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THE IMPLICATIONS OF SOME EXPERIMENTAL FINDINGS TO THE POSSIBILITY OF THE EXISTENCE OF WEIGHT MASS ANOMALIES

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One of the major assertions of gravitational theory is that the weight to mass ratio of a material body is independent of the nature of that body. This law is assumed to hold even if the body is an atom or an elementary particle. In fact this law, in the form of the principle of equivalence, is the cornerstone of general relativity. However, this law is of primary importance to gravitational experimentation for more direct reasons than its connection with general relativity. For if this law is completely true, the possibility of altering the gravitational behavior of matter is small. Of course the law of the constancy of the weight to mass ratio has been shown to hold very accurately by the experiments of Eotvos (1) and Southerns (2) for material bodies large enough to be weighed. These experiments will be described in more detail later. This paper discusses the evidence, from these and other experiments, which are relevant to the application of this law to individual atoms, protons, neutrons and electrons.

First it will be useful to review the definitions of mass and weight, the weight to mass ratio being the ratio of these two properties of the same body. Suppose a body has an acceleration due to the action of a force of any type upon it. Then according to Newton's second law, the ratio of force to acceleration is a constant, which is independent of the nature of the force, and depends only on the nature of the particle. This constant is called the inertial mass, or more simply, the mass. Weight, on the other hand, is related only to a gravitational force. Specifically, a body in a gravitational field undergoes a gravitational force which is equal to the product of the gravitational field intensity and the weight of the body.

With no further information one might expect some bodies to have weight, and some to have no weight. In other words a gravitational field might exert a force on some bodies but none on other bodies. However, experiments have shown not only that all bodies have weight, but that the ratio of the weight to the mass of a body is a constant which is the same for all matter. The most precise of these experiments was carried out by Eotvos (1) in the early part of this century. He compared the weight to mass ratios of platinum, copper, water, wood, copper sulfate, copper sulfate solution, asbestos and tallow. He found that the weight to mass ratios were the same to better than one part in one hundred million. This established the law with tremendous precision for material bodies large enough to be weighed. This constant ratio shall be referred to as the large body ratio in this paper. Southerns(2) carried out similar experiments on radioactive material showing that mass, which is later converted to energy, also has this same ratio.

For atoms or subatomic particles two types of deviations from the law of constant weight to mass ratio might be imagined. These are:

(1) The ratio of one type of particle might differ from the ratio for another type of particle. For example a proton might have a different ratio from an electron.

(2) The ratio for a single type of particle might have a spread

about some average value for that ratio. (3) For example it is conceivable that the ratio could differ among individual electrons but that the ratio average for all electrons would equal the large body ratio.

Consider the first type of deviation, the possibility that different types of particles have different ratios. That is, this part of the discussion is concerned only with the average ratio for a type of particle. The question of whether the second kind of deviation also exists will be discussed later. Since the Eotvos type experiments were performed for so many different elements and compounds, it is certain that the average ratio of any particular kind of atom is equal to the large body ratio. For, too many different substances were used to allow the possibility of fortuitous cancellation of differences in the ratio among different elements. However, what the Eotvos experiment says about the weight to mass ratio of neutrons, protons and electrons is not as evident. Different substances have different relative numbers of protons, neutrons and electrons. Thus helium has two protons, two electrons, and two newtrons. Uranium has one hundred forty six neutrons, ninety two protons and ninety two electrons. Now if protons, neutrons and electrons have different weight to mass ratios, then the total weight to mass ratio for the atom depends on the relative numbers of different particles making up the atom. To show this, let the weight to mass ratio for the proton, neutron and electron be written as Xp, Xn and Xe, and their respective masses as Mp, Mn and Me. However, some of the mass of the particles making up a nucleus is converted into energy on formation of the nucleus. Let Mb be the mass equivalent of the released energy and let Xb be its weight to mass ratio. Since this energy is different for each atom we denote it by the name of the atom in parenthesis. Thus, for helium, the weight to mass ratio is

$$\frac{2X_pM_p + 2X_eM_e + 2X_nM_n - X_b(M_b \text{ of helium})}{2M_p + 2M_e + 2M_n - (M_b \text{ of helium})}$$

This expression comes about because XpMp is the proton weight, XnMn is the neutron weight, and so forth. On the other hand, the ratio for the uranium^{238} atom is

$$\frac{92X_pM_p + 92X_eM_e + 146X_nM_n - X_b(M_b \text{ of uranium}^{238})}{92M_p + 92M_e + 146M_n - (M_b \text{ of uranium}^{238})}$$

We can write similar expressions for many other types of atoms.

To write the general expression for the weight to mass ratio of an atom it should be observed that the Eotvos type experiment only applies to neutral atoms. Therefore in all these expressions the number of protons equals the number of electrons. Hence, the general expression for an atom with Z protons and N neutrons is:

$$\frac{Z(X_pM_p + X_eM_e) + NX_nM_n - X_b(M_b \text{ of atom})}{Z(M_p + M_e) + NM_n - (M_b \text{ of atom})} = \text{large body ratio.}$$

Since Z, N and Mb can have as many different sets of values as there are atoms, this expression can only be true if $X_n = X_b = \frac{(X_pM_p + X_eM_e)}{(M_p + M_e)}$ = large body ratio. Since Xb was used here only as a mathematical convenience, it will not be discussed further. The above equality holds almost to the accuracy of the Eotvos experiment itself. Now $\frac{(X_pM_p + X_eM_e)}{(M_p + M_e)}$ is the weight to mass ratio for a proton plus an electron. Thus from the Eotvos type experiment it follows that the ratio for the neutron or for a proton plus an electron is equal to the large body ratio.

To determine the ratio for protons alone or for electrons alone other data is needed. Essentially, ionized material must be weighed or the gravitational deflection of free protons or neutrons must be measured. At the end of this essay the difficulties of such an experiment are discussed. However, from general observations, it can be concluded that no very large deviations of the proton or electron ratio from the large body ratio exist. Examples of such observations are that no change of weight on charging a body have ever been noticed or that proton beams show no detectable abnormal gravitational behavior. On the other hand, there is no experimental evidence of the possibility of small deviations. For example, the electron might have no weight and the proton have a weight equal to the product of the large body ratio and the mass of an electron plus a proton. Such a deviation, while beyond the observational limits of any experiment yet performed, still exactly satisfies the requirement that   large body ratio.

The second possible type of deviation from the law of constancy of weight to mass ratio is that a single type of particle might have an entire set of different ratios. It is only required that the average of these ratios would equal the large body ratio. Such a spread could not be determined by the Eotvos type experiments because these methods give information only on the average properties of particles. To study this type of deviation, the gravitational effect on individual particles must be measured. The author proposed a method of doing this with neutral atoms in a previous essay (3). It has since been pointed out that an experiment of Stern, Estermann and Simpson (4) while performed for another purpose, and differing in some respects from the experiment proposed by the author, gives the same information. This experiment of Stern et. al. was carried out to study velocity distribution in a beam. A two meter long beam of casium atoms was produced in a very good vacuum. The gravitational force was balanced out by a magnetic force produced by the interaction of the atomic magnetic moment with an inhomogeneous magnetic field. From the vertical deflection, the strength of the magnetic field and the ratio of magnetic moment to mass, the weight to mass ratio can be calculated. The average vertical deflection gave a ratio equal to the large body ratio, as would be expected from the previous discussion. From the spread in the vertical deflections, differences in the weight to mass ratio of individual atoms can be determined, However, the spread in vertical deflections agreed to within a few percent with the deflections expected from the velocity distribution of the beam. A similar experiment with potassium atoms gave similar results. Thus to within a few percent the weight to mass ratio of individual cesium or potassium atoms is the same as the large body ratio and no appreciable deviation of the second kind exists.

There is also experimental data available on the weight to mass ratio of individual neutrons. McReynolds (5) measured the gravitational deflection due to the Earth's field of a beam of thermal neutrons. Specifically, the beam was twelve meters long, and deflection between two different velocity distributions was measured. The average weight to mass ratio is equal, within the experimental error, to the large body ratio in agreement with the conclusions drawn from the Eotvos experiment. Further, the spread in gravitational deflection is explainable by the velocity distribution. Thus, here, as with the neutral atoms, there is no evidence that there is any variation in the weight to mass ratio among individual neutrons.

Little can be said on experimental grounds of the possibility of deviations of the second kind in protons, because the average weight to mass ratio of protons is known only very roughly. The absence of appreciable ratio variation in individual neutral atoms means only that no very large deviation would be expected among individual protons. Since the electron comprises less than one two-thousandth of the mass of an atom, nothing can be said about deviations of the second kind in electrons.

In summary, the experimental facts show that the large body weight to mass ratio is equal to the weight to mass ratio of all types of atoms and neutrons. Further, the large body ratio is equal to the average value of the ratio of a proton plus an electron. Also, no deviations of the second kind occur in neutrons or atoms. That is, every individual atom and individual neutron has the same ratio. Experimentally the weight to mass ratio for protons or electrons, while not showing very large anomalies, cannot be proven equal to the large body ratio with any accuracy.

Thus there is a great need for a precise experimental determination of the weight to mass ratio of protons or electrons. Since the ratio for a proton plus an electron is known already, the determination of the ratio for either particle is sufficient. The difficulty of a direct determination of the gravitational deflection of a charged particle, in an experiment similar to the neutron or neutral atom experiment, is due to electrical forces being much greater than gravitation forces. For example, one electron five meters away from a second electron exerts as much force on that second electron as the gravitational field does. Thus stray electrons or ions which are always present on the walls of an apparatus can exert sufficient force to completely mask the gravitational force. Even if the surface charges are neglected, image charges of the electron beam itself and self repulsion in the beam may obscure the gravitational deflection. This last problem is avoided in a static measurement of the ratio such as a weighing of ionized matter. However this last method has the additional difficulty of requiring a high proportion of ionized to un-ionized matter in the sample being weighed. Of course all these problems can be resolved to some extent, but it is questionable if an experiment of either of the above types can be designed in which all the adverse effects can simultaneously be sufficiently minimized. Probably a completely new type of experiment will have to be devised to measure the weight to mass ratio of the proton or electron. Such a measurement may detect a deviation from the law of constant weight to mass ratio. If such an anomaly can be shown to exist there is the possibility of finding a material which would be acted upon in an unusual manner in a gravitational field.

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Summary

A fundamental law of gravitation is that the weight to mass ratio of a body is independent of the nature of the body. This law has experimentally been shown to be true for weighable bodies. This essay surveys the experimental evidence for the application of this law to atoms, protons, neutrons and electrons. It is concluded that the experimental facts prove the law holds for atoms and neutrons. However, there is a possibility of deviations from this law in the case of electrons and protons, since only the ratio for an electron plus a proton has been measured. Such an anomaly would present the possibility of altering the behavior of matter in a gravitational field.

FOOTNOTES

(1) Eotvos, Ann. der Physik, 68, 11, (1922)

(2) Southerns, Proc. Royal Soc., 84A, 325, (1910)

(3) The possibility of such a deviation was suggested in an essay submitted last year by the author to the foundation.

(4) Stern, Estermann, and Simpson, Phys. Rev., 71, 238, (1947)

(5) McReynolds, Phys. Rev., 83, 172, (1951)