THE RATIO OF THE TWO ELEMENTARY CHARGES.

By F. W. LOOMIS.

SYNOPSIS.

Since the oil drops in Millikan's experiments were exactly neutral, $\pm$ a small integral number of electronic charges, to 1/1000 of an electron, and since they contained as many as 4×10^{14} protons and nearly the same number of electrons, it follows that *the magnitudes of the charges on protons and electrons are equal to one part in 4×10^{17} .*

IN recent years and particularly since the work of Aston it has become generally accepted that all matter is made up of protons and electrons. It is usually taken for granted that the charge on the electron is the negative of that on the proton, but the exactness of this relation is rarely discussed.

Some information can be obtained from positive rays. Aston¹ has found that the positively charged atom of hydrogen, *i.e.*, the proton, shows a deflection corresponding to $m/e = 1.008$ (in units of atomic weight and electronic charge). Since it is a pure element and its chemical atomic weight is 1.008, the magnitude of the charge is found to be equal to that of the electron within the accuracy of Aston's measurements, or 1/10 of 1 per cent. This accuracy is sufficient to establish that the number of protons in a "neutral" atom is equal to the number of electrons, including of course those in the nucleus. Hence it is possible that a more precise measurement of the ratio of the charges might be made by measuring the deflectability of the "neutral" atom; though there would be difficulties due to the confusion of the trace of the "neutral" particles with the darkening caused by the light from the discharge tube.

But much the most precise value of this ratio can be deduced from Millikan's oil-drop experiments.² Millikan measured the net charge on oil drops charged in several ways with from 1 to 136 electrons and having masses up to 7×10^{-10} grams. He found that, within 1/10 of 1 per cent., the charge on these drops was always an integral multiple of $e = 4.774 \times 10^{-10}$ esu. Now, since there are about 6×10^{23} protons in a gram of matter, these drops contained 4×10^{14} protons and very nearly the same number of electrons. Hence, since each drop, whatever num-

¹ Aston, Phil. Mag., 38 (1919), p. 317.

² Millikan, Phil. Mag., 34 (1917), p. 1. The Electron, p. 109.

ber of protons it contained, could be made exactly neutral within 1/1000 of the electronic charge, it follows that the ratio of the average charge on a proton to the average charge on an electron is equal to -1 to one part in $1000 \times 4 \times 10^{14}$, *i.e.*, to $-1 \pm 2.5 \times 10^{-18}$. Moreover it would seem a highly improbable coincidence if the charges of protons or electrons should vary among different classes, being different say, in carbon from in hydrogen, or if the charge of the peripheral electrons should differ from those in the K ring or the nucleus, yet in such a way that the average charge on the proton came out exactly equal to the average charge on the electron. So that this experiment may also be considered a precise confirmation of the relativity law of the invariance of electric charge.¹

Probably no physical constant is more accurately known than this ratio. The precision of the measurement arises, somewhat as in interference measurements, from the fact that one is able to compare the charge on a large and necessarily integral number (4×10^{14}) of protons with a similar number of electrons to a precision of 1/1000 of a single charge. Millikan² considered the evidence that his experiments afforded on the equality of positive and negative elementary charges. But, writing at a time when Aston's work had not yet identified the universal atom of positive electricity, or proton, and when it was natural to think in terms of a single substance theory of electricity, he merely stated that the positive and negative charges acquired by his drops were all integral multiples of e , and hence "the mean value of the positive electron agrees with the mean value of the negative electron to within less than 1 part in 2000." He was not then in a position to count up the total number of positive and negative elementary charges and state that they were equal to within one part in 4×10^{17} .

It is at present most convenient to think of matter, or electricity, as made up of two fundamental entities, corresponding to protons and electrons. But the exactness of this simple relation between them, analogous to that between inertia and gravitation, is convincing evidence of an underlying unity.

All this does not in any way affect the theory which attributes gravitation to a slight excess in the attraction between charges of opposite sign over the repulsion between charges of the same sign. Which

¹ Thus, if the velocities of extra-nuclear electrons can be calculated from X-ray data by the Bohr theory, it follows from the fact that the above phenomenon is observed both with oil and mercury drops that, if the charge is proportional to $(1 - v^2/c^2)^n$, then $|n| < 10^{-14}$; or if the charge is expressible as a power series in v/c , then the first term which can have a coefficient as great as 0.001 is the 48th. Still more exact statements can be inferred from any of the usual assumptions about the velocities of nuclear electrons.

² Millikan, *The Electron*, pp. 80-83.

theory, in view of the now recognized identity between electricity and matter, is really not an explanation of gravity at all, but merely an unexceptionable statement that the net force between particles is the sum of the electric and gravitational forces. Even the precision of Millikan's measurements is not enough to detect this excess gravitational force, as one can see without computations; for the effect to be expected is essentially the *gravitational* attraction between the oil drop and the electrons which are driven around from one condenser plate to the other when the electric field is put on. Obviously this is quite beyond the range of Millikan's measurements, which would have to be accurate to one part in 10^{40} to show it.

NEW YORK UNIVERSITY.