the ordinary social and political interests of society (he always said he had no time to get married), and uninfluenced, partly, perhaps, from his peculiar defect of vision, colour blindness, by the beauty of nature as it affects the imagination of ordinary people, Dalton all the more enjoyed the power of grasping in his mental vision ideas and principles which were hidden from the mass of mankind.

Dalton's independence of spirit and determination of mind were shown very early. One day, when he was between eleven and twelve years of age, he posted a notice on the door of his father's weaver's cottage at Eaglesfield, near Cockermouth, where he was born (September 5, 1766), stating that he had opened a school for children, and that the village children would be taught on reasonable terms. This school he first taught in an old barn, then in his father's cottage, and afterwards in the Friends' meeting-house at Eaglesfield. As a schoolmaster he began life, and as a schoolmaster he ended it. By teaching he through life earned his bread—first in Eaglesfield, next in Kendal (where he undertook a school in conjunction with his brother), and afterwards in Manchester, first (in 1781) as a science tutor to the Manchester New College, then existing in this city, and lastly as a private tutor of mathematics and science to anybody who could afford to pay from eighteenpence to half-a-crown a lesson. This routine instruction was, however, only the outside occupation of his mind. All the time he was teaching the children at Eaglesfield, the boys at

Kendal, and the young men and young women in Manchester, his innermost powers were quite otherwise engaged; first, by solving mathematical problems, published in a magazine which was in those early days much sought after; then by the study, in Kendal, of many branches of scientific inquiry, especially those interesting meteorological phenomena which all true lovers of nature must admire; thus laying the foundation for those grand scientific discoveries which have since made his name immortal. In November, 1802, he read a paper before the Literary and Philosophical Society of Manchester—a society which boasts the names of many great men on the long roll of its members, and has done and is still doing great and good work in the encouragement and advancement of science in this country.

This paper is entitled "An Experimental Inquiry into the proportion of the several gases contained in the Atmosphere," and it is interesting to us because it contains the germ of his great work; for he found, on investigating the properties of the atmosphere, that one of its component gases—namely, oxygen—has the power of combining chemically, in two different proportions, with this colourless gas called nitric oxide, to form two distinct compounds, and that the quantities by weight of oxygen which thus combine are in the simple ratio of one to two.

Dalton likewise showed that it was impossible to get any intermediate compound between these two. The nitric oxide in the one case took up twice as much oxygen as it did in the other; and it was this circumstance which first drew John Dalton's mind to his great discovery.

The fact thus discovered by Dalton, that one chemical element or compound can combine with another chemical element in two different proportions by weight, which stand to each other in the simple ratio of one to two, was borne out by the study, in the year 1804, of two other sets of colourless gases.

Here I have two other compounds which were examined by Dalton; they are both colourless and invisible gases. One of them is termed carbonic oxide gas, and the other is termed carbonic acid gas. They both contain carbon, and they both contain oxygen.

Dalton found that this substance—carbonic acid gas—contains exactly twice as much oxygen as this carbonic oxide gas contains, and he, as before, found it to be impossible to get any intermediate compound containing anything less than double the quantity of oxygen. I will show you again that we have here two very different substances. This body—carbonic acid—will extinguish the burning candle which I introduce into it; whilst in the other case of the carbonic oxide gas we shall find that when we bring a light to it the gas will burn with a bright blue flame.

This carbonic acid is a very heavy gas, so much so that I will show you that I can pour carbonic acid gas as if it were water into this deep beaker glass which is suspended on a balance, and, as I pour it in, I think you will notice that the beam will go down, showing that carbonic acid is a heavy gas. You see by the fact that a lighted taper is extinguished when I introduce it into the beaker, that I can pour in this gas from one vessel to another as I can pour water. On the other hand, I cannot pour this carbonic oxide gas into a vessel in like manner, as this gas is not heavier than air. Remember, then, that Dalton discovered that carbonic acid gas contains *twice as much oxygen* as carbonic oxide gas does.

I will give you a third example of this same fact, namely, that bodies exist containing the same elementary constituents—in this case carbon and hydrogen—in which the quantity of the two constituents stands in a simple relation the one to the other. Here are the other two colourless invisible gases; one of these is termed marsh gas, or fire-damp—the other is termed olefiant gas, or oil-making gas. These two bodies contain carbon and hydrogen, but this olefiant gas contains, as Dalton showed in 1804, *exactly twice as much carbon* as the marsh gas does. The marsh gas burns, as you see, with a scarcely luminous flame, but when I burn the olefiant gas, you will notice that the flame is much more luminous. Here, then, we have an important difference between these two gases.

I shall now show you that both of these gases contain carbon, and that this olefiant gas contains a great deal more carbon than the marsh gas. If I could weigh it before you, or measure it, as Dalton did, we should find that it was exactly twice as much. I have here a bottle filled with this olefiant gas, and I have here another bottle filled with a gas which is not a colourless, but a yellow gas, called chlorine. If I bring these two substances together—chlorine and olefiant gas—and then apply a light to the mixture, you will see that the colourless olefiant gas contains carbon. Now you observe a sudden flash, followed by a black smoke; and here you see the black carbon, or charcoal, which was contained in the olefiant gas. Now I will do the same with the marsh gas, and we shall not get so much carbon; we may get a little, enough, perhaps, to show that carbon is contained in the gas, but not much more. I take another vessel of chlorine, bring the two vessels together and apply a light, and here, you see, we get some carbon, but not nearly so much as before.

Now then comes the question—How does Dalton explain this? Dalton was not satisfied with these experiments; he was not satisfied with merely ascertaining that there is twice as much carbon in the one gas as in the other, or twice as much nitrogen in the one gas as in the other. He had experimentally discovered the law of combination in multiple proportions, but he wished to go deeper into things. He wished to know *why* this was so. He wished to know why it was that one compound contained just twice as much of one constituent as the other compound did, and why we cannot produce a substance containing an intermediate quantity of the constituent. Pondering on this subject, he arrived at his atomic theory, which serves to explain the fact of what chemists now call the law of "*multiple proportions;*" that is to say, that bodies are capable of combining with one another in one proportion by weight, in twice that proportion, in three times that proportion, and so on, but in no intermediate proportion.

Dalton now said, if we suppose that atoms exist, and that by their contact they form chemical compounds, and further supposing that the atom of each elementary body has a fixed weight which differs from that of the atom of any other element, then we are able to explain why we get combinations to occur only in this proportion of one given weight, and twice that weight, or three times that weight, and so on. I must not forget to remind you that these atoms are so small that it is perfectly impossible for us ever to hope to see them; nor must I forget to refer you to an admirable and learned lecture on the nature of the atomic hypothesis given in this Hall by Professor Clifford two years ago. I may tell you that a great living physicist, Sir William Thomson, has calculated approximately—for we are as yet unable to do more—how large, or rather how small, the atoms are; and he has come to this conclusion—that if you were to take a drop of water, and magnify it up to a globe of the size of the earth, then the atom contained in that drop of water would not be so large as cricket balls, nor so small as shot pellets. This may serve to give you an idea of the minute character of the atoms of which matter is composed.

Now let us attempt to get hold of the idea present in John Dalton's mind. He argued thus: All the atoms of nitrogen have each a certain definite unalterable weight, and we may suppose the atom to be represented by this white block. What happens, he then continues, when this atom of nitrogen combines with an atom of oxygen? When they come into contact and clash together a chemical compound is formed, a substance differing altogether both from nitrogen and from oxygen—a substance having peculiar properties of its own—a distinct chemical compound. Now, he continues, if any chemical action takes place between oxygen and nitrogen, the least quantity of each which can combine is one atom, because the atom is indivisible, and, if more nitrogen is capable of entering into combination with the substance already formed, to produce a second new substance, the smallest quantity of nitrogen which can do this is again one atom; so that, of the two compounds, one consists of one atom of oxygen and one atom of nitrogen, and the other of one atom of oxygen and two atoms of nitrogen.

Thus: [N] + [O] = [NO]

And [N] [N] + [O] = [NNO]

We may build up these compounds with our cubes: here is the one and here is the other. It is now clear why we can produce no compounds intermediate between these two—we cannot divide the atom of nitrogen. It is an indivisible particle, and is, therefore, the smallest portion of nitrogen capable of entering into combination.

This, then, was Dalton's explanation of the formation of these two gases of which I have spoken.

Let us next pass on to the second case considered by Dalton of the two compounds of carbon and oxygen—carbonic oxide and carbonic acid gases. Here again we can make the matter plain to ourselves by the help of a model. This black cube represents an atom of carbon, and this red one an atom of oxygen. Now when this one atom of carbon combines with oxygen, the least quantity it can combine with is one atom, and that simplest of all combinations constitutes, according to Dalton, the first of these bodies—carbonic oxide gas. Now, continued he, the second compound—carbonic acid gas—which we know to contain twice as much oxygen as carbonic oxide—is one which is built up of one atom of carbon and of two of these red atoms of oxygen, and it is therefore clear that we cannot have any intermediate form between the two compounds, and the fact is explained that in these two gases the proportion of oxygen is as one to two. We may next take a third illustration used by Dalton. This olefiant gas is, according to him, a compound of one atom of carbon and one atom of hydrogen. Here we can build up olefiant gas, according to Dalton's view. Marsh gas, or, as he calls it, carburetted hydrogen arising from stagnant water, on the other hand, is a compound containing twice as much hydrogen as olefiant gas, and it is therefore represented as made up of this one atom of carbon and these two of hydrogen. Here again, then, no intermediate compound is known, and Dalton's atomic theory tells us why.

I may perhaps be here allowed to remind you that this atomic explanation of the facts of combination in multiple proportions was one which could only have arisen where the conceptions are as clear as crystal, and this was a striking characteristic of Dalton's mind. Nor could this passage from the actually visible concrete masses of matter to the invisible minute atoms—a passage which seems so easy when it has once been made—have been achieved by any but a master spirit? By a process of reasoning upon the results of experiment—a process which I am afraid I cannot make clear to you to-night—Dalton was able to ascertain *the relative weights of the atoms.* He could not take a single atom and weigh it, but he could ascertain the relative weights of the atoms—that is to say the proportion which existed, for instance, between the weight of the atom of oxygen and the weight of the atom of hydrogen; and the relative weights of the atoms found in the following table are those first published by Dalton in a paper read on October 21st, 1803, but not printed until 1805.

TABLE OF THE RELATIVE WEIGHTS OF THE ULTIMATE PARTICLES OF GASEOUS AND OTHER BODIES (JOHN DALTON, 1803) :—

Hydrogen	1
Azot	4·2
Carbon	4·3
Ammonia	5·2
Oxygen	5·5
Water	6·5
Phosphorus	7·2
Phosphuretted hydrogen	8·2
Nitrous gas	9·7*
Ether	9·6
Gaseous oxide of carbon	9·8
Nitrous oxide	13·9*

* Misprints of 9·3 and 13·7 occur here in the original table.

Sulphur	14·4
Nitric acid	15·2
Sulphuretted hydrogen	15·4
Carbonic acid	15·3
Alcohol	15·1
Sulphureous acid	19·9
Sulphuric acid	25·4
Carburetted hydrogen from stagnant water	6·3
Olefiant gas	5·3

A glance at this table shows us that Dalton took hydrogen, being the lightest substance known, as the unit of comparison, and he compared the weights of the ultimate particles of all the other elements and compounds with that of hydrogen taken as 1. Then he found that the atom of azot, or nitrogen as we now call it, was 4·2; that of carbon 4·3, that of oxygen 5·5, and so on. A more careful inspection of the table, especially with regard to the three sets of gases about which I have spoken, will reveal to us Dalton's views as to the constitution of these substances. Thus opposite nitrous gas—now termed nitric oxide gas—we find the figures 9·7. What do these signify? They mean that this gas is made up of one atom of nitrogen (or azot) weighing 4·2, and one atom of oxygen weighing 5·5, and that the weight of the compound atom (if we may use the term) of nitrous gas weighs 9·7. Opposite nitrous oxide we find placed 13·9; this means that the ultimate particle of this gas contains two atoms of azot weighing twice 4·2, and one atom of oxygen weighing 5·5. In like manner t gaseous oxide of carbon has the number 9·8 placed against i viz., 4·3 + 5·5; whilst opposite carbonic acid we find 15·3, viz., 4·3 × 2 + 5·5.

Thus, then, Dalton built up his atomic theory; but, in order to make this theory more manifest, Dalton was in the habit of drawing his atoms, for he had a strictly mechanical turn of mind. Here you see the mode in which Dalton pictured or symbolised his atoms. This is a drawing of Dalton's atoms, expressed by symbols: oxygen is represented by a circle with a dot in the middle, hydrogen by a simple circle, and the other elements were expressed by circles with a line or a cross drawn through or upon them. This will give you an idea of the matter-of-fact as well as speculative character of Dalton's mind, and how he made clear to himself and to the world the new notion of the existence of these elementary atoms, each one having a given unalterable weight by which the element was characterised.

You must not go away with the supposition that the numbers I have referred to, or even the composition which I have given to the gases in question, have not undergone great changes since Dalton's time. All the conclusions which Dalton drew depended upon experiment, and since his day many of his experiments have been found to be inaccurate, and, therefore, many of his conclusions have had to be remodelled. The modern tables of atomic weights which chemists now employ, contain totally different numbers for the elementary atomic weights from those originally proposed in 1803. But although the details have thus been changed, the principles upon which Dalton founded his theory remain firmly fixed, and every subsequent discovery and every subsequent investigation has only served to confirm and corroborate the truth and value of the labours of this grand old Quaker.

Of the scientific importance of this discovery there can be no question; indeed, chemistry could hardly be said to exist as a science before the establishment of the laws of combination in multiple proportions, and the subsequent progress of chemical science materially depended upon the determination of these combined proportions or atomic weights of the elements first set up by Dalton. So that amongst the founders of our science, next to the name of the great French philosopher, Lavoisier, will stand in future ages the name of John Dalton, of Manchester.

Even from a practical and business point of view, the discovery of these combining proportions is of the greatest value. Thus, for instance, in the manufacture of oil of vitriol, a substance which is required in thousands and thousands of tons every year for different industrial purposes, before John Dalton had determined how much sulphur, and how much oxygen, and how much hydrogen combine together to form this sulphuric acid or oil of vitriol, no manufacturer could tell, except by rule of thumb, how much of each particular constituent had to be brought together. It was necessary, in order that the chemical manufacturer should be able to prepare this substance economically, that he should be able to ascertain, with the greatest precision, how much sulphur he must burn, how much air he must use, and how much water he must add in order with the greatest economy to produce this product for the market. It is the same with every chemical action that occurs, and it is to John Dalton—who made his living by giving private lessons at half-a-crown each—that we owe this knowledge which has made the fortunes of thousands, because he first told us the laws which govern these chemical actions.

As showing what a clear-headed man with indomitable perseverance and entire devotion to his science may accomplish, in spite of adverse circumstances, it would be well for all of you to read, mark, and inwardly digest the life and labours of this remarkable man. You will find these labours more fully and vividly depicted than I can attempt to do to-night in a book which has recently been written by my friend Dr. Lonsdale, viz., "The Lives of the Cumberland Worthies," of whom Dr. Dalton was one of the foremost. You will there find, not only a clear and concise account of his numerous scientific discoveries, but also a lively picture of the man himself, which, I venture to think, will not soon be forgotten by those who read it.

In looking back upon John Dalton's work, it is marvellous to see with what small means he accomplished great ends. His apparatus was extremely simple, much of it home-made, and often of the rudest description. His experiments, however, were all of a quantitative character; he wanted always to use his experiments as a step to a generalisation. He was constantly on the look-out for laws, and these laws he verified by experiment. But, as read by the light of modern and more exact research, many of Dalton's experimental methods prove to be crude, and even erroneous. They, nevertheless, served their end; they led Dalton to generalise, and to set up laws the truth of which modern accurate investigation has only more fully confirmed.

The question may next naturally arise in your minds, What use have the chemists since Dalton's time made of the atomic theory; how have they enlarged it, and how have they built up their scientific edifice upon it? They have not been idle. Since Dalton's time the atomic theory has been advanced in a great many directions. We are now able to do a great deal more than he was even able to conceive in the way of building up these atoms together and making a complicated chemical edifice. We are now beginning to know something of the way in which these atoms are attached together, the way in which the chemical house, if we may so express it, is built up; and, singularly enough, we have even come back again to the old notion of certain claws or points of attachment by which the atoms are fixed together. But the foundations of this edifice were laid by John Dalton; and all that we have done is to go on building upon the lines which he laid down.

In Dalton's time chemists were able to prepare artificially but a limited number of compounds; now they are able to build up an enormous number. Then, the substances which were found in animal and vegetable bodies were supposed to be produced by the action of life, and capable of production only by the action of life; now, many of these so-called animal and vegetable substances can be artificially prepared.

In the year 1828 a great discovery was made by a celebrated German chemist, Professor Wöhler. He found that this beautiful white substance—urea—which occurs in the animal body, and which it was supposed up to that time could only be produced by the action of life, can be built up from its inorganic constituents; for he was able to take the atoms of carbon, oxygen, nitrogen, and hydrogen, and build up this body, which had not been artificially produced before. This was the beginning of the breaking down of that barrier between organic (or animal and vegetable) substance and inorganic (or mineral) substance, which has now almost disappeared. We are now daily learning how to produce more and more of these substances which are found in or are the products of animal and vegetable life.

Up to this time chemists have gone on building, and building, and building, until liquids having the most complicated composition, and solids having the most complicated crystalline structure, have been formed. There is, however, another kind of material, termed *organised* material. I will show you, as an example of this organised or structural matter, a picture of some starch granules on the screen. Here again are some similar simple forms of organised material, the red blood corpuscles which float in the blood of all red-blooded animals. Each of these small cells has a distinct structure, which is different altogether from that of the crystalline or the liquid form of matter. The two halves of a globule, when divided, are not the same as a whole globule. Here, for the present, the synthetic or building-up power of our chemistry ends. We have not been able, and the evidence at present rather goes to show that there is not much hope of our being able, to construct these granules artificially; so that the great question of spontaneous generation, or the production of animal or vegetable life, or organised material, from inorganic sources, without the intermediation of any germ—this question, which has been so much discussed on so many occasions—is in this position, that so far as science has progressed at present, we have not been able to obtain any organism without the intervention of some sort of previously existing germ. Still we must not shut our eyes to the fact that there is still a wide field for observation and experiment yet to cover before we can regard this question as satisfactorily decided. We are only just beginning experimentally to touch questions of this nature, and it is far too early for us to feel much confidence in any wide or general conclusion drawn from the limited experience of the present day.

Ladies and gentlemen,—I believe I have exhausted the time allotted for my subject this evening. I trust I have made clear to you the very great importance of John Dalton's discoveries; and I cannot but hope that you will hereafter not only honour his name the more, but feel a greater interest in the man and his discoveries. I would only say a word in conclusion as regards the moral which we must draw from John Dalton's life and labours. What lesson do they teach? Surely this—that in order to flourish and produce fruit, such as we have been studying, science must be free—free to experiment and observe without let or hindrance; free to draw the conclusions which may flow from such experiments or observation; free, above all, to speculate and theorise into regions removed far beyond the reach of our senses.