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# ATOMS.

## A LECTURE

BY

PROFESSOR CLIFFORD, M.A.,

OF CAMBRIDGE.

DELIVERED IN THE HULME TOWN HALL, MANCHESTER,
NOVEMBER 20TH, 1872;

ALSO BEFORE THE SUNDAY LECTURE SOCIETY, IN LONDON,
ON THE 7TH OF JANUARY, 1872.

*Mr. Davies Benson in the chair.*

[REPORTED BY HENRY PITMAN.]

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IF I were to wet my finger and then rub it along the edge of this glass, I should no doubt persuade the glass to give out a certain musical note. So also if I were to sing to that glass the same note loud enough, I should get the glass to answer me back with a note.

I want you to remember that fact, because it is of capital importance for the arguments we shall have to consider to-night. The very same note which I can get the tumbler to give out by agitating it, by rubbing the edge, that same note I can also get the tumbler to answer back to me when I sing to it. Now, remembering that, please to conceive a rather complicated thing that I am now going to try to describe to you. The same property that belongs to the glass belongs also to a bell which is made out of metal. If that bell is agitated by being struck, or in any other way, it will give out the same sound that it will answer back if you sing that sound to it; but if you sing a different sound to it then it will not answer.

Now suppose that I have several of these metal bells which answer to quite different notes, and that they are all fastened to a set of elastic stalks which spring out of a certain centre to which they are fastened. All these bells, then, are not only fastened to these stalks, but they are held there in such a way that they can spin round upon the points to which they are fastened.

And then the centre to which these elastic stalks are fastened or suspended, you may imagine as able to move in all manner of directions, and that the whole structure made up of these bells and stalks and centre is able to spin round any axis whatever. We must also suppose that there is surrounding this structure a certain framework. We will suppose the framework to be made of some elastic material, so that it is able to be pressed in to a certain extent. Suppose that framework is made of whalebone, if you like. Now this structure I am going for the present to call an "atom." I do not mean to say that atoms are made of a structure like that. I do not mean to say that there is anything in an atom which is in the shape of a bell; and I do not mean to say that there is anything analogous to an elastic stalk in it. But what I mean is this—that an atom is something that is capable of vibrating at certain definite rates; also that it is capable of other motions of its parts besides those vibrations at certain definite rates; and also that it is capable of spinning round about any axis. Now by the framework which I suppose to be put round that structure made out of bells and elastic stalks, I mean this—that supposing you had two such structures, then you cannot put them closer together than a certain distance, but they will begin to resist being put close together after you have put them as near as that, and they will push each other away if you attempt to put them closer. That is all I mean then. You must only suppose that that structure is described, and that set of ideas is put together, just for the sake of giving us some definite notion of a thing which has similar properties to that structure. But you must not suppose that there is any special part of an atom which has got a bell-like form, or any part like an elastic stalk made out of whalebone.

Now having got the idea of such a complicated structure, which is capable, as we said, of vibratory motion, and of other sorts of motion, I am going on to explain what is the belief of those people who have studied the subject about the composition of the air which fills this room. The air which fills this room is what is called a gas; but it is not a simple gas; it is a mixture of two different gases, oxygen and nitrogen. Now what is believed about this air is that it consists of quite distinct portions or little masses of air—that is, of little masses each of which is either oxygen or nitrogen; and that these little masses are perpetually flying about in all directions. The number of them in this room is so great that it strains the powers of our numerical system to count them. They are flying about in all directions and mostly in straight lines, except where they get quite near to one another, and then they rebound and fly off in other directions. Part of these little masses which compose the air are of one sort—they are called oxygen. All those little masses which are called oxygen are alike; they are of the same weight; they have the same rates of vibration; and they go about on the average at a certain rate. The other part of these little masses is called nitrogen, and they have a different weight; but the weight of all the nitrogen masses is the same, as nearly as we can make out. They have again the same rates of vibration; but the rates of vibration that belong to them are different from the rates of vibration that belong to the oxygen masses; and the nitrogen masses go about on the average at a certain rate, but this rate is different from the average rate at which the oxygen masses go about. So then, taking up that structure which I endeavoured to describe to you at first, we should represent the state of the air in this room as being made up of such a lot of compound atoms of those structures of bells and stalks, with frameworks round them, that I described to you, being thrown about in all directions with great rapidity, and continually impinging against one another, each flying off in a different direction, so that they would go mostly in straight lines (you must suppose them for a moment not to fall down towards the earth), excepting where they come near enough for their two frameworks to be in contact, and then their frameworks throw them off in different directions: that is a conception of the state of things which actually takes place inside of gas.

Now, the conception which scientific men have of the state of things which takes place inside of a liquid is different from that. We should conceive it in this way: We should suppose that a number of these structures are put so close together that their frameworks are always in contact; and yet they are moving about and rolling among one another, so that no one of them keeps the same place for two instants together, and any one of them is travelling all over the whole space. Inside of this glass, where there is a liquid, all the small particles or molecules are running about among one another, and yet none of them goes for any appreciable portion of its path in a straight line, because there is no small distance that it goes without being in contact with others all around it; and the effect of this contact of the others all around it is that they press against it and force it out of a straight path. So that the path of a particle in a liquid is a sort of wavy path; it goes in and out in all directions, and a particle at one part of the liquid will, at a certain time, have traversed all the different parts one after another.

The conception of what happens inside of a solid body, say a crystal of salt, is different again from this. It is supposed that the very small particles which constitute that crystal of salt do not travel about from one part of the crystal to another, but that each one of them remains pretty much in the same place. I say "pretty much," but not exactly, and the motion of it is like this: Suppose one of my structures, with its framework round it, to be fastened up by elastic strings, so that one string goes to the ceiling, and another to the floor, and another to each wall, so that it is fastened by all these strings. Then if these strings are stretched, and a particle is displaced in any way, it will just oscillate about its mean position, and will not go far away from it; and if forced away from that position it will come back again. That is the sort of motion that belongs to a particle in the inside of a solid body. A solid body, such as a crystal of salt, is made up, just as a liquid or a gas is made up, of innumerable small particles, but they are so attached to one another that each of them can only oscillate about its mean position. It is very probable that it is also able to spin about any axis in that position or near it; but it is not able to leave that position finally, and to go and take up another position in the crystal; it must stop in or near about the same position.

These, then, are the views which are held by scientific men at present about what actually goes on inside of a gaseous body, or a liquid body, or a solid body. In each case the body is supposed to be made up of a very large number of very small particles; but in one case these particles are very seldom in contact with one another, that is, very seldom within range of each other's action; in this case they are during the greater part of the time moving separately along straight lines. In the case of a liquid they are constantly within the range of each other's action, but they do not move along straight lines for any appreciable part of the time; they are always changing their position relatively to the other particles, and one of them gets about from one part of the liquid to another. In the case of a solid they are always also within the range of each other's action, and they are so much within that range that they are not able to change their relative positions; and each one of them is obliged to remain in very nearly the same position.

Now what I want to do this evening is to explain to you, so far as I can, the reasons which have led scientific men to adopt these views; and what I wish especially to impress upon you is this, that what is called the "atomic theory"—that is what I have just been explaining—is no longer in the position of a theory, but that such of the facts as I have just explained to you are really things which are definitely known and which are no longer suppositions; that the arguments by which scientific men have been led to adopt these views are such as, to anybody who fairly considers them, justify that person in believing that the statements are true.

Now first of all I want to explain what the reasons are why we believe that the air consists of separate portions, and that these portions are repetitions of the same structures. That is to say that in the air we have two structures really, each of them a great number of times repeated. Take a simple illustration, which is a rather easier one to consider. Suppose we take a vessel which is filled with oxygen. I want to show what the reasons are which lead us to believe that that gas consists of a certain structure which is a great number of times repeated, and that between two examples of that structure which exist inside of the vessel there is a certain empty space which does not contain any oxygen. That oxygen gas contained in the vessel is made up of small particles which are not close together, and each of these particles has a certain structure, which structure also belongs to the rest of the particles. Now this argument is rather a difficult one, and I shall ask you therefore to follow it as closely as possible, because it is an extremely complicated argument to follow out the first time that it is presented to you.

I want to consider again the case of this finger glass. You must often have tried that experiment—that a glass will give out when it is agitated the same note which it will return when it is sung to. Well, now, suppose that I have got this room filled with a certain number of such atomic structures as I have endeavoured to describe—that is to say, of sets of bells, the bells answering to certain given notes. Each of these little structures is exactly alike, that is to say, it contains just the bells corresponding to the same notes. Well, now, suppose that you sing to a glass or to a bell, there are three things that may happen. First, you may sing a note which does not belong to the bell at all. In that case the bell will not answer; it will not be affected or agitated by your singing that note, but it will remain quite still. Next, if you sing a note that belongs to the bell, but if you sing it rather low, then the effect of that note will be to make the bell move a little, but the bell will not move so much as to give back the note in an audible form. Thirdly, if you sing the note which belongs to the bell loud enough, then you will so far agitate the bell that it will give back the note to you again. Now exactly that same property belongs to a stretched string, or the string of a piano. You know that if you sing a certain note in a room where there is a piano, the string belonging to that note will answer you if you sing loud enough. The other strings won't answer at all. If you don't sing loud enough the string will be affected, but not enough to answer you. Now let us imagine a screen of piano strings, all of exactly the same length, of the same material, and stretched equally, and that this screen of strings is put across the room; that I am at one end and that you are at another, and that I proceed to sing notes straight up the scale. Now while I sing notes which are different from that note which belongs to the screen of strings, they will pass through the screen without being altered, because the agitation of the air which I produce will not affect the strings. But that note will be heard quite well at the other side of the screen. You must remember that when the air carries a sound it vibrates at a certain rate belonging to the sound. I make the air vibrate by singing a particular note, and if that rate of vibration corresponds to the strings the air will pass on part of its vibration to the strings, and so make the strings move. But if the rate of vibration is not the one that corresponds to the strings, then the air will not pass on any of its vibrations to the strings, and consequently the sound will be heard equally loud after it has passed through the strings. Having put the strings of the piano across the room, if I sing up the scale, when I come to the note which belongs to each of the strings my voice will suddenly appear to be deadened, because at the moment that the rate of vibration which I impress upon the air coincides with that belonging to the strings, part of it will be taken up in setting the strings in motion. As I pass the note, then, which belongs to the strings, that note will be deadened.

Instead of a screen of piano strings let us put in a series of sets of bells, three or four belonging to each set, so that each set of bells answers to three or four notes, and so that all the sets are exactly alike. Now suppose that these sets of bells are distributed all over the middle part of the room, and that I sing straight up the scale from one note to another until I come to the note that corresponds to one of the bells in these sets, then that note will appear to be deadened at the other end, because part of the vibration communicated to the air will be taken up in setting those bells in motion. When I come to another note which belongs to them, that note will also be deadened; so that a person listening at the other end of the room would observe that certain notes were deadened, or even had disappeared altogether. If, however, I sing loud enough, then I should set all these bells vibrating. What would be heard at the other end of the room? Why just the chord compounded out of those sounds that belonged to the bells, because the bells having been set vibrating would give out the corresponding notes. So you see there are here three facts. When I sing a note which does not belong to the bells, my voice passes to the end of the room without diminution. When I sing a note that does belong to the bells, then if it is not loud enough it is deadened by passing through the screen; but if it is loud enough it sets the bells vibrating, and is heard afterwards. Now just notice this consequence. We have supposed a screen made out of these structures that I have imagined to represent atoms, and when I sing through the scale at one end of the room certain notes appear to be deadened. If I take away half of those structures, what will be the effect? Exactly the same notes will be deadened, but they will not be deadened so much; the notes which are picked out of the thinner screen to be deadened will be exactly the same notes, but the amount of the deadening will not be the same.

So far we have only been talking about the transmission of *sound*. You know that sound consists of certain waves which are passed along in the air; they are called "aerial vibrations." Now we also know that light consists of certain waves which are passed along not in the air, but along another medium. I cannot stop at present to explain to you what the sort of evidence is upon which that assertion rests, but it is the same sort of evidence as that which I shall try to show you belongs to the statement about atoms; that is to say, the "undulatory theory," as it is called, of light; the theory that light consists of waves transmitted along a certain medium, has passed out of the stage of being a theory, and has passed into the stage of being a demonstrated fact. The difference between a theory and a demonstrated fact is something like this: If you supposed a man to have walked from Chorlton Town Hall down here say in ten minutes, the natural conclusion would be that he had walked along the Stretford Road. Now that theory would entirely account for all the facts, but at the same time the facts would not be proved by it. But suppose it happened to be winter time, with snow on the road, and that you could trace the man's footsteps all along the road, then you would know that he had walked along that way. Now the sort of evidence we have to show that light does consist of waves transmitted through a medium is the sort of evidence that footsteps upon the snow make; it is not a theory merely which simply accounts for the facts, but it is a theory which can be reasoned back to from the facts without any other theory being possible. So that you must just for the present take it for granted that the arguments in favour of the hypothesis that light consists of waves are such as to take it out of the region of hypothesis, and make it into demonstrated fact.

Very well, then, light consists of waves transmitted along this medium in the same way that sound is transmitted along the air. The waves are not of the same kind; but still they are waves, and they are transmitted as such; and the different colours of light correspond to the different lengths of these waves, or to the different rates of the vibration of the medium, just as the different pitches of sound correspond to the different lengths of the air waves, or to the different rates of the vibration of the air. Now if we take any gas, such as oxygen, and we pass light through it, we find that that gas intercepts, or weakens, certain particular colours. If we take any other gas, such as hydrogen, and pass light through it, we find that that gas intercepts, or weakens, certain other particular colours of the light. Now, there are two ways in which it can do that: it is clear that the undulations, or waves, are made weaker, because they happen to coincide with the rate of vibration of the gas they are passing through. But the gas may vibrate as a whole in the same way that the air does when you transmit sound. Or the waves may be stopped, because the gas consists of a number of small structures; just as my screen, which I imagine to consist of structures; or just as the screen of piano strings is made up of the same structure many times repeated. Either of these suppositions would apparently at first account for the fact that certain waves of light are intercepted by the gas, while others are let through. But now how is it that we can show one of these suppositions is wrong and the other is right? Instead of taking so small a structure as piano strings, let us suppose we had got a series of fiddles, the strings of all of them being stretched exactly in tune. I suppose this case because it makes a more complicated structure, for there would be two or three notes corresponding in each fiddle. If you suppose this screen of fiddles to be hung up and then compressed, what will be the effect? The effect of the compression will be, if they are all in contact, that each fiddle itself will be altered. If the fiddles are compressed longways, the strings will give lower notes than before, and consequently the series of notes which will be intercepted by that screen will be different from the series of notes which were intercepted before. But if you have a screen made out of fiddles which are at a distance from one another, and then if you compress them into a smaller space by merely bringing them nearer together, without making them touch, then it is clear that exactly the same notes will be intercepted as before; only, as there will be more fiddles in the same space, the deadening of the sound will be greater.

Now when you compress any gas you find that it intercepts exactly the same colours of light which it intercepted before it was compressed. It follows, therefore, that the rates of vibration which it intercepts depend not upon the mass of the gas whose properties are altered by the compression, but upon some individual parts of it which were at a distance from one another before, and which are only brought nearer together without being absolutely brought into contact so as to squeeze them. That is the sort of reasoning by which it is made clear that the interception of light, or particular waves of light by means of a gas, must depend on certain individual structures in the gas which are at a distance from one another, and which by compression are not themselves compressed, but only brought nearer to one another.

There is an extremely interesting consequence which follows from this reasoning, and which was deduced from it by Professor Stokes in the year 1851, and which was afterwards presented in a more developed form in the magnificent researches of Kirchhoff—namely the reasoning about the presence of certain matter in the sun. If you analyse the solar light by passing it through a prism, the effect of the prism is to divide it off so as to separate the light into the different colours which it contains. That line of variously coloured light which is produced by the prism is, as you know, called the spectrum. Now when that spectrum is made in a very accurate way, so that the parts of it are well defined, it is observed to contain certain dark lines. That is, there is a certain kind of light which is missing in the sun light; certain kinds of light, as we travel along the scale of lights, are missing. Why are they missing? Because there is something that the light has passed through which intercepts or weakens those kinds of light. Now that something which the light has passed through, how shall we find out what it is? It ought to be the same sort of substance which if it were heated would give out exactly that kind of light. Now there is a certain kind of light which is intercepted which makes a group of dark lines in the solar spectrum. There are two principal lines which together are called the line D; and it is found that exactly that sort of light is emitted by sodium when heated hot enough. The conclusion therefore is that that matter which intercepts that particular part of the solar light is sodium, or that there is sodium somewhere between us and the hot portion of the sun which sends us the light. And other reasons lead us to conclude that this sodium is not in the atmosphere of the earth, but in the neighbourhood of the sun—that it exists in a gaseous state in the sun's atmosphere. And nearly all the lines in the solar spectrum have been explained in that way, and shown to belong to certain substances which we are able to heat here, and to show that when they are heated they give out exactly the same kind of light which they intercepted when the light was first given out by the sun and they stood in the way. So you see that is a phenomenon exactly like the phenomenon presented by the finger-glass that we began with.

Precisely the same light which any gas will give out when it is heated, that same kind of light it will stop or much weaken it if the light is attempted to be passed through it. That means that this medium which transmits light, and which we call the "luminiferous ether," has a certain rate of vibration for every particular colour of the spectrum. When that rate of vibration coincides with one of the rates of vibration of an atom, then it will be stopped by that atom, because it will set the atom vibrating itself. If therefore you pass light of any particular colour through a gas whose atoms are capable of the corresponding rate of vibration, the light will be cut off by the gas. If on the other hand you so far heat the gas that the atoms are vibrating strongly enough to give out light, it will give out a light of a kind which it previously stopped.

We have reason then for believing that a simple gas consists of a great number of atoms; that it consists of very small portions, each of which has a complicated structure, but that structure is the same for each of them, and that these portions are separate, or that there is space between them.

In the next place I want to show you what is the evidence upon which we believe that these portions of the gas are in motion—that they are constantly moving.

If this were a political instead of a scientific meeting, there would probably be some people who would be inclined to disagree with us, instead of all being inclined to agree with one another; and these people might have taken it into their heads, as has been done in certain cases, to stop the meeting by putting a bottle of sulphuretted hydrogen in one corner of the room and taking the cork out. You know that after a certain time the whole room would contain sulphuretted hydrogen, which is a very unpleasant thing to come in contact with. Now how is it that that gas which was contained in a small bottle could get in a short time over the whole room unless it was in motion? What we mean by motion is change of place. Now the gas was in one corner and it is afterwards all over the room. There has therefore been motion somewhere, and this motion must have been of considerable rapidity, because we know that there was the air which filled the room beforehand to oppose resistance to that motion. We cannot suppose that the sulphuretted hydrogen gas was the only thing that was in motion, and that the air was not in motion itself, because if we had used any other gas we should find that it would diffuse itself in exactly the same way. Now an argument just like that applies also to the case of a liquid. Suppose this room were a large tank entirely filled with water and anybody were to drop a little iodine into it, after a certain time the whole of the water would be found to be tinged of a blue colour. Now that drop may be introduced into any part of the tank you like, either at the top or bottom, and it will always diffuse itself over the whole water. There has here again been motion. We cannot suppose that the drop which was introduced was the only thing that moved about, because any other substance would equally have moved about. And the water has moved into the place where the drop was, because in the place where you put the drop there is not so much iodine as there was to begin with. Well then it is clear that in the case of a gas, these particles of which we have shown it to consist must be constantly in motion; and we have shown also that a liquid must consist of parts that are in motion, because it is able to admit the particles of another body among them.

Now when we have decided that the particles of a gas are in motion, there are two things that they may do—they may either hit against one another, or they may not. Now it is established that they do hit against one another, and that they do not proceed along straight lines independent of one another. But I cannot at present explain to you the whole of the reasoning upon which that conclusion is grounded. It is grounded upon some rather hard mathematics. It was shown by Professor Clerk Maxwell that a gas cannot be a medium consisting of small particles moved about in all directions in straight lines, which do not interfere with one another, but which bound off from the surfaces which contain this medium. Supposing we had a box containing a gas of this sort. Well, these particles do not interfere with one another, but only rebound when they come against the sides of the box; then that portion of the gas will behave not like a gas but like a solid body. The peculiarity of liquids and gases is that they do not mind being bent and having their shape altered. It has been shown by Clerk Maxwell that a medium whose particles do not interfere with one another would behave like a solid body and object to be bent. It was a most extraordinary conclusion to come to, but it is entirely borne out by the mathematical formulæ. It is certain that if there were a medium composed of small particles flying about in all directions and not interfering with one another, then that medium would be to a certain extent solid, that is, would resist any bending or change of shape. By that means then it is known that these particles do run against one another. Now they come apart again. There were two things of course they might do, they might either go on in contact, or they might come apart. Now we know that they come apart for this reason—we have already considered how two gases in contact will diffuse into one another. If you were to put a bucket containing carbonic acid (which is very heavy) upon the floor of this room it would after a certain time diffuse itself over all the room; you would find carbonic acid gas in every part of the room. Now Graham found that if you were to cover over the top of that bucket with a very thin cover made out of graphite, or blacklead, then the gas would diffuse itself over the room pretty nearly as fast as before. The graphite acts like a porous body, as a sponge does to water, and lets the gas get through. The remarkable thing is that if the graphite is thin the gas will get through nearly as fast as it will if nothing is put between to stop it. Graham found out another fact. Suppose that bucket to contain two very different gases, say a mixture of hydrogen and carbonic acid gas. Then the hydrogen would come out through the blacklead very much faster than the carbonic acid gas. Now it is found by mathematical calculation that if you have two gases, which are supposed to consist of small particles which are all banging about, the gas whose particles are lightest will come out quickest; that a gas which is four times as light will come out twice as fast; and a gas nine times as light will come out three times as fast, and so on. Consequently, when you mix two gases together and then pass them through a thin piece of blacklead, the lightest gas comes out quickest, and is as it were sifted from the other. Now suppose we put pure hydrogen into a bucket and put blacklead on the top, and then see how fast the hydrogen comes out. If the particles of the hydrogen are different from one another, if some are heavier, the lighter ones will come out first. Now let us suppose we have got a vessel which is divided into two parts by a thin wall of blacklead. We will put hydrogen into one of these parts and allow it to come through this blacklead into the other part; then if the hydrogen contains any molecules or atoms which are lighter than the others, those will come through first. If we test the hydrogen that has come through, we shall find that the atoms, as a rule, on one side of this wall are lighter than the atoms on the other side. How should we find that out? Why we should take these two portions of gas, and we should try whether one of them would pass through another piece of blacklead quicker than the other; because if it did, it would consist of lighter particles. Graham found that it did not pass any quicker. Supposing you put hydrogen into one half of such a vessel, and then allow the gas to diffuse itself through the blacklead, the gas on the two sides would be found to be of precisely the same qualities. Consequently, there has not been in this case any sifting of the lighter particles from the heavier ones; and consequently there could not have been any lighter particles to sift, because we know that if there were any they would have come through quicker than the others. Therefore we are led to the conclusion that in any simple gas, such as hydrogen or oxygen, all the atoms are, as nearly as possible, of the same weight. We have no right to conclude that they are exactly of the same weight, because there is no experiment in the world that enables us to come to an exact conclusion of that sort. But we are enabled to conclude that, within the limits of experiment, all the atoms af a simple gas are of the same weight. What follows from that? It follows that when they bang against one another, they must come apart again; for if two of them were to go on as one, that one would be twice as heavy as the others, and would consequently be sifted back. It follows therefore that two particles of a gas which bang against one another must come apart again, because if they were to cling together they would form a particle twice as heavy, and so this clinging would show itself when the gas was passed through the screen of blacklead.

Now there are certain particles or small masses of matter which we know to bang against one another according to certain laws; such, for example, as billiard balls. Now the way in which different bodies, after hitting together, come apart again depends on the constitution of those bodies. The earlier hypothesis about the constitution of a gas supposed that the particles of them came apart according to the same law that billiard balls do; but that hypothesis, although it was found to explain a great number of phenomena, did not explain them all. And it was Professor Clerk Maxwell again who found the hypothesis which does explain all the rest of the phenomena. He found that particles when they come together separate as if they repelled one another, or pushed one another away; and as if they did that much more strongly when close together than when further apart. You know that what is called the great law of gravitation asserts that all bodies pull one another together according to a certain law, and that they pull one another more when close than when further apart. Now that law differs from the law which Clerk Maxwell found out as affecting the repulsion of gaseous particles. The law of attraction of gravitation is this; that when you halve the distance, you have to multiply the attraction four times—twice two make four. If you divide the distance into three, you must multiply the attraction nine times—three times three are 9. Now in the case of atomic repulsion you have got to multiply not twice two, or three times three, but five twos together—which multiplied make 32. If you halve the distance between two particles you increase the repulsion 32 times. So also five threes multiplied together make 243; and if you divide the distance between two particles by three, then you increase the repulsion by 243. So you see the repulsion increases with enormous rapidity as the distance diminishes. That law is expressed by saying that the repulsion of two gases is inversely as the fifth power of the distance. But now I must warn you against supposing that that law is established in the same sense that these other statements that we have been making are established. That law is true provided that there is a repulsion between two gaseous particles, and that it varies as a power of the distance; it is proved that if there is any law of repulsion, and if the law is that it varies as some power of the distance, then that power cannot be any other than the fifth. It has not been shown that the action between the two particles is not something perhaps more complicated than this, but which on the average produces the same results. But still the statement that the action of gaseous molecules upon one another can be entirely explained by the assumption of a law like that, is the newest statement in physics since the law of gravitation was discovered. You know that there are other actions of matter which apparently take place through intervening spaces and which always follow the same law as gravitation, such as the attraction or repulsion of magnetical or electrical particles: those follow the same law as gravitation. But here is a law of repulsion which follows a different law to that of gravitation, and in that lies the extreme interest of Professor Clerk Maxwell's investigation.

Now the next thing that I want to give you reasoning for is again rather a hard thing in respect of the reasoning, but the fact is an exremely simple and beautiful one. It is this. Suppose I have two vessels, say cylinders, with stoppers which do not fit upon the top of the vessel, but slide up and down inside and yet fit exactly. These two vessels are of exactly the same size; one of them contains hydrogen and the other contains oxygen. They are to be of the same temperature and pressure, that is to say they will bear exactly the same weight on the top. Very well, these two vessels having equal volumes of gas of the same pressure and temperature will contain just the same number of atoms in each, only the atoms of oxygen will be heavier than the atoms of hydrogen. Now how is it that we arrive at that result? I shall endeavour to explain the process of reasoning. Boyle discovered a law about the dependence of the pressure of a gas upon its volume, which showed that if you squeezed a gas into a smaller space it will press so much the more as the space has been diminished. If the space has been diminished one-half, then the pressure is doubled; if the space is diminished to one-third, then the pressure is increased to three times what it was before. This holds for a varying volume of the same gas. That same law would tell us that if we put twice the quantity of gas into the same space, we should get twice the amount of pressure. Now Dalton made a new statement of that law, which expresses it in this form, that when you put more gas into a vessel which already contains gas, the pressure that you get is the sum of the two pressures which would be got from the two gases separately. You will see directly that that is equivalent to the other law. But the importance of Dalton's statement of the law is this, that it enabled the law to be extended from the case of the same gas to the case of two different gases. If instead of putting a pint of oxygen into a vessel already containing a pint, I were to put in a pint of nitrogen, I should equally get a double pressure. The oxygen and nitrogen when mixed together would exert the sum of the pressures upon the vessel that the oxygen and nitrogen would exert separately. Now the explanation of that pressure is this. The pressure of the gas upon the sides of the vessel is due to the impact of these small particles which are constantly flying about and impinging upon the sides of the vessel. It is first of all shown mathematically that the effect of that impinging would be the same as the pressure of the gas. But the amount of the pressure could be found if we knew how many particles there were in a given space, and what was the effect of each one when it impinged on the sides of the vessel. You see directly why it is that putting twice as many particles, which are going at the same rate, into the same vessel, we should get twice the effect. Although there are just twice as many particles to hit the sides of the vessel, they are apparently stopped by each other when they bound off. But the effect of there being more particles is to make them come back quicker; so that altogether the number of impacts upon the sides of the vessel is just doubled when you double the number of particles. Now supposing we have got a cubic inch of space, then the amount of pressure upon the side of that cubic inch depends upon the number of particles inside the cube, and upon the energy with which each one of them strikes against the sides of the vessel.

Well now again there is a law which connects together the pressure of a gas and its temperature. It is found that there is a certain absolute zero of temperature, and that if you reckon your temperature from that then the pressure of the gas is directly proportional to the temperature, that twice the temperature will give twice the pressure of the same gas, and three times the temperature will give three times the pressure of the same gas.

Well now we have just got to remember these two rules—the law of Boyle, as expressed by Dalton, connecting together the pressure of a gas and its volume, and this law which connects together the pressure with the absolute temperature. You must remember that it has been calculated by mathematics that the pressure upon one side of a vessel of a cubic inch has been got by multiplying together the number of particles into the energy with which each of them strikes against the side of the vessel. Now if we keep that same gas in a vessel and alter its temperature, then we find that the pressure is proportional to the temperature; but since the number of molecules remains the same when we double the pressure, we must alter that other factor in the pressure, we must double the energy with which each of the particles attacks the side of the vessel. That is to say, when we double the temperature of the gas we double the energy of each particle; consequently the temperature of the gas is proportional always to the energy of its particles. That is the case with a single gas. If we mix two gases, what happens? They come to exactly the same temperature. It is calculated also by mathematics that the particles of one gas have the same effect as those of the other; that is, the light particles go faster to make up for their want of weight. If you mix oxygen and hydrogen, you find that the particles of hydrogen go four times as fast as the particles of oxygen. Now we have here a mathematical statement—that when two gases are mixed together, the energy of the two particles is the same; and with any one gas considered by itself that energy is proportional to the temperature. Also when two gases are mixed together the two temperatures become equal. If you think over that a little you will see that it proves that whether we take the same gas or different gases, the energy of the single particles is always proportional to the temperature of the gas.

Well now what follows? If I have two vessels containing gas at the same pressure and the same temperature (suppose that hydrogen is in one and oxygen in the other) then I know that the temperature of the hydrogen is the same as the temperature of the oxygen, and that the pressure of the hydrogen is the same as the pressure of the oxygen. I also know (because the temperatures are equal) that the average energy of a particle of the hydrogen is the same as that of a particle of the oxygen. Now the pressure is made up by multiplying the energy by the number of particles in both gases; and as the pressure in both cases is the same, therefore the number of particles is the same. That is the reasoning; I am afraid it will seem rather complicated at first hearing, but it is this sort of reasoning which establishes the fact that in two equal volumes of different gases at the same temperature and pressure, the number of particles is the same.

Now there is an exceedingly interesting conclusion which was arrived at very early in the theory of gases, and calculated by Mr. Joule. It is found that the pressure of a gas upon the sides of a vessel may be represented quite fairly in this way. Let us divide the particles of gas into three companies or bands. Suppose I have a cubical vessel in which one of these companies is to go forward and backward, another right and left, and the other to go up and down. If we make those three companies of particles to go in their several directions, then the effect upon the sides of the vessel will not be altered; there will be the same impact and pressure. It was also found out that the effect of this pressure would not be altered if we combined together all the particles forming one company into one mass, and made them impinge with the same velocity upon the sides of the vessel. The effect of the pressure would be just the same. Now we know what the weight of a gas is, and we know what the pressure is that it produces, and we want to find the velocity it is moving at on the average. We can find out at what velocity a certain weight has got to move in order to produce a certain definite impact. Therefore we have merely got to take the weight of the gas, divide it by three, and to find how fast that has got to move in order to produce the pressure, and that will give us the average rate at which the gas is moving. By that means Mr. Joule calculated that in air of ordinary temperature and pressure the velocity is about 500 metres per second, nearly five miles in sixteen seconds, or nearly twenty miles a minute—about sixty times the rate of an ordinary train.

The average velocity of the particles of gas is about 1½ times as great as the velocity of sound. Now you can easily remember the velocity of sound in air at freezing point—it is 333 metres per second; so that about 1½ times, really 1·432 of that would be the average velocity of a particle of air. At the ordinary temperature—60 degrees Fahrenheit—the velocity would, of course, be greater.

Now then just let us consider how much we have established so far about these small particles of which we find that the gas consists. We have so far been treating mainly of gases. We find that a gas, such as the air in this room, consists of small particles, which are separate with spaces between them. They are as a matter of fact of two different types, oxygen and nitrogen. All the particles of oxygen contain the same structure, and the rates of internal vibration are the same for all these particles. It is also compounded of particles of nitrogen which have different rates of internal vibration. We have shown that these particles are moving about constantly. We have shown that they impinge against and interfere with one another's motion; and we have shown that they come apart again. We have shown that in vessels of the same size containing two different gases of the same pressure and temperature there is the same number of those two different sorts of particles. We have shown also that the average velocity of these particles in the air of this room is about twenty miles a minute.

Now there is one other point of very great interest to which I want to call your attention. The word "atom," as you know, has a Greek origin; it means—that which is not divided. Various people have given it the meaning of that which *cannot* be divided; but if there is anything which cannot be divided we do not know it, because we know nothing about possibilities or impossibilities, only about what has or has not taken place. Let us then take the word in the sense in which it can be applied to a scientific investigation. An atom means something which is not divided *in certain cases that we are considering*. Now these atoms I have been talking about may be called physical atoms, because they are not divided under those circumstances that are considered in physics. These atoms are not divided under the ordinary alteration of temperature and pressure of gas, and variation of heat; they are not in general divided by the application of electricity to the gas, unless the stream is very strong. But there is a science which deals with operations by which these atoms which we have been considering can be divided into two parts, and in which therefore they are no longer atoms. That science is chemistry. The chemist therefore will not consent to call these little particles that we are speaking of by the name of atoms, because he knows that there are certain processes to which he can subject them which will divide them into parts, and then they cease to be things which have not been divided. Now I will give you an instance of that. The atoms of oxygen which exist in enormous numbers in this room consist of two portions, which are of exactly the same structure. Every molecule, as the chemist would call it, travelling in this room, is made up of two portions which are exactly alike in their structure. It is a complicated structure; but that structure is double. It is like the human body—one side is like the other side. How do we know that? We know it in this way. Suppose that I take a vessel which is divided into two parts by a division which I can take away. One of these parts is twice as large as the other part, and will contain twice as much gas. Into that part which is twice as big as the other I put hydrogen; into the other I put oxygen. Suppose that one contains a quart and the other a pint; then I have a quart of hydrogen and a pint of oxygen in this vessel. Now I will take away the division so that they can permeate one another, and then if the vessel is strong enough I pass an electric spark through them. The result will be an explosion inside the vessel; it won't break if it is strong enough; but the quart of hydrogen and the pint of oxygen will be converted into steam; they will combine together to form steam. If I choose to cool down that steam until it is just as hot as the two gases were before I passed the electric spark through them, then I shall find that at the same pressure there will only be a quart of steam. Now let us remember what it was that we established about two equal volumes of different gases at the same temperature and pressure. First of all, we had a quart of hydrogen with a pint of oxygen. We know that that quart of hydrogen contains twice as many hydrogen molecules as the pint of oxygen contains of oxygen molecules. Let us take particular numbers. Suppose instead of a quart or a pint we take a smaller quantity, and say that there are 100 hydrogen and 50 oxygen molecules. Well after the cooling has taken place, I should find a volume of steam which was equal to the volume of hydrogen, that is I should find 100 steam molecules. Now these steam molecules are made up of hydrogen and oxygen molecules. I have got therefore 100 things which are all exactly alike, made up of 100 things and 50 things—100 hydrogen and 50 oxygen, making 100 steam molecules. Now since the 100 steam molecules are exactly alike, we have those 50 oxygen molecules distributed over the whole of these steam molecules. Therefore unless the oxygen contains something which is common to the hydrogen also, it is clear that each of those 50 molecules of oxygen must have been divided into two; because you cannot put 50 horses into 100 stables, so that there shall be exactly the same amount of horse in each stable; but you can divide 50 *pairs* of horses among 100 stables. There we have the supposition that there is nothing common to the oxygen and hydrogen, that there is no structure that belongs to each of them. Now that supposition is made by a great majority of chemists. Sir Benjamin Brodie, however, has made a supposition that there is a structure in hydrogen which is also common to certain other elements. He has himself, for particular reasons, restricted that supposition to the belief that hydrogen is contained as a whole in many of the other elements. Let us make that further supposition and it will not alter our case at all. We have then one hundred hydrogen and fifty oxygen molecules, but there is something common to the two. Well this something we will call X. Of this we have to make one hundred equal portions. Now that cannot be the case unless that structure occurred twice as often in each molecule of oxygen as in each molecule of hydrogen. Consequently, whether the oxygen molecule contains something common to hydrogen or not, it is equally true that the oxygen molecule must contain the same thing repeated twice over; it must be divisible into two parts which are exactly alike.

Similar reasoning applies to a great number of other elements; to all those which are said to have an even number of atomicities. But with regard to those which are said to have an odd number, although many of these also are supposed to be double, yet the evidence in favour of that supposition is of a different kind; and we must regard the supposition as still a theory and not yet a demonstrated fact.

Now I have spoken so far only of gases. I must for one or two moments refer to some calculations of Sir Wm. Thompson, which are of exceeding interest as showing us what is the proximity of the molecules in liquids and in solids. By four different modes of argument derived from different parts of science, and pointing mainly to the same conclusion, he has shown that the distance between two molecules in a drop of water is such that there are between five hundred millions and five thousand millions of them in an inch. He expresses that result in this way—that if you were to magnify a drop of water to the size of the earth, then the coarseness of the graining of it would be something between that of cricket balls and small shot. Or we may express it in this rather striking way. You know that the best microscopes can be made to magnify from 6,000 to 8,000 times. A microscope which would magnify that result as much again would show the molecular structure of water.

There is another scientific theory analogous to this one which leads us to hope that some time we shall know more about these molecules. You know that since the time that we have known all about the motions of the solar system, people have speculated about the origin of it; and a theory started by Laplace and worked out by other people has, like the theory of luminiferous ether, been taken out of the rank of hypothesis into that of fact. We know the rough outlines of the history of the solar system, and there are hopes that when we know the structure and properties of a molecule, what its internal motions are and what are the parts and shape of it, somebody may be able to form a theory as to how that was built up and what it was built out of. It is obvious that until we know the shape and structure of it, nobody will be able to form such a theory. But we can look forward to the time when the structure and motions in the inside of a molecule will be so well known that some future Kant or Laplace will be able to form a hypothesis about the history and formation of matter.

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In acknowledging a vote of thanks, Professor Clifford took the opportunity of recommending his auditors to read Professor Clerk Maxwell's book on the Theory of Heat, at the end of which would be found a short exposition of the molecular theory of matter.

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NOTE.—*The mathematical development of this subject is due to Clausius and Maxwell. References to the chief papers will be found at the beginning of Maxwell's memoir* "*On the Dynamical Theory of Gases,*" *Phil. Trans.*, 1867.

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