FARADAY MICHAEL

ON THE VARIOUS FORCES OF NATURE AND THEIR RELATIONS TO EACH OTHER

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Содержание

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PREFACE

Which was first, Matter or Force? If we think on this question, we shall find that we are unable to conceive of matter without force, or of force without matter. When God created the elements of which the earth is composed, He created certain wondrous forces, which are set free, and become evident when matter acts on matter. All these forces, with many differences, have much in common, and if one is set free, it will immediately endeavour to free its companions. Thus, heat will enable us to eliminate light, electricity, magnetism, and chemical action; chemical action will educe light, electricity, and heat. In this way we find that all the forces in nature tend to form mutually dependent systems; and as the motion of one star affects another, so force in action liberates and renders evident forces previously tranquil.

We say tranquil, and yet the word is almost without meaning in the Cosmos. – Where do we find tranquillity? The sea, the seat of animal, vegetable, and mineral changes, is at war with the earth, and the air lends itself to the strife. The globe, the scene of perpetual intestine change, is, as a mass, acting on, and acted on, by the other planets of our system, and the very system itself is changing its place in space, under the influence of a known force springing from an unknown centre.

For many years the English public had the privilege of listening to the discourses and speculations of Professor Faraday, at the Royal Institution, on Matter and Forces; and it is not too much to say that no lecturer on Physical Science, since the time of Sir Humphrey Davy, was ever listened to with more delight. The pleasure which all derived from the expositions of Faraday was of a somewhat different kind from that produced by any other philosopher whose lectures we have attended. It was partially derived from his extreme dexterity as an operator: with him we had no chance of apologies for an unsuccessful experiment – no hanging fire in the midst of a series of brilliant demonstrations, producing that depressing tendency akin to the pain felt by an audience at a false note from a vocalist. All was a sparkling stream of eloquence and experimental illustration. We would have defied a chemist loving his science, no matter how often he might himself have repeated an experiment, to feel uninterested when seeing it done by Faraday.

The present publication presents one or two points of interest. In the first place, the Lectures were especially intended for young persons, and are therefore as free as possible from technicalities; and in the second place, they are printed as they were spoken, *verbatim et literatim*. A careful and skilful reporter took them down; and the manuscript, as deciphered from his notes, was subsequently most carefully corrected by the Editor as regards any scientific points which were not clear to the short-hand writer; hence all that is different arises solely from the impossibility, alas! of conveying the manner as well as the matter of the Lecturer.

May the readers of these Lectures derive one-tenth of the pleasure and instruction from their perusal which they gave to those who had the happiness of hearing them!

W. CROOKES.

LECTURE I.
THE FORCE OF GRAVITATION

It grieves me much to think that I may have been a cause of disturbance in your Christmas arrangements[1], for nothing is more satisfactory to my mind than to perform what I undertake; but such things are not always left in our own power, and we must submit to circumstances as they are appointed. I will to-day do my best, and will ask you to bear with me if I am unable to give more than a few words; and as a substitute, I will endeavour to make the *illustrations* of the sense I try to express as full as possible; and if we find by the end of this lecture that we may be justified in continuing them, thinking that next week our power shall be greater, – why, then, with submission to you, we will take such course as you may think fit, – either to go on, or discontinue them; and although I now feel much weakened by the pressure of illness (a mere cold) upon me, both in facility of expression and clearness of thought, I shall here claim, as I always have done on these occasions, the right of addressing myself to the younger members of the audience. And for this purpose, therefore, unfitted as it may seem for an elderly infirm man to do so, I will return to second childhood and become, as

[1] Page 13. The opening lecture was twice postponed on account of Dr. Faraday's illness.

it were, young again amongst the young.

Let us now consider, for a little while, how wonderfully we stand upon this world. Here it is we are born, bred, and live, and yet we view these things with an almost entire absence of wonder to ourselves respecting the way in which all this happens. So small, indeed, is our wonder, that we are never taken by surprise; and I do think that, to a young person of ten, fifteen, or twenty years of age, perhaps the first sight of a cataract or a mountain would occasion him more surprise than he had ever felt concerning the means of his own existence, – how he came here; how he lives; by what means he stands upright; and through what means he moves about from place to place. Hence, we come into this world, we live, and depart from it, without our thoughts being called specifically to consider how all this takes place; and were it not for the exertions of some few inquiring minds, who have looked *into* these things and ascertained the very beautiful laws and conditions by which we *do* live and stand upon the earth, we should hardly be aware that there was anything wonderful in it. These inquiries, which have occupied philosophers from the earliest days, when they first began to find out the laws by which we grow, and exist, and enjoy ourselves, up to the present time, have shewn us that all this was effected in consequence of the existence of certain *forces*, or *abilities* to do things, or *powers*, that are so common that nothing can be more so; for nothing is commoner than the wonderful powers by which we are enabled to stand upright – they are essential to our existence every moment.

It is my purpose to-day to make you acquainted with some of these powers; not the vital ones, but some of the more elementary, and, what we call, *physical* powers: and, in the outset, what can I do to bring to your minds a notion of neither more nor less than that which I mean by the word *power*, or *force*? Suppose I take this sheet of paper, and place it upright on one edge, resting against a support before me (as the roughest possible illustration of something to be disturbed), and suppose I then pull this piece of string which is attached to it. I pull the paper over. I have therefore brought into use a *power* of doing so – the *power* of my hand carried on through this string in a way which is very remarkable when we come to analyse it; and it is by means of these powers conjointly (for there are several powers here employed) that I pull the paper over. Again, if I give it a push upon the other side, I bring into play a *power*, but a very different exertion of power from the former; or, if I take now this bit of shell-lac [a stick of shell-lac about 12 inches long and 1½ in diameter] and rub it with flannel, and hold it an inch or so in front of the upper part of this upright sheet, the paper is immediately moved towards the shell-lac, and by now drawing the latter away, the paper falls over without having been touched by anything. You see – in the first illustration I produced an effect than which nothing could be commoner – I pull it over now, not by means of that string or the pull of my hand, but by some action in the shell-lac. The shell-lac, therefore, has a *power* wherewith it acts upon the sheet of paper; and as an illustration of the exercise of another kind of power, I might use gunpowder with which to throw it over.

Now, I want you to endeavour to comprehend that when I am speaking of a *power* or *force*, I am speaking of that which I used just now to pull over this piece of paper. I will not embarrass you at present with the *name* of that power, but it is clear there was a *something* in the shell-lac which acted by attraction, and pulled the paper over; this, then, is one of those things which we call *power*, or *force*; and you will now be able to recognise it as such in whatever form I shew it to you. We are not to suppose that there are so very many different powers; on the contrary, it is wonderful to think how few are the powers by which all the phenomena of nature are governed. There is an illustration of another kind of power in that lamp; *there* is a power of heat – a power of doing something, but not the same power as that which pulled the paper over: and so, by degrees, we find that there are certain other powers (not many) in the various bodies around us. And thus, beginning with the simplest experiments of pushing and pulling, I shall gradually proceed to distinguish these powers one from the other, and compare the way in which they combine together. This world upon which we stand (and we have not much need to travel out of the world for illustrations of our subject; but the mind of man is not confined like the matter of his body, and thus he may and does travel outwards; for wherever his sight can pierce, there his observations can penetrate) is pretty nearly a round globe, having its surface disposed in a manner of which this terrestrial globe by my side is a rough model; so much is land and so much is water, and by looking at it here we see in a sort of map or picture how the world is formed upon its surface. Then, when we come to examine further, I refer you to this sectional diagram of the geological strata of the earth, in which there is a more elaborate view of what is beneath the surface of our globe. And when we come to dig into or examine it (as man does for his own instruction and advantage, in a variety of ways), we see that it is made up of different kinds of matter, subject to a very few powers, and all disposed in this strange and wonderful way, which gives to man a history – and such a history – as to what there is in those veins, in those rocks, the ores, the water springs, the atmosphere around, and all varieties of material substances, held together by means of *forces* in one great mass, 8,000 miles in diameter, that the mind is overwhelmed in contemplation of the wonderful history related by these strata (some of which are fine and thin like sheets of paper), – all formed in succession by the forces of which I have spoken.

I now shall try to help your attention to what I may say by directing, to-day, our thoughts to one kind of power. You see what I mean by the term *matter*– any of these things that I can lay hold of with the hand, or in a bag (for I may take hold of the air by enclosing it in a bag) – they are all portions of matter with which we have to deal at present, generally or particularly, as I may require to illustrate my subject. Here is the sort of matter which we call *water*, – it is *there* ice [pointing to a block of ice upon the table], *there* water [pointing to the water boiling in a flask], *here* vapour – you see it issuing out from the top [of the flask]. Do not suppose that that ice and that water are two entirely different things, or that the steam rising in bubbles and ascending in vapour *there* is absolutely different from the fluid water. It may be different in some particulars, having reference to the *amounts* of power which it contains; but it is the same, nevertheless, as the great ocean of water around our globe, and I employ it here for the sake of illustration, because if we look into it we shall find that it supplies us with examples of all the powers to which I shall have to refer. For instance, here is water – it is heavy; but let us examine it with regard to the *amount* of its heaviness, or its gravity. I have before me a little glass vessel and scales [nearly equipoised scales, one of which contained a half-pint glass vessel], and the glass vessel is at present the lighter of the two; but if I now take some water and pour it in, you see that that side of the scales immediately goes down; that shews you (using common language, which I will not suppose for the present you have hitherto applied very strictly) that it is *heavy*: and if I put this additional weight into the opposite scale, I should not wonder if this vessel would hold water enough to weigh *it* down. [The Lecturer poured more water into the jar, which again went down.] Why do I hold the bottle *above* the vessel to pour the water into it? You will say, because experience has taught me that it is necessary. I do it for a better reason – because it is a law of nature that the water should fall towards the earth, and therefore the very means which I use to cause the water to enter the vessel are those which will carry the whole body of water down. That power is what we call *gravity*, and you see *there* [pointing to the scales] a good deal of water gravitating towards the earth. Now *here* [exhibiting a small piece of platinum[2]] is another thing which gravitates towards the earth as much as the whole of that water. See what a little there is of it —*that* little thing is heavier than so much water [placing the metal in opposite scales to the water]. What a wonderful thing it is to see that it requires so much water as *that* [a half-pint vessel full] to fall towards the earth, compared with the little mass of substance I have *here*! And again, if I take this metal [a bar of aluminium[3] about eight times the bulk of the platinum], we find the water will balance that as well as it did the platinum; so that we get, even in the very outset, an example of what we want to understand by the words *forces* or *powers*.

I have spoken of water, and first of all of its property of falling downwards. You know very well how the oceans surround the globe – how they fall round the surface, giving roundness to it, clothing it like a garment; but, besides that, there are other properties of water. *Here*, for instance, is some quick-lime, and if I add some water to it, you will find another power or property

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[2] Page 22. *Platinum*, with one exception, the heaviest body known, is 21½ times heavier than water.

[3] Page 22. *Aluminium* is 2½ times heavier than water.

in the water.[4] It is now very hot, it is steaming up, and I could perhaps light phosphorus or a lucifer match with it. Now, that could not happen without a *force* in the water to produce the result; but that force is entirely distinct from its power of falling to the earth. Again, here is another substance [some anhydrous sulphate of copper[5]] which will illustrate another kind of power. [The Lecturer here poured some water over the white sulphate of copper, which immediately became blue, evolving considerable heat at the same time.] Here is the same water, with a substance which heats nearly as much as the lime does; but see how differently. So great indeed is this heat in the case of lime, that it is sufficient sometimes (as you see here) to set wood on fire; and this explains what we have sometimes heard, of barges laden with quick-lime taking fire in the middle of the river, in consequence of this power of heat brought into play by a leakage of the water into the barge. You see how strangely different subjects for our consideration arise, when we come to think over these various matters, – the power of heat evolved by acting upon lime with water, and the power which water has of turning this salt of copper from white to blue.

I want you now to understand the nature of the most simple

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[4] Pages 23 and 24. *Power or Property in Water.*– This power – the heat by which the water is kept in a *fluid* state – is said, under ordinary circumstances, to be *latent* or *insensible*. When, however, the water changes its form, and, by uniting with the lime or sulphate of copper, becomes *solid*, the heat which retained it in a liquid state is evolved.

[5] Page 23. *Anhydrous Sulphate of Copper*: sulphate of copper deprived of its water of crystallisation. To obtain it, the blue sulphate is calcined in an earthen crucible.

exertion of this power of matter called *weight*, or *gravity*. Bodies are heavy – you saw that in the case of water when I placed it in the balance. Here I have what we call a *weight* [an iron half cwt.] – a thing called a weight, because in it the exercise of that power of pressing downwards is especially used for the purposes of weighing; and I have also one of these little inflated india-rubber bladders, which are very beautiful although very common (most beautiful things are common), and I am going to put the weight upon it, to give you a sort of illustration of the downward pressure of the iron, and of the power which the air possesses of resisting that pressure. It may burst, but we must try to avoid that [During the last few observations the Lecturer had succeeded in placing the half cwt. in a state of quiescence upon the inflated india-rubber ball, which consequently assumed a shape very much resembling a flat cheese with round edges.] There you see a bubble of air bearing half a hundred weight, and you must conceive for yourselves what a wonderful *power* there must be to pull this weight downwards, to sink it thus in the ball of air.

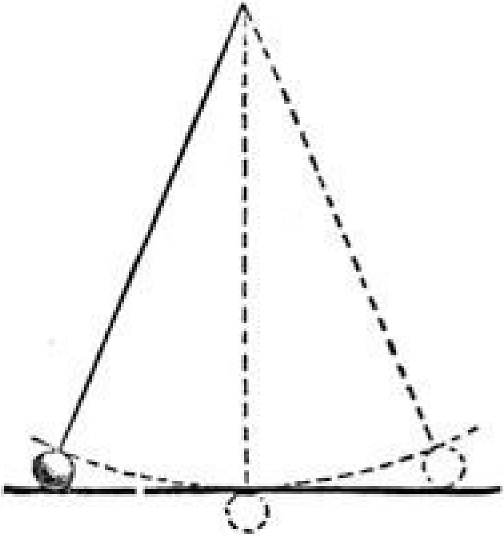

Fig. 1.

Let me now give you another illustration of this power. You know what a pendulum is. I have one here (fig. 1), and if I set it swinging, it will continue to swing to and fro. Now, I wonder whether you can tell me why that body oscillates to and fro – that pendulum bob as it is sometimes called. Observe, if I hold the straight stick horizontally, as high as the position of the balls at the two ends of its journey you see that the ball is in a higher position at the two extremities than it is when in the middle. Starting from one end of the stick, the ball falls towards the centre; and then rising again to the opposite end, it constantly tries to fall to the lowest point, swinging and vibrating most beautifully, and with wonderful properties in other respects – the time of its vibration, and so on – but concerning which we will not now trouble ourselves.

If a gold leaf, or piece of thread, or any other substance, were hung where this ball is, it would swing to and fro in the same manner, and in the same time too. Do not be startled at this statement: I repeat, in the same manner and in the same time; and you will see by and by how this is. Now, that power which caused the water to descend in the balance – which made the iron weight press upon and flatten the bubble of air – which caused the swinging to and fro of the pendulum, – that power is entirely due to the attraction which there is between the falling body and the earth. Let us be slow and careful to comprehend this. It is not that the earth has any *particular* attraction towards bodies which fall to it, but, that *all* these bodies possess an attraction, every one towards the other. It is not that the earth has any special power which these balls themselves have not; for just as much power as the earth has to attract these two balls [dropping two ivory balls], just so much power have they in proportion to their bulks to draw themselves one to the other; and the only reason why they fall so quickly to the earth is owing to its greater size. Now, if I were to place these two balls near together, I should not be able, by the most delicate arrangement of apparatus, to make you, or myself, sensible that these balls did attract one another: and yet we know that such is the case, because, if instead of taking a small ivory ball, we take a mountain, and put a ball like this near it, we find that, owing to the vast size of the mountain, as compared with the billiard ball, the latter is drawn slightly towards it; shewing clearly that an attraction *does* exist, just as it did between the shell-lac which I rubbed and the piece of paper which was overturned by it.

Now, it is not very easy to make these things quite clear at the outset, and I must take care not to leave anything unexplained as I proceed; and, therefore, I must make you clearly understand that all bodies are attracted to the earth, or, to use a more learned term, *gravitate*. You will not mind my using this word; for when I say that this penny-piece *gravitates*, I mean nothing more nor less than that it falls towards the earth, and if not intercepted, it would go on falling, falling, until it arrived at what we call the *centre of gravity* of the earth, which I will explain to you by and by.

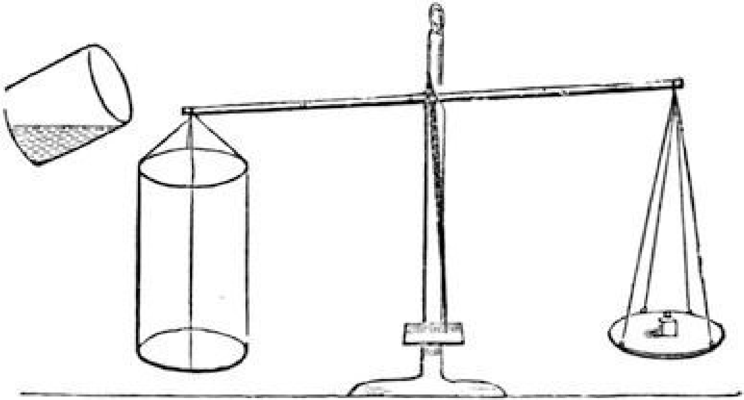

Fig. 2.

I want you to understand that this property of gravitation is never lost, that every substance possesses it, that there is never any change in the quantity of it; and, first of all, I will take as illustration a piece of marble. Now this marble has weight – as you will see if I put it in these scales; it weighs the balance down, and if I take it off, the balance goes back again and resumes its equilibrium. I can decompose this marble and change it, in the same manner as I can change ice into water and water into steam. I can convert a part of it into *its own* steam easily, and shew you that this steam from the marble has the property of remaining in the same place at common temperatures, which *water*-steam has not. If I add a little liquid to the marble, and decompose it[6], I get that which you see – [the Lecturer here put several lumps of marble into a glass jar, and poured water and then acid over them; the carbonic acid immediately commenced to escape with considerable effervescence] – the appearance of boiling, which is only the separation of one part of the marble from another. Now this [marble] steam, and that [water] steam, and all other steams *gravitate*, just like any other substance does – they all are attracted the one towards the other, and all fall towards the earth; and what I want you to see is, that *this* steam gravitates. I have here (fig. 2) a large vessel placed upon a balance, and the moment I pour this steam into it, you see that the steam gravitates. Just watch the index, and see whether it tilts over or not. [The Lecturer here poured the carbonic acid out of the glass in which it was being generated into the vessel suspended on the balance, when the gravitation of the carbonic acid was at once apparent.] Look how it is going down. How pretty that is! I poured nothing in but the invisible steam, or vapour, or gas which came from the marble, but you see that part of the marble, although it has taken the shape of air, still gravitates as

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[6] Page 29. *Add a little liquid to the marble, and decompose it.*– Marble is composed of *carbonic acid* and *lime*, and, in chemical language, is called *carbonate of lime*. When sulphuric acid is added to it, the carbonic acid is set free, and the sulphuric acid unites with the lime to form sulphate of lime.*Carbonic acid*, under ordinary circumstances, is a colourless invisible gas, about half as heavy again as air. Dr. Faraday first shewed that, under great pressure, it could be obtained in a liquid state. Thilorier, a French chemist, afterwards found that it could be solidified.

it did before. Now, will it weigh down that bit of paper? [Placing a piece of paper in the opposite scale.] Yes, more than that; it nearly weighs down this bit of paper. [Placing another piece of paper in.] And thus you see that *other* forms of matter besides solids and liquids tend to fall to the earth; and, therefore, you will accept from me the fact – that *all* things gravitate, whatever may be their form or condition. Now *here* is another chemical test which is very readily applied. [Some of the carbonic acid was poured from one vessel into another, and its presence in the latter shewn by introducing into it a lighted taper, which was immediately extinguished.] You see from this result also that it gravitates. All these experiments shew you that, tried by the balance, tried by pouring like water from one vessel to another, this steam, or vapour, or gas, is, like all other things, attracted to the earth.

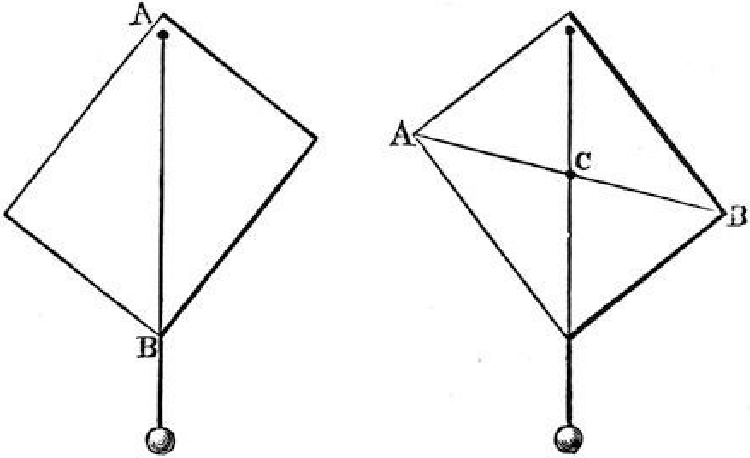
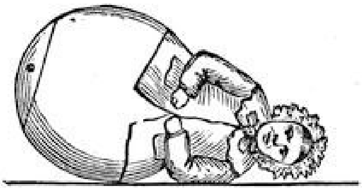


Fig. 3. and Fig. 4.

There is another point I want in the next place to draw your attention to. I have here a quantity of shot; each of these falls separately, and each has its own gravitating power, as you perceive when I let them fall loosely on a sheet of paper. If I put them into a bottle, I collect them together as one mass; and philosophers have discovered that there is a certain point in the middle of the whole collection of shots that may be considered as the *one point* in which all their gravitating power is centred, and that point they call the *centre of gravity*: it is not at all a bad name, and rather a short one – the centre of gravity. Now suppose I take a sheet of pasteboard, or any other thing easily dealt with, and run a bradawl through it at one corner A (fig.

3), and Mr. Anderson hold that up in his hand before us, and I then take a piece of thread and an ivory ball, and hang that upon the awl – then the centre of gravity of both the pasteboard and the ball and string are as near as they can get to the centre of the earth; that is to say, the whole of the attracting power of the earth is, as it were, centred in a single point of the cardboard – and this point is exactly below the point of suspension. All I have to do, therefore, is to draw a line, A B, corresponding with the string, and we shall find that the centre of gravity is somewhere in that line. But where? To find that out, all we have to do is to take another place for the awl (fig. 4), hang the plumb-line, and make the same experiment, and there [at the point C] is the centre of gravity – there where the two lines which I have traced cross each other; and if I take that pasteboard, and make a hole with the bradawl through it at that point, you will see that it will be supported in any position in which it may be placed. Now, knowing that, what do I do when I try to stand upon one leg? Do you not see that I push myself over to the left side, and quietly take up the right leg, and thus bring some central point in my body over this left leg. What is that point which I throw over? You will know at once that it is the *centre of gravity*– that point in me where the whole gravitating force of my body is centred, and which I thus bring in a line over my foot.



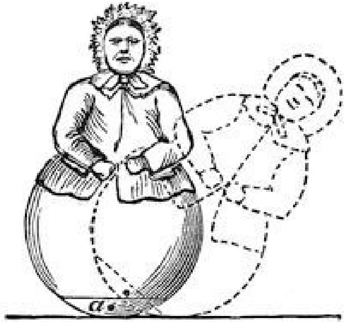


Fig. 5. and Fig. 6.

Here is a toy I happened to see the other day, which will, I think, serve to illustrate our subject very well. That toy *ought* to lie something in this manner (fig. 5); and would do so if it were uniform in substance. But you see it does not; it will get up again. And now philosophy comes to our aid; and I am perfectly sure, without looking inside the figure, that there is some arrangement by which the centre of gravity is at the lowest point when the image is standing upright; and we may be certain, when I am tilting it over (see fig. 6), that I am lifting up the centre of gravity (*a*), and raising it from the earth. All this is effected by putting a piece of lead inside the lower part of the image, and making the base of large curvature; and there you have the whole secret. But what will happen if I try to make the figure stand upon a sharp point? You observe, I must get that point *exactly* under the centre of gravity, or it will fall over thus [endeavouring unsuccessfully to balance it]; and this you see is a difficult matter – I cannot make it stand steadily. But if I embarrass this poor old lady with a world of trouble, and hang this wire with bullets at each end about her neck, it is very evident that, owing to there being those balls of lead hanging down on either side, in addition to the lead inside, I have lowered the centre of gravity, and now she will stand upon this point (fig. 7); and what is more, she proves the truth of our philosophy by standing sideways.

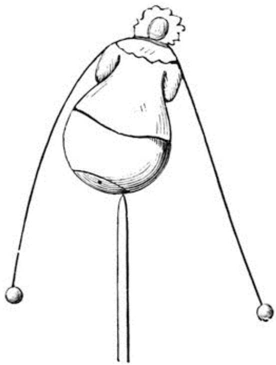


Fig. 7.

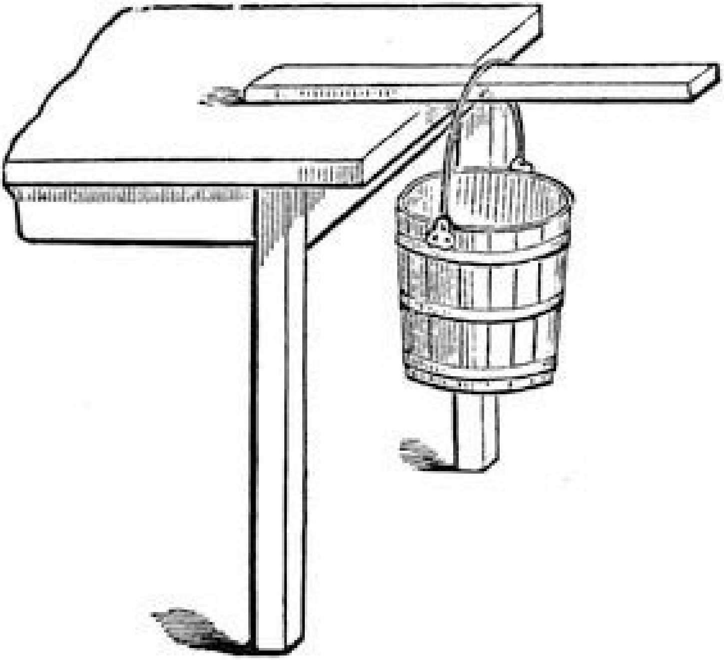


Fig. 8.

I remember an experiment which puzzled me very much when a boy. I read it in a conjuring book, and this was how the problem was put to us: “How,” as the book said, “how to hang a pail of water, by means of a stick, upon the side of a table” (fig. 8). Now, I have here a table, a piece of stick, and a pail, and the proposition is, how can that pail be hung to the edge of this table? It is to be done; and can you at all anticipate what arrangement I shall make to enable me to succeed? Why, this. I take a stick, and put it in the pail between the bottom and the horizontal piece of wood, and thus give it a stiff handle – and there it is; and what is more, the more water I put into the pail the better it will hang. It is very true that before I quite succeeded I had the misfortune to push the bottoms of several pails out; but here it is hanging firmly (fig. 9), and you now see how you can hang up the pail in the way which the conjuring books require.

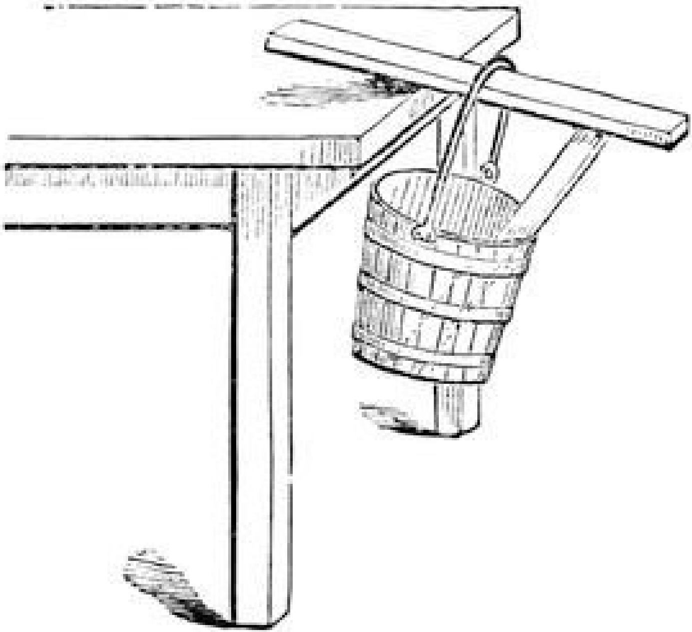


Fig. 9.

Again, if you are really so inclined (and I do hope all of you are), you will find a great deal of philosophy in this [holding up a cork and a pointed thin stick about a foot long]. Do not refer to your toy-books, and say you have seen that before. Answer me rather, if I ask you have you *understood* it before? It is an experiment which appeared very wonderful to me when I was a boy; I used to take a piece of cork (and I remember, I thought at first that it was very important that it should be cut out in the shape of a man; but by degrees I got rid of that idea), and the problem was to balance it on the point of a stick. Now, you will see I have only to place two sharp-pointed sticks one on each side, and give it wings, thus, and you will find this beautiful condition fulfilled.

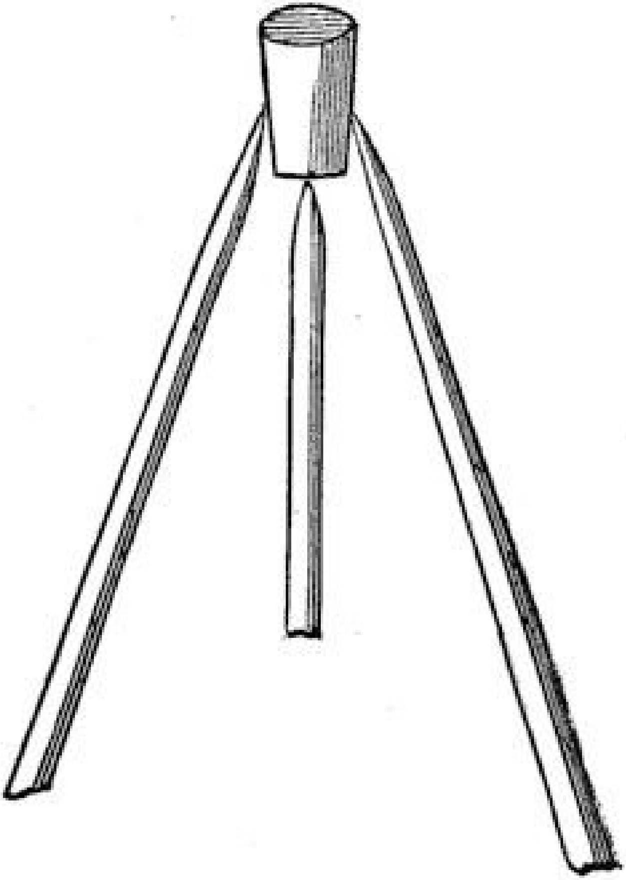


Fig. 10.

We come now to another point: – All bodies, whether heavy or light, fall to the earth by this force which we call gravity. By observation, moreover, we see that bodies do not occupy the same time in falling. I think you will be able to see that this piece of paper and that ivory ball fall with different velocities to the table [dropping them]; and if, again, I take a feather and an ivory ball, and let them fall, you see they reach the table or earth at different times – that is to say, the ball falls faster than the feather. Now, that should not be so, for all bodies do fall equally fast to the earth. There are one or two beautiful points included in that statement. First of all, it is manifest that an ounce, or a pound, or a ton, or a thousand tons, all fall equally fast, no one faster than another: here are two balls of lead, a very light one and a very heavy one, and you perceive they both fall to the earth in the same time. Now, if I were to put into a little bag a number of these balls sufficient to make up a bulk equal to the large one, they would also fall in the same time; for if an avalanche fall from the mountains, the rocks, snow and ice, together falling towards the earth, fall with the same velocity, whatever be their size.

I cannot take a better illustration of this than that of gold leaf, because it brings before us the reason of this apparent difference in the time of the fall. Here is a piece of gold-leaf. Now, if I take a lump of gold and this gold-leaf, and let them fall through the air together, you see that the lump of gold – the sovereign, or coin – will fall much faster than the gold leaf. But why? They are both gold, whether sovereign or gold-leaf. Why should they not fall to the earth with the same quickness? *They would do* *so*, but that the air around our globe interferes very much where we have the piece of gold so extended and enlarged as to offer much obstruction on falling through it. I will, however, shew you that gold-leaf *does* fall as fast when the resistance of the air is excluded – for if I take a piece of gold-leaf and hang it in the centre of a bottle, so that the gold, and the bottle, and the air within shall all have an equal chance of falling, then the gold-leaf will fall as fast as anything else. And if I suspend the bottle containing the gold-leaf to a string, and set it oscillating like a pendulum, I may make it vibrate as hard as I please, and the gold-leaf will not be disturbed, but will swing as steadily as a piece of iron would do; and I might even swing it round my head with any degree of force, and it would remain undisturbed. Or I can try another kind of experiment: – if I raise the gold-leaf in this way [pulling the bottle up to the ceiling of the theatre by means of a cord and pulley, and then suddenly letting it fall to within a few inches of the lecture-table], and allow it then to fall from the ceiling downwards (I will put something beneath to catch it, supposing I should be *maladroit*), you will perceive that the gold-leaf is not in the least disturbed. The resistance of the air having been avoided, the glass bottle and gold-leaf all fall exactly in the same time.

Here is another illustration, – I have hung a piece of gold-leaf in the upper part of this long glass vessel, and I have the means, by a little arrangement at the top, of letting the gold-leaf loose. Before we let it loose we will remove the air by means of an air pump, and while that is being done, let me shew you another experiment of the same kind. Take a penny-piece, or a half-crown, and a round piece of paper a trifle smaller in diameter than the coin, and try them, side by side, to see whether they fall at the same time [dropping them]. You see they do not – the penny-piece goes down first. But, now place this paper flat on the top of the coin, so that it shall not meet with any resistance from the air, and upon *then* dropping them you see they *do* both fall in the same time [exhibiting the effect]. I dare say, if I were to put this piece of gold-leaf, instead of the paper, on the coin, it would do as well. It is very difficult to lay the gold-leaf so flat that the air shall not get under it and lift it up in falling, and I am rather doubtful as to the success of this, because the gold-leaf is puckery; but will risk the experiment. There they go together! [letting them fall] and you see at once that they both reach the table at the same moment.

We have now pumped the air out of the vessel, and you will perceive that the gold-leaf will fall as quickly in this vacuum as the coin does in the air. I am now going to let it loose, and you must watch to see how rapidly it falls. There! [letting the gold loose] there it is, falling as gold should fall.

I am sorry to see our time for parting is drawing so near. As we proceed, I intend to write upon the board behind me certain words, so as to recall to your minds what we have already examined – and I put the word Forces as a heading; and I will then add, beneath, the names of the special forces according to the order in which we consider them: and although I fear that I have not sufficiently pointed out to you the more important circumstances connected with this force of Gravitation, especially the law which governs its attraction (for which, I think, I must take up a little time at our next meeting), still I will put that word on the board, and hope you will now remember that we have in some degree considered the *force of gravitation*– that force which causes all bodies to attract each other when they are at sensible distances apart, and tends to draw them together.

LECTURE II.
GRAVITATION – COHESION

Do me the favour to pay me as much attention as you did at our last meeting, and I shall not repent of that which I have proposed to undertake. It will be impossible for us to consider the Laws of Nature, and what they effect, unless we now and then give our sole attention, so as to obtain a clear idea upon the subject. Give me now that attention, and then, I trust, we shall not part without your knowing something about those Laws, and the manner in which they act. You recollect, upon the last occasion, I explained that all bodies attracted each other, and that this power we called *gravitation*. I told you that when we brought these two bodies [two equal sized ivory balls suspended by threads] near together, they attracted each other, and that we might suppose that the whole power of this attraction was exerted between their respective centres of gravity; and furthermore, you learned from me, that if, instead of a small ball, I took a larger one, like *that* [changing one of the balls for a much larger one], there was much more of this attraction exerted; or, if I made this ball larger and larger, until, if it were possible, it became as large as the Earth itself – or, I might take the Earth itself as the large ball – that *then* the attraction would become so powerful as to cause them to rush together in this manner [dropping the ivory ball]. You sit *there* upright, and I stand upright *here*, because we keep our centres of gravity properly balanced with respect to the earth; and I need not tell you that on the other side of this world the people are standing and moving about with their feet towards our feet, in a reversed position as compared with us, and all by means of this power of gravitation to the centre of the earth.

I must not, however, leave the subject of gravitation, without telling you something about its laws and regularity; and first, as regards its power with respect to the distance that bodies are apart. If I take one of these balls and place it within an inch of the other, they attract each other with a certain power. If I hold it at a greater distance off, they attract with less power; and if I hold it at a greater distance still, their attraction is still less. Now this fact is of the greatest consequence; for, knowing this law, philosophers have discovered most wonderful things. You know that there is a planet, Uranus, revolving round the sun with us, but eighteen hundred millions of miles off; and because there is another planet as far off as three thousand millions of miles, this law of attraction, or gravitation, still holds good – and philosophers actually discovered this latter planet, Neptune, by reason of the effects of its attraction at this overwhelming distance. Now I want you clearly to understand what this law is. They say (and they are right) that two bodies attract each other *inversely as the square of the distance*– a sad jumble of words until you understand them; but I think we shall soon comprehend what this law is, and what is the meaning of the "inverse square of the distance."

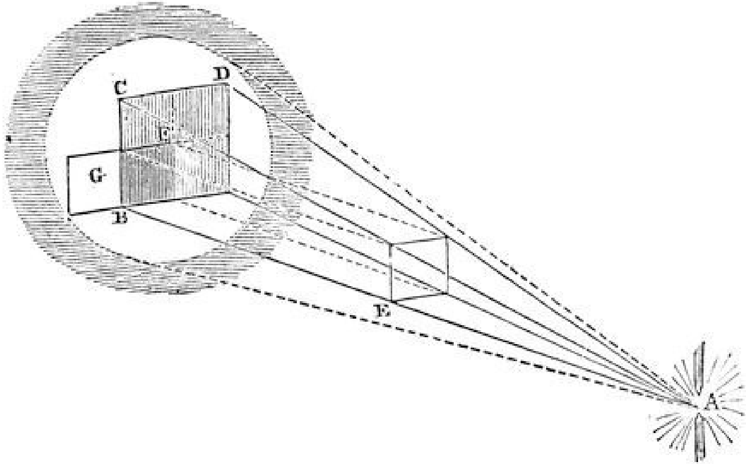


Fig. 11.

I have here (fig. 11) a lamp A, shining most intensely upon this disc, B, C, D; and this light acts as a sun by which I can get a shadow from this little screen, B F (merely a square piece of card), which, as you know, when I place it close to the large screen, just shadows as much of it as is exactly equal to its own size. But now let me take this card E, which is equal to the other one in size, and place it midway between the lamp and the screen: now look at the size of the shadow B D – it is four times the original size. Here, then, comes the "inverse square of the distance." This distance, A E, is *one*, and that distance, A B, is *two*; but that size E being *one*, this size B D of shadow is *four* instead of *two*, which is the *square* of the distance; and, if I put the screen at one-third of the distance from the lamp, the shadow on the large screen would be *nine* times the size. Again, if I hold this screen *here*, at B F, a certain amount of light falls on it; and if I hold it nearer the lamp at E, *more* light shines upon it. And you see at once how much – exactly the quantity which I have shut off from the part of this screen, B D, now in shadow; moreover, you see that if I put a single screen here, at G, by the side of the shadow, it can only receive *one-fourth* of the proportion of light which is obstructed. That, then, is what is meant by the *inverse* of the square of the distance. This screen E is the brightest, because it is the nearest; and there is the whole secret of this curious expression, *inversely as the square of the distance*. Now, if you cannot perfectly recollect this when you go home, get a candle and throw a shadow of something – your profile, if you like – on the wall, and then recede or advance, and you will find that your shadow is exactly in proportion to the *square* of the distance you are off the wall; and then if you consider how much light shines on you at one distance, and how much at another, you get the inverse accordingly. So it is as regards the attraction of these two balls – they attract according to the square of the distance, inversely. I want you to try and remember these words, and then you will be able to go into all the calculations of astronomers as to the planets and other bodies, and tell why they move so fast, and why they go *round* the sun without falling into it, and be prepared to enter upon many other interesting inquiries of the like nature.

Let us now leave this subject which I have written upon the board under the word Force – Gravitation – and go a step further. All bodies attract each other at sensible distances. I shewed you the electric attraction on the last occasion (though I did not call it so); that attracts at a distance: and in order to make our progress a little more gradual, suppose I take a few iron particles [dropping some small fragments of iron on the table]. There, I have already told you that in all cases where bodies fall, it is the *particles* that are attracted. You may consider these then as separate particles magnified, so as to be evident to your sight; they are loose from each other – they all gravitate – they all fall to the earth – for the force of gravitation *never* fails. Now, I have here a centre of power which I will not name at present, and when these particles are placed upon it, see what an attraction they have for each other.

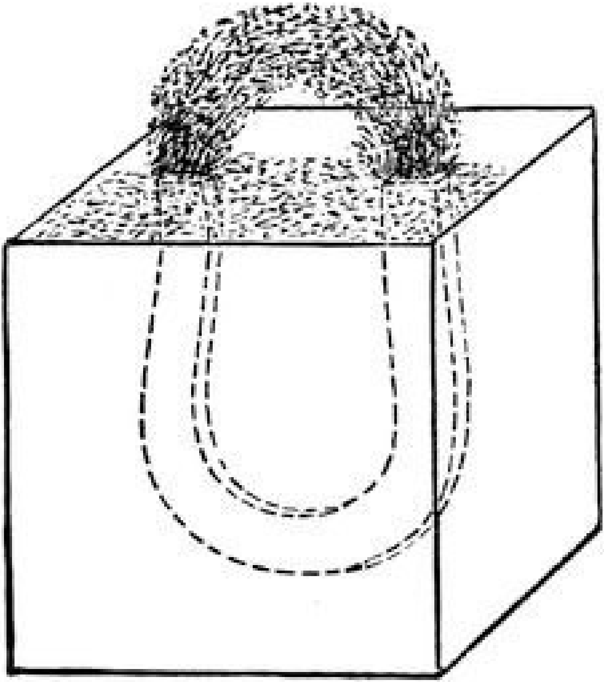


Fig. 12.

Here I have an arch of iron filings (fig. 12) regularly built up like an iron bridge, because I have put them within a sphere of action which will cause them to attract each other. See! – I could let a mouse run through it, and yet if I try to do the same thing with them *here* [on the table], they do not attract each other at all. It is *that* [the magnet] which makes them hold together. Now, just as these iron particles hold together in the form of an elliptical bridge, so do the different particles of iron which constitute this nail hold together and make it one. And here is a bar of iron – why, it is only because the different parts of *this* iron are so wrought as to keep close together by the attraction *between* the particles that it is held together in one mass. It is kept together, in fact, merely by the attraction of one particle to another, and that is the point I want now to illustrate. If I take a piece of flint and strike it with a hammer, and break it thus [breaking off a piece of the flint], I have done nothing more than separate the particles which compose these two pieces so far apart, that their attraction is too weak to cause them to hold together, and it is only for that reason that there are now two pieces in the place of one. I will shew you an experiment to prove that this attraction does still exist in those particles, for here is a piece of glass (for what was true of the flint and the bar of iron is true of the piece of glass, and is true of every other solid – they are all held together in the lump by the attraction between their parts), and I can shew you the attraction between its separate particles; for if I take these portions of glass, which I have reduced to very fine powder, you see that I can actually build them up into a solid wall by pressure between two flat surfaces. The power which I thus have of building up this wall is due to the attraction of the particles, forming as it were the cement which holds them together; and so in this case, where I have taken no very great pains to bring the particles together, you see perhaps a couple of ounces of finely-pounded glass standing as an upright wall. Is not this attraction most wonderful? *That* bar of iron one inch square has such power of attraction in its particles – giving to it such strength – that it will hold up twenty tons weight before the little set of particles in the small space, equal to one division across which it can be pulled apart, will separate. In this manner suspension bridges and chains are held together by the attraction of their particles; and I am going to make an experiment which will shew how strong is this attraction of the particles. [The Lecturer here placed his foot on a loop of wire fastened to a support above, and swung with his whole weight resting upon it for some moments.] You see while hanging here all my weight is supported by these little particles of the wire, just as in pantomimes they sometimes suspend gentlemen and damsels.

How can we make this attraction of the particles a little more simple? There are many things which if brought together properly will shew this attraction. Here is a boy's experiment (and I like a boy's experiment). Get a tobacco-pipe, fill it with lead, melt it, and then pour it out upon a stone, and thus get a clean piece of lead (this is a better plan than scraping it – scraping alters the condition of the surface of the lead). I have here some pieces of lead which I melted this morning for the sake of making them clean. Now these pieces of lead hang together by the attraction of their particles; and if I press these two separate pieces close together, so as to bring their particles within the sphere of attraction, you will see how soon they become one. I have merely to give them a good squeeze, and draw the upper piece slightly round at the same time, and here they are as one, and all the bending and twisting I can give them will not separate them again: I have joined the lead together, not with solder, but simply by means of the attraction of the particles.

This, however, is not the best way of bringing those particles together – we have many better plans than that; and I will shew you one that will do very well for juvenile experiments. There is some alum crystallised very beautifully by nature (for all things are far more beautiful in their natural than their artificial form), and here I have some of the same alum broken into fine powder. In it I have destroyed that force of which I have placed the name on this board – Cohesion, or the attraction exerted between the particles of bodies to hold them together. Now I am going to shew you that if we take this powdered alum and some hot water, and mix them together, I shall dissolve the alum – all the particles will be separated by the water far more completely than they are here in the powder; but then, being in the water, they will have the opportunity as it cools (for that is the condition which favours their coalescence) of uniting together again and forming one mass.[7]

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[7] Page 55. *Crystallisation of Alum.*– The solution must be saturated – that is, it must contain as much alum as can possibly be dissolved. In making the solution, it is best to add powdered alum to hot water as long as it dissolves; and when no more is taken up, allow the solution to stand a few minutes, and then pour it off from the dirt and

undissolved alum.

Конец ознакомительного фрагмента.