THE REALM OF SCIENCE

THE EARTH A STEEL BALL.

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THAT astronomy habitually deals with numbers, distances and quantities that stagger our ordinary imagination, is a fact now quite universally conceded by the general reader. While he is favorably disposed to grant almost everything that astronomy demands, there are some things, however, at which, what he calls his inborn common sense, rebels, and which seem to him impositions upon his credulity. One of these things refers to the constitution of the earth's interior. When the highest mountains are less than six miles high, and the deepest oceans less than ten miles deep, thus giving us a total range of only sixteen miles out of the four thousand that lie between us and the earth's centre, it seems the height of rashness and precipitation to pretend to judge upon the constitution of the immense interior and unexplorable regions that must forever remain to us a *terra incognita.*

And yet astronomers can do it and do it well. Like other men, they are gifted with intelligence and reason, and when a direct attack upon a set problem is hopeless, they may draw very solid conslusions by means of indirect methods. Let me illustrate by an experiment lately performed in the Creighton College Physical Laboratory.

What plumbers would call a three-eighths inch brass tube about ten inches long, had a small quantity of water put into it. Clamping the tube between two boards and turning it by means of a crank fastened to one end, soon developed enough heat by the friction to change some of the water into steam and to blow out the cork that had been put into the other end of the tube.

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The experiment was quite a favorite one with the students, probably because it gave them a chance to display their athletic powers and to scientifically measure their strength.

Not all of the water is changed to steam in the experiment, and the problem is to find out exactly how much. As much of the remaining water is spurted out of the tube along with the cork, and it is a hopeless task to collect it and compare it with that originally put into the tube, the student must resort to the indirect method of computing it. Precise figures must of course be employed, but in order not to weary the non-mathematical reader, let us use only round numbers.

A cubic inch of water makes a cubic foot of steam very nearly under ordinary conditions. We know what fraction of a cubic foot the tube will hold, and can hence compute the quantity of the steam and of the water. However, besides overcoming the pressure of the air, the steam must also have the strength to blow out the cork, the pull to dislodge which is found by a spring balance. In this indirect way we may find out exactly how much water was changed to steam and how much physical strength was required to do it, and thereby obtain results that are much more reliable than those that direct weighing could give.

In a similar way astronomers can acquire information in regard to the earth's interior. The first step in this problem is to find the exact size and shape of the earth and thereby know its volume. This is a long and involved operation, although the general principles of it are readily grasped by the student. We may dilate upon it on another occasion.

The second step is to find the weight of the whole earth, that is, the total quantity of matter that it contains. This operation is more delicate, probably, than the first, although not quite so long. In principle, it consists in comparing the weight of a small object with the attraction exerted upon it by a very large one, its weight being nothing but the attraction of the earth. This will enable us to find out how much larger the earth is than the large object we use in the experiment. It may be worth our while in passing to know the answer. We are told that the earth weighs six thousands of millions of millions of millions of tons, that is 6 with 21 cyphers after it—6,000,000000,-000000,000000.

The third step is an easy one. It consists in dividing the mass or quantity of matter in the earth by its volume. This will give us its density or compactness, which is about five and two-thirds times that of water. That is to say, the earth is 5 2/3 times as dense or as heavy as an equal bulk of water would be. This is of course the average density of the whole earth. It is of interest to compare this number with that of some familiar substances. Thus, water being taken as the standard, the density of aluminum is 2.6, of brass and copper 8, iron 7, lead 11, mercury 13.6, silver 10.5, and gold 19.

We said that 5 2/3 was the average density of the whole earth. We know that the average density of the rocks and minerals and ores on the earth's surface is only about 2½, from which it follows that the interior of the earth must be very much more dense than 5 2/3 times water. This of course was to be expected. But science gives our surmise some definite numerical shape.

There is another important property of bodies that concerns us much in this paper. It is called rigidity, and is the force with which they tend to preserve their shape and to resist deformation. This property belongs to solids only, because liquids and gases have no rigidity whatever and obey perfectly the least force that is brought to bear upon them. In the popular mind rigidity is thought to be proportionate to density. This is manifestly untrue, since lead is nearly five times as dense as aluminum, but has very little rigidity. The arms of a delicate balance, in which rigidity is the first requisite, are often made of aluminum, but no one would dream of making them of lead.

Now the rigidity of the earth is about the same as that of steel, that is as far as the preservation of its shape is concerned, the earth is practically a steel ball. This ought to do away with all apprehension concerning the wholesale destruction of a continent by an earthquake.

The proof of this great rigidity of the earth is an indirect one, but not the less cogent for that reason. Celestial mechanics tells us that two near large bodies mutually distort one another's spherical shape, so that both become elongated along the line that joins their centres. Hence the earth and the moon must exert such a disturbing pull on one another, so much so that the movable parts on their surfaces must show it. This is a fact, as we know, in regard to the tides which the moon raises on the earth. And this fact is so well established that we always predict the tides according to the position of the moon. The conformation of our continents and the diurnal rotation of the earth on its axis, together with the motions of the moon in its orbit, introduce various complications into the problem. The sun's attractions complicate matters still more. But the patience of astronomers has ferreted out all, or practically all, of the data of the problem. Then, since all the causes concerned, such as distances, positions and the like, act in recurring periods of a day, a month, a year, or other times, the genius of astronomers has put their mathematical equations into a mechanical form, and constructed a tide-predicting machine, in which the periods are represented by wheels with the proper number of cogs, the magnitudes by the lengths of adjustable bars through their centres, and their mutual relations to one another by their proper positions or inclinations at any assumed moment. A single chain or wire running over all the pulleys, with one end anchored and the other attached to a weight, is then made to feel the effect of each component by raising or lowering the weight, which thus obeys the resultant of all the components and by means of an attached pen inscribes its position on a moving strip of paper. Such a tide-predicting machine has been constructed by the United States Coast and Geodetic Survey, and is sometimes exhibited at our World's Fairs or other occasions. The machine, once all its parts are properly set, will then run out a graph of the tides for any determined place for as long a time ahead as we please. And the difference between the machine predictions and the actual tides amounts at most to a few inches.

Now, as no body has perfect rigidity, the solid earth itself ought to obey the moon's tide-rising force and show a bulge towards the moon, modified of course, by the sun, by its own rotation and other facts. The result of the coming and going bulge would be a swaying of the earth's surface, a change of inclination of the surface of still water or of any liquid. As the masses and distance apart of the earth and moon are well known, we can compute the theoretical inclination of a sheet of still water upon a perfectly rigid earth. If there is a difference between this theoretical and the actual inclination, it must be due to the swaying of the earth's surface, and will give us the data from which we can compute the actual rigidity of the earth.

Professor Michelson, of the University of Chicago, one of the ablest physicists living, lately laid down two large pipes, each 500 feet long, on a perfect level, one north and south, and the other east and west, and half-filled them with water. Delicate recording instruments at the four ends kept account of the difference of level. After an extended series of observations and an exhaustive mathematical analysis, he confirmed Darwin's former results that the earth is as rigid as steel. We may rest assured, therefore, that our earthly home is perfectly secure and not in the least liable to being twisted out of shape by the attractions of wandering comets.

The objection will, of course occur to the reader: what then about earthquakes? These are purely local accidents and their causes not at all deep-seated. Seismological observations have already proved that the cause cannot be as deep as a hundred miles. And that tremors should be propagated for thousands of miles is rather reassuring than otherwise. They are very microscopic at such distances and only detectable with the most delicate instruments. A steel ball as big as the earth would surely transmit such vibrations without the least detriment to its rigidity. If these tremors would not be propagated at all, we would have reason to worry.

Those who hold that we are living on a shell, and that the interior of the earth must be liquid, have never given the subject a few minutes of serious thought, since the tidal attraction of our own moon would easily rupture such a shell and imperil the safety of whole continents.

That the heat increases the deeper we go, does not prove that we must soon come to liquid rocks. Physics tells us that pressure raises the temperature of boiling and liquefaction. Water in a locomotive boiler must be heated far above its ordinary boiling point. When the boiler bursts and the pressure is relieved, the super-heated water is all instantly changed to steam and thus adds immensely to the horrors of the explosion.

For this reason the rocks in the interior of the earth are not liquefied by the enormous heat, which most probably prevails there. What the temperature really is, we can only surmise. It may, however, not at all increase at the same ratio as the depth, and there may be a region of constant or even of lowering temperature, just as there is in our atmosphere.

That the enormous and increasing pressure does not grind the rocks to powder and thus destroy their rigidity, may be owing to its perfect uniformity and invariability. Rather, the pressure ought to compact debris to solid rock so that, except at its surface, the whole earth ought to be one immense and rigid rock. Vacant spaces are not likely to exist at great depths as they do near the surface, where parts are liable to cave in or settle, and thus cause what is called a tectonic earthquake. These latter constitute the greater class of earthquakes and occurred in the San Francisco quake of 1906, and in that of Avenzano a few months ago. While, of course, earthquakes are horrible visitations, they are known to be restricted to certain regions, and are largely aided in their work of destruction and death by fires and faulty building construction. Like volcanoes, they are purely surface phenomena. For with an average rigidity equal to that of steel, the earth is a secure home. Science has thus found another instance of the wisdom of the Infinite Creator.