GRAVITY CAN GLUE TOGETHER ENERGY TO MAKE MATTER 1957

by John A. Wheeler

Today we describe the physical world in terms of elementary particles and forces acting between these particles - gravitation, electromagnetism, and other forces. The question raises itself whether a deeper-going analysis of nature will explain forces in terms of particles, or account for the structure of particles in terms of fields of force, or leave particles and fields coequal in the final reckoning. The purpose of this essay is to show that one gets an entirely new light on this question by considering the action of gravitational forces, which are so often considered to have nothing to do with the problem of the constitution of matter. It turns out that gravitational forces are able in principle to hold together an electromagnetic wave disturbance in a limited domain of space. Moreover, the energy of this electromagnetic wave can in principle be great enough, and the mass of this energy large enough, to provide all by itself the stabilizing gravitational force. In other words, well established principles of the classical physics of gravitation and electromagnetism lead one to recognize the potential existence of a new kind of object which I shall call "geon" as an abbreviation for the term "gravitational-electromagnetic entity". Such an object is ethereal and immaterial in the sense that nowhere within it is there any matter in the ordinary sense of that term. Yet the geon possesses mass and moves through space as a single object. This entity furnishes for the first time a singularity-free, self-consistent picture of the Newtonian concept of "body", over the range of sizes where one can analyse geons with getting into quantum phenomena. To show that the existence of a geon is in principle possible is therefore to show that gravitation can glue together energy to make matter.

The potential existence and the properties of a geon depend upon four well established physical effects: the bending of light by a gravitational field, as for example the gravitational field of the sun; the fact that gravitational forces arise from mass; the equivalence of energy to mass; and the proportionality of electro-magnetic energy density to the square of the electromagnetic field strength. The first effect says that a pencil of radiation of radius r and of velocity c can be bent into a circle of a much larger radius R by a centrally directed gravitational acceleration of the order of $g \quad c^2/R$. The second effect is summarized in Newton's law of gravitation, according to which $g \quad GM/R^2$, where G is Newton's constant of gravitation and M is the mass--in this case the mass of the geon. These two relations together say that the radius of a classical geon is connected with its mass by a formula.

$$(\text{radius}) = R \qquad (G/c^2)M = (0.74 \times 10^{-28}\,\text{cm/gm}) \text{ times } (\text{mass})$$

The third and fourth relations connect the mass with the volume of the geon and the strength of the electromagnetic field, and show that the smaller the geon, the stronger the fields. A detailed analysis of these fields and of the stability and properties of geons is contained in a technical account, "Geons", the manuscript of which has been sent to The Physical Review for publication and a copy of which is attached to the original copy of this essay as an appendix. There it is shown that the most stable geons have a doughnut shape: the gravitational field of the electromagnetic wave acts as a wave guide to hold the wave together.

The energy of a geon slowly leaks out. At the same time the mass and radius of the object slowly fall. The rate of loss of energy is the smaller, the shorter the wave length of the radiation compared to the radius of the doughnut. Thus a geon shows a characteristic radioactivity. In addition to spontaneously losing energy, a geon which makes an encounter with another geon will bring about a transmutation in which the two geons may coalesce or break up into smaller geons plus free radiation energy. In this sense geons show some of the properties of the material particles we know in nature.

As immaterial field energy which gravitation can bind together to make material mass we have not only electromagnetic waves, but also neutrino radiation. Preliminary experimental evidence for the absorbability of neutrinos has recently been obtained by Reines and Cowan, increasing the evidence that neutrinos form a fundamental element in the description of nature. Thus one has to recognize in principle not only electromagnetic geons, but also neutrino geons, and geons of a mixed constitution.

What does one mean by the words "potential existence" and "existence in principle" as applied to geons describable in terms of classical physics? Only this, that such objects are so large (10^{10}cm to 10^{28}cm; 10^{39}gm to 10^{58}gm) that one has no reason to believe that such objects still exist in nature, if they ever did at one time. By now, their natural radioactive decay and their collisions with each other will presumably have reduced them all below a critical size where one has to use quantum-language to describe their behavior. This limit occurs for electric fields in excess of about 10^{16} volts/cm, above which space is known to give birth spontaneously to pairs of positive and negative electrons.

Small geons thus become quantum objects. With decreasing mass, fluctuations in the gravitational fields begin to grow in importance compared to the static average gravitational field. Small geons thus bring us into an entirely new kind of physics, where we deal with a mixture of gravitation theory and quantum theory at small distances. No one has yet analyzed this kind of physics in any detail. We are in no position to say that small geons are the same as the elementary particles that we find in nature. But we are in a position where we cannot avoid this issue: If small geons are not the elementary particles that constitute our physical world, what are they? Whatever the answer that physics gives to this question in the future, we can at least say this much now: The existence in principle of classical geons tells us that gravitation is a glue that can bind together immaterial energy to make objects that have mass.