GRAVITY FOR GEOLOGISTS.

WHEN I was quite a small boy I was fully prepared to believe that the world was round, if older people said so; but I refused to believe that I was ever on the underneath side of it. Like most of you when you also were young, I had swung upside down from the branches of trees and the cross-bar, and could stand on my head, provided that there was a wall behind against which I could put my feet when I felt wobbly: so I knew what it felt like to be upside down, and refused to believe that either I or people in England (and it must be one or the other) walked about upside down on the spherical earth. Later on I knew it must be true, but was not in the least helped by being told that none of us were upside down, because there wasn't any such thing as up and down; that the sky was always " up ", and as long as I kept the sky above my head I was right side up, but that when I put my head nearer the ground and my feet up towards the sky, I was officially " upside down ". What difference could it make whether I tipped upside down from a cross-bar, or walked round to the other side of the world, or let the earth revolve and tip me upside down? In any case, I would now be presenting my feet to the patch of sky that previously had admired the top of my head.

You will find many quite elderly people today who know all about stocks and shares, and modern literature, accountancy, and such things, who still are far from convincing as to why I am not red in the face for twelve hours in the day and comfortably right side up for the remainder of the time. To tell me that there is no such thing as " up and down " is just silly—they are words and ideas we use all the time, and must have some meaning. Possibly we are upside down during the night, and sleep through it—which might account for the red faces and wobbly walk of some people late at night if they insist on staying up? That, of course, is equally silly, and would never convince the police. Nowadays I think I know as much as anyone else about it, and I can tell you quite certainly that up and down are definite words—but that we musn't concentrate on the " up ", but on the " down ". The earth is always down from us, so that things fall " down " and are pulled " down " always to the earth. " Up " is merely the opposite to down. We have got so accustomed to considering the immensity around us that we do tend to forget the very great importance to us of this otherwise trivial speck of dust in space, which forms our earth.

Now we will jump straight to the information obtained for us by Isaac Newton, who spent his eighty-five years of life in England between 1642 and 1727, and studied the subject of gravitational attraction, amongst other things. He formulated a law of universal gravitation, and found that all matter behaved as though it was attracted to all other matter, either here at the surface of the earth, or out in the depths of our solar system ; that not only do things tend to fall to the earth, because the earth pulls them, but that the earth tends to fall to the things, because the things pull the earth with exactly the same force with which the earth pulls them ; that the earth pulls the moon to it so that it would fall on the earth but for the speed with which it rushes round in the orbit in which it is trapped, ever trying to escape ; that the sun pulls the earth, so that we would fall hurtling into that vast flaming mass if we slowed sufficiently in our rush round our annual orbit ; and that all these forces are nicely balanced. The law of universal gravitation is that all bodies attract one another with pulls or forces proportional to the product of their masses, and inversely proportional to the square of their distances apart.

This is quite easily shown even in an ordinary physical laboratory—and is often demonstrated there. This is *not* the experiment, but will give us a simple example : suppose we take two big spheres of lead, and suspend them from the roof by two long wires, so that they hang side by side, and nearly touching. To take figures, we will use lead balls a foot in diameter, so that they will *each* contain about 3,000 pounds of lead ; it seems a lot, but lead is nearly eleven and a half times as dense as water, and a cubic foot of water has a mass of over 62 pounds. We will now hang these lead spheres so that, when quite still and steady, they *nearly* touch. Then some bits of lead (the far side of each ball) are a little more than *two* feet apart, and some bits are a very small distance apart (those facing one another on the inside) so that on an average for the two spheres it works out as though all the lead in one ball were *one* foot away from all the lead in the other ball : just as though all the lead in each ball could be imagined concentrated at its centre, so far as the effect on the other ball was concerned. We find that both suspending wires are pulled out of the vertical, because the two lead masses are attracted to one another ; the pull is not much compared with the pull on each to the great massive ball, our earth, below them; but it is relatively enough to be able to cause observable and measurable effects, and to enable us to calculate what the pull of lead ball on lead ball amounts to. We find that the force between them, the pull of the one lead mass or the other, is just about one one-hundredth of a poundal.* Here I have regretfully to acknowledge that although you may know by definition what a poundal is, you cannot think in terms of poundals, always having thought about forces in terms of the pull of the earth on bodies. But, for a moment, hold fast to this one one-hundredth of a poundal, the pull we find to exist between the two 3,000 pound lead balls, that pulls their suspending wires out of the vertical.

You could not stagger round with one of these lead masses, although it is only a foot in diameter; 3,000 pounds is getting on for a ton and a quarter. Even the feeblest amongst you, however, could manage to carry a one pound lump of lead—in other words, you can resist the pull on that small lump towards the other large lump, the spherical world below you. The pull is so big that you can feel it. You call it the "weight" of the body, and say the body "weighs" a pound. That pull, a pound weight, would vary a little from place to place, so we do not like using it as a unit of force; we prefer to use the absolute unit, the poundal, there being about 32 poundals to the pound weight.

All this time you have been mentally holding fast to the idea of the one one-hundredth of a poundal pull between our two large lead spheres; that pull, then, is a little under one three-thousandth of the weight of a pound. You know the little one gramme masses in your balance boxes? It is not very heavy, is it? That is, the pull to earth on it is quite small? The pull between these massive lead balls, 3,000 pounds each, nearly in contact, is only about $\frac{1}{7}$th of the weight of the little gramme mass. (A threepenny-bit has a mass of approximately $1\frac{1}{4}$ grammes.)

That is our experiment in the laboratory; but all the time we have also been carrying out the experiment on a much vaster scale, because we have been holding a sphere one foot in diameter close to a sphere 8,000 miles

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* A poundal is the absolute unit of force in the British system, and is equal to that force which produces an acceleration of 1 foot per second per second in the direction of the force when acting on a mass of 1 pound.

in diameter, but not letting it fall on to it. Come out with me into space, and look down on this other experiment; there below us is a big ball, our earth, 8,000 miles through; and that relatively tiny ball *very* close to it is one of our lead balls one foot in diameter; it is our laboratory experiment over again, and in this case we measure the pull between them as 3,000 pounds weight. That is what we *mean* by weight—the pulls recorded in this bigger experiment. Every mass, whether by itself or as part of a larger body, is pulled towards the masses that go to make up the world sphere; some of those bits of world mass are 8,000 miles away, on the other side; some are quite close to us; on *an average*, the world masses are 4,000 miles away from us, as though at the centre of our spherical world.

That, then, is our *down*—it is always *down* in the direction in which the lead masses, and stones, and trees and birds, and us, and every drop of blood and every bit of us is being pulled. Certainly things round about pull us, just as the lead ball pulls on lead ball; but those pulls are very tiny pulls compared with that due to the vast mass below us. Certainly the moon, and the sun, and other planets and stars pull us also—but they are far away, and exert again a very tiny pull compared with the giant earth pull. *Down* is always to the centre of the earth; *up* is merely the opposite direction. We are not " upside down " unless we insist on presenting our heads towards the centre of the world, and our feet towards the sky.

Going back to our two big masses of lead in the laboratory, suppose that, still keeping the centre of two spheres one foot apart, we reduce *one or the other* of them to a ball of half the volume, and thus half the mass of lead: the pull of ball on ball now drops back to half what it was before; if we reduce *both* to 1,500 pounds of lead, that is, *both* to half mass, but still keep their centres a foot apart, we find that we only have a quarter of our first pull. Many other experiments show us quite definitely that the apparent effect of what we call " gravitational attraction " is directly proportional to the product of the two masses concerned.

Let us get that quite clear—it does not matter whether both are 3,000 pound balls, so that their product is 9,000,000, or whether one is a 1,000 pound ball and the other a 9,000 pound ball—for the same product the pull is the same, so long as we do not alter the distance apart of the centres of masses. If that *product* be doubled, then the pull is doubled, and so on.

Now you see how we can find the mass of the big world ball—except that we do not yet know the effect of altering the distance of the centres from one foot to 4,000 miles apart. Tests with all sorts of bodies, in many different kinds of experiments, show that the change is easily calculated. When we move the centres of the masses further apart, we get a weaker pull; when we move their centres closer together, a stronger pull; you probably will not remember it, but when our two lead balls, each of one foot diameter, were nearly touching, their *centres* were one foot apart, and the pull of 3,000 ball on 3,000 pound ball was one one-hundredth of a poundal, or about one three-thousandth of the weight of a pound. If we hung them so that there was a whole foot gap between the two balls, then the distance from centre to centre woud now be two feet, double what it was before; and the pull would have dropped to a *quarter* of its value. *Doubling* the distance apart of the centres of masses, for the same masses, sends the pull down to a *quarter*. Similarly, if the masses were *three feet* centre to centre, the pull would drop to a *ninth*; *four feet* centre to centre, to a *sixteenth*, and so on. So that we say the pull is inversely as the square of the distances apart from centre of mass to centre of mass.

Now we can carry our reasoning on to the earth mass by a simple piece of reasoning and a simple piece of arithmetic. Here it is: If a 3,000 pound mass pull on another 3,000 pound mass with a force of about one three-thousandth of a pound weight, when their centres are a foot apart, what must be the earth mass that pulls on each one of those 3,000 pound masses with a force of 3,000 pounds weight when their centres are 4,000 miles apart?

That is an easy piece of proportionality, and you can do it in your head as I possibly am doing it now. The answer is that the new big ball in our world experiment must have a mass of $5 \cdot 87 \times 10^{21}$ tons. Nearly six thousand million million million tons. If you want to see it in front of you, write down 587, and then put nineteen noughts after it and then the word tons. It is quite a considerable mass, isn't it? and so is most attractive to us.

It is very lucky for us that it has such a big mass, otherwise loose objects would not be able to be whirled round on it, but would shoot off into space like drops of water from the spokes of an umbrella when you whirl it quickly. If you sit on the equator, you are spun round at over a thousand miles an hour in the circle of 8,000 miles diameter as the earth turns on its axis. Also, you might get left behind if you did not hang on round the curve, as the earth sweeps out its approximately circular path round the sun throughout the year; but the earth pull is so strong that it holds us and other loose things, including the air, and water, and water vapour, firmly enough for us not to worry. The moon, on the other hand, had not a big enough mass to pull objects to it whilst it swirled round rapidly, and so lost them all; it has also lost all its fast moving particles, so that there is not any air or water vapour, and thence no water, there. It takes a pull or push into the centre to help any object travel round in a curved path, as lots of people have found who have tried to take a sharp curve on a slippery road in a motor car travelling too fast.

One of Newton's big discoveries was that this same law of gravitational attraction applied beyond our own earth, it not making any difference whether we use a pound of lead or a pound of the earth, or a pound of moon, or a pound of the sun. Knowing the masses of bodies and the distances apart, we know the pull; or if we know the pull, and the distance apart, and *one* of the masses, we can calculate the other. The pull can be worked out if. we know the curved path in which the satellite or planet is going, and how fast it is travelling in that path—in other words, even the earth itself has to "hold on round the curve" as it travels in its orbit round the sun. Tie a stone on to a spring balance and whirl it round and round in a circle, and the balance will show the pull required for that mass to do that particular curved path at so many revolutions per second. In our experiment in the solar system the earth, our world, is the stone, and it swirls round in a path of about 93 million miles radius round the sun every 365 days or thereabouts. We know what pull is required to do that, although there is no string or spring balance in between. So we know the pull between the big spheres the earth and the sun, and we know the distance apart; we have previously calculated the magnitude of one of the pulling masses, that of the earth; hence we know the mass of the sun. The mass of the earth was too great for you to imagine—getting on for six thousand million million million tons; the sun is calculated to be about 330,000 times as great as that. If you *must* write it down, write a 2, and then put twenty-seven noughts after that, and then the word tons. That is close enough to the mass of the sun for everyday purposes.

Now we have the mass of the sun, and so can calculate the mass of all the other planets, and then of the satellites that circle round them in turn.

Can we check this up ? Yes, we can check this up. The planets are also going to pull on one another, and they are going to get themselves into all sorts of relative positions and distances apart, which will introduce little perturbations or wobbles into their paths, which astronomers with a desire to do an enormous lot of calculation can work out. They have been worked out, and just the right wobbles in planetary orbits are present. That, of course, is much more comprehensive and complicated calculating, but still based on the same law of universal gravitation, and it all fits in.

Here is an even more amazing thing—in some cases wobbles in the orbits of our more distant planets have been unexplained ; and, working backwards from this wobble, astronomers have calculated that it should be due to such and such a mass, in such and such an orbit, and it should be in such and such a place at such and such a time. You see that the hitherto undetected planet has not a chance ; telescopes are turned on to it, and it is picked out from the unnamed obscurity in which it has previously lurked ; it is then observed carefully to see if it is following the orbit that has been calculated for it ; and it is certainly a reward for quite a lot of calculating to see the far distant planet definitely shifting on at the right rate in its far-flung orbit round our sun.

Only within this last couple of years has the last observed of the planets been picked up—he was known by calculation to exist, but had not been located ; you will understand that we only see a planet by the light it reflects from our sun, and the outermost ones are a very long way off. He was named before he was observed, and has now been picked up and followed round for a part of his path ; he takes a very long time to get round. His name is Pluto. I want particularly to introduce you to Pluto, because he has not yet got into school books, which take you out from the sun past the orbits of Mercury, Venus, our Earth, Mars, Jupiter, Saturn, Uranus and Neptune. Now you must add Pluto, and should have added him two years ago—but news travels slowly.

This is really only the very beginning of an article on gravity and gravitational attraction ; but you can console yourselves with the thought that it is the end of this one.