WEIGHING THE EARTH.

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ABSTRACT.

Of the many methods adopted up to the present for accomplishing this, none appear to me to be as free as they might be from many sources of error.

As in all other scientific systems of taking measurements, especially those in which the object of measurement is not directly comparable with our established units, special instruments have to be constructed by which certain measurements are taken, these serving us by the aid of the known laws involved with sufficient data to make calculations from which we derive the answer sought.

This necessitates the selecting of a method out of the possible many at our disposal, which, with the same degree of care taken in those measurements, will lead, all things considered, to the most reliable result.

The less the number of such measurements, and the larger the parts measured (the size of a part here refers to it as a multiple of the smallest portions of it capable of measurement), as a rule, the more dependable must be the result.

From the above considerations I commend the following method :—

Newton's discovery that all particles of matter attract all others by forces varying inversely as the square of their distances leads to the following principles upon which depend the reasons for the special arrangements and calculations necessary to our purpose.

All material bodies attract one another directly and jointly as their masses, and inversely as the squares of their distances.

In effect their masses may be considered concentrated at their centres of mass (centres of gravity) so far as distances beyond their circumferences are concerned, but within their circumferences the law of variation, as far as distances are concerned, depends in homogeneous masses directly with regard to those centres, because anywhere within a spherical shell of matter the forces of the particles of the shell are self-destructive. From this it is evident that a body falling towards the earth is continually acted upon by an increasing force until it reaches in general the surface, after which, if its way were clear to the centre of the earth, the force would fall off to nothing—thus there is a place of maximum force—the effective surface, very approximately sea-level over the ocean, and rising over that level as a comparatively smooth surface over the land, averaging its level.

Now, it is well-known that a pendulum's rate of swing depends upon the force of gravitation and its length as an equivalent simple pendulum—one in which all the matter is supposed concentrated at its centre of oscillation. Take two pendulums synchronised, one placed within a heavy shell—of lead, say—and the other vertically above and immediately outside; the one above experiences the full force of all the matter in the world, provided there be nothing else above its horizontal plane, whereas the one within is deprived of the force due to the mass of the shell. Consequently, the pendulum within loses relatively to that outside.

The weight of the world being some six thousand million billions of tons, any mass we could make use of for our shell would be so extremely small in comparison that the loss of force by its self-destruction, as far as the pendulum within is concerned, can only make a very small difference in its rate of vibration, notwithstanding the fact that the virtual proximity largely compensates—the earth's distance being gravitationally its radius, or, roughly, seven million yards, to the few yards of the shell from the outside pendulum. Thus a mass of a few tons in the shell is virtually many billions of tons in its comparative effect.

By well-known mathematical formulae, after securing the ratio of times of the clocks as indicated by dials and special optical arrangements, we can calculate how many times the quantity of matter in the earth is greater than that in the shell.

To obtain this ratio of times within a reasonable period to any serviceable degree of accuracy, we must adopt methods of measuring the difference of rates of the pendulums by the smallest possible parts of a second.

If the pendulums be arranged to swing in vertical planes at right angles to each other, and if plane mirrors be attached to them, we can optically combine their movements, which combination can be shown to result in an elliptical movement—at quarter phase the axes of the ellipse correspond with the directions of vibration of the pendulums, and their lengths with their effective amplitudes of movement. The changes of form and position of those axes vary with the change of phase, and this can be measured to small fractions of a second by means of photography.

By a suitable arrangement of things, cross wires can be projected upon a very large screen, and can be instantly photographed by means of an electric spark automatically made by one of the clocks.

Carefully adjusted diagrams and measured parts would enable us to measure the loss of the internal clock to many thousandths of a second.

In some period between three and four years there are just one hundred millions of seconds; the clock, whose time is representative of the denominator of the fraction which is the desired ratio of times, could be made to exactly, after registering that number of seconds, record the exact difference of time, at least to within the limits of the possibility of optics, electricity and photography. The pendulum completing the electric circuit at its lowest and fastest position of movement, thus insuring the greatest accuracy of time. The result would be the ratio of times as a decimal fraction, i.e., in its most calculable form.

After explaining the general plan of my scheme, many points of detail require attention.

Since such extreme accuracy in the synchronising of the pendulums is necessary, this must be especially referred to. There can be no real synchronising unless every precaution be taken to ensure the isochronism of each as well—perhaps the technicalities of this can be left. I might mention that the best form of suspension for isochronism is a double spring. The pendulums should be made of materials the least affected by changes of temperature, and be operated in vacuo—the clocks being wound by electricity. The pendulum springs should be of exactly the same strength, the pendulums of identical form, weight, and distribution of the same. The clock trains should be exactly alike, and be driven by the same actual weight—the principle of uniform tension of the driving cord or chain ensuring equal power to the movements, and, consequently, perfectly equal impulse to the pendulums.

The place of experiment should be upon a plain, with no hills, or even tall buildings, above the horizon. There should be no sources of vibration near, such as railways, cart roads, etc. Even the masses of the clock trains, the protecting structures must be considered and gravitationally balanced.

The centrifugal force of the earth's rotation must be allowed for; also we should have to consider the gravitational effects of a periodic character due to the sun and moon at least. There may be yet more disturbing factors to deal with—perhaps the electro-dynamic forces due to the earth's magnetic lines of force.

From an astronomical point of view the gaseous matter is as much a portion of the mass as the liquid and solid portion. Our method does not weigh the atmosphere, this being a spherical shell, within which we must of necessity perform our experiments, its gravitational forces are self-destructive, as far as we are concerned. However, this can be easily figured out and added in. Knowing the area of the surface of the earth, the average pressure at the surface and law of relation between volumes and pressures of gases—Boyle's law—we can easily measure its mass; of course, this is not the mere product of surface and pressure as it would be were the earth's surface a plane.