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The Possibility of New Gravitational Effects

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In an appraisal of the possibilities of utilizing the force of gravitation to further benefit humanity it is necessary to draw upon as much experience in dealing with nature as we, as individuals, and as our society, as heir to centuries of scientific investigation, have been able to accumulate. It is clear that our direct personal contact with all the physical phenomena of nature, by which are revealed her inner workings, is necessarily much smaller than the sum total of all the observations and experiments which have been recorded by the human race. This latter material forms what we may call the physical experience belonging to our civilization. From this raw material generalizations are extracted which in a more or less compact and orderly fashion render an accurate account of the huge variety of observations and results of experiments. This business of abstracting and generalizing we call science. The generalizations we call, of course, scientific theories.

Now it frequently happens that a theory can be extended, or extrapolated, beyond its original domain of phenomena which it was designed to describe. It may or may not prove valid in this larger domain. As a simple example, a "theory" based on limited geographical experience in the Middle Ages was that the earth was flat. However when ships began to sail to more remote parts of the world this "theory" was found to be inadequate to describe the many new facts (e. g. circumnavigation) which were uncovered. Thus the "theory" broke down when applied to the earth as a whole, but nevertheless still remained a reliable guide for a traveler who confined himself to a relatively small region, such as Europe alone.

We are concerned in this essay with phenomena involving gravitation. Here also a theory (Newtonial inverse square attraction) which was considered to explain all the known facts except for the slightly too rapid advance of the perihelion of Mercury was confronted with a contender (Einstein's general theory of relativity). The latter, in addition to accounting for all observations and experiments already made, predicted that actual observations of certain phenomena not previously considered would differ from the predictions based on Newtonian theory. Thus it was that the measurement of the deflection of light passing the sun, and the red shift of light leaving ~~heavy~~ dense stars spelled the breakdown of Newton's theory of gravitation when extended to this more remote domain of phenomena. Now in dealing with the possibility of the finding of new gravitational effects we must use as complete knowledge as is already available of such effects, which means we must use Einstein's theory in so far as it differs appreciably from Newton's. In any case a theory which accounts reasonably well for the existing facts is an essential stepping stone for these considerations.

But there are those who would say that in seeking new effects great imagination is necessary. This is to a large extent true, but it must be imagination tempered with seasoned judgement and knowledge. Clearly speculations, based alone on imagination, which are unable to give a true account of phenomena already known, are not likely to describe accurately phenomena as yet unsuspected and not yet investigated. Therefore, unless another theory can be produced which includes all that the present one does, it is essential for the validity of our speculations that we stay within the framework of the existing theory of gravitation. Although it may eventually break down in as yet unexplored domains of physics and be supplanted by a more encompassing and qualitatively different (and probably more complicated) theory, it is at present the most reliable guide we have.

Let us then turn to the principal features of general relativity. The most important is that it is a field theory. This means that the gravitational interaction of matter is to be considered as broken into two parts:

1) The production of the field or disturbance in space by the matter existing everywhere. One portion of space is considered to influence (more strongly if it contains matter) its neighbor, the latter to pass on the condition in turn to its neighbor, and so on until the disturbance has been extended throughout the universe. The situation is analogous to the spreading of waves over the surface of a pond. There are partial differential equations to describe accurately how the neighbors act on one another.

2) The exertion of actual forces upon matter at any given point by the field or disturbance which happens to exist at that point.

Because of this split one might expect to be able to attack the problem of finding gravitational shields, absorbers, reflectors, or similar devices through an investigation of either of the two aspects separately. One might hope to find a new way of producing the field, or a new way of having the field act on the matter. But a particle which according to 2) is acted upon by the field will also produce a field of its own. When this is added to the original field already present one is able to describe the total field in terms of the equations of 1). These equations require the field at every point of space to change in a certain manner with time, and thereby also specify the way the portion due to the particle alone varies with time. But because the particle and the field it produces are intimately connected, we consequently see that the motion of the particle is also determined by 1) and that 2) is not actually a separate independent phase of the theory. The realization and proof of this fact is a development of recent years. More precisely, Einstein, Schild, and Infield have proved that the equation of motion of a particle can be derived from the gravitational field equations.

Therefore there is only one feature of the theory to consider in surveying known and in scouting for unknown gravitational effects, viz. the production of the field by matter. To make this discussion in this essay more exact it is necessary to introduce a slight amount of mathematical symbolism. The field to which the Einstein theory refers is to be considered as an all-pervading influence throughout our abstract coordinate framework of space and time which at any given point and moment affects physical apparatus, such as measuring rods and clocks, when they are placed there. The physical changes in length of a rod (which are in principle measurable but too small in practice to detect) and the slowing down or speeding up of ~~the~~ a clock as it is moved from place to place are expressed mathematically by ten quantities, termed the field quantities and designated by g_{11}, g_{22}, g_{33}, g_{44}, g_{12}, g_{13}, g_{14}, g_{23}, g_{24}, and g_{34}, or abbreviated by g_{ij}. This large number of quantities is necessary to describe the many different orientations of the measuring rod and the many different ways in which space and time measurements can be combined. Our description of nature, at least as far as gravitational effects are concerned, is to be regarded as complete when for any given distribution of matter the g_{ij} are determined for all of space and time. With the field equations this is precisely what Einstein's theory of gravitation is able to do. As explained above, all physically observed accelerations and motions of mass particles are determined by the g_{ij}.

It is in the positivistic spirit of modern physics that we do not inquire as to what this influence on space "actually is", or "how" the disturbance spreads from one part of space to another. Indeed such questions, until they can be phrased in terms of actual physical experiments, are regarded as meaningless. An example of a meaningful question would be: "In which direction will a stone move when I let it go?" The answer which is predicted by theory, and which experiment, as continually assimilated into our personal badkground since birth, confirms, is of course, "toward the center of the earth". If we were able to successfully answer all such questions for all conceivalbe experiments on the objective world in all possible situations we would say we understood nature completely.

To return to our description of the gravitational field, we concentrate our attention on the g_{ij}. In regions where there is no gravitational field to affect the rods and clocks, these factors take on the simple values $g_{11}=g_{22}=g_{33}=-1$, $g_{44}=1$, $g_{12}=g_{13}=g_{14}=g_{23}=g_{24}=g_{34}=0$. The presence of a gravitational field reveals itself as a deviation from these quantities. But it is important to realize that the deviation with even the most extreme fields is very small. Therefore these quantities will always have a set of values near this simple set.

The most important of the g_{ij} is g_{44} and it alone need be considered if we are not interested in such very delicate effects as the extra advance of the perihelion of Mercury by 43 seconds of arc per century, or the slight deflection of light as it passes by the sun. The reason is essentially that we have chosen as the natural and standard unit of measurement of space the distance a light wave travels in one second. Ordinary objects rarely travel at comparable velocities. There the spatial separation of events involving such objects will be negligible compared to the time separations of these events. For example, a clock sitting at rest on a desk will continue to tick off time separations, but will have zero spatial separations between beats. Since it happens that g_{44} refers only to time separations while all the others involve also the smaller spatial separations, we see that the former is the most important. Following these approximations it can then be easily shown that the g_{44} is calculated from the distribution of the existing matter by means of what is called an inhomogeneous wave equation. This equation, which we include for the sake of completeness, taking the cartesian coordinates x, y, z as measured in the usual spatial units, is

$$\text{(A)} \quad \frac{\partial^2 g_{44}}{\partial x^2} + \frac{\partial^2 g_{44}}{\partial y^2} + \frac{\partial^2 g_{44}}{\partial z^2} - \frac{1}{c^2}\frac{\partial^2 g_{44}}{\partial t^2} = -8\pi \frac{G}{c^2}\rho$$

where G is the universal gravitation constant, c the velocity of light, and ρ the mass density of matter. It is now very important to note that except for the time derivative this is quite similar to the well known Laplace equation for the Newtonian gravitational potential, φ, which reads

$$\text{(B)} \quad \frac{\partial^2 \varphi}{\partial x^2} + \frac{\partial^2 \varphi}{\partial y^2} + \frac{\partial^2 \varphi}{\partial z^2} = -4\pi G \rho$$

The time derivative has the effect of replacing the instantaneous propagation of the gravitational field as Newton envisaged by wave propagation with the velocity of light. However the speed of light is so enormous that this slight retardation is seldom of any importance. With all of the above qualifications we see that we have $g_{44} = 1 + \frac{2\phi}{c^2}$ and can calculate gravitational affects in terms of the Newtonian potential, ϕ. For terrestrial conditions Einstein's theory of gravitation reduces to Newton's classical theory of the universal inverse square attraction with negligible error in the approximation.

Before elaborating on the important consequences of the last sentence let us first make these abstract equations a bit more concrete by an explicit example which will verify a statement already made above. We have said that the deviation of g_{44} from 1 is very small even in the presence of a strong field. This deviation is $\frac{2\phi}{c^2}$, which we would like to evaluate for the gravitational field at the earth's surface. Here GM/R by Newtonian physics, where R is the radius of the earth, or about 4,000 miles. But it can easily be shown that the acceleration of a freely falling body, 32ft/sec, is given by a GM/R². Consequently

$$\frac{2\phi}{c^2} = \frac{2\times 32\,\mathrm{ft/sec^2} \times 4000\,\mathrm{mi}}{(186{,}000\,\mathrm{mi/sec})^2} = \frac{4\times 64\times 4000}{(186{,}000)^2 \times 5280} = \frac{4\times 6.4\times 4}{1.86\times 1.86\times 5.28}\times 10^{-9} = 5.67\times 10^{-9}.$$

Being about one billionth, this is an extremely small fractional change and quite undetectable. Although general relativity has its foundation in changes of lengths and of intervals of time, this feature does not contradict our "common sense" because these changes are imperceptible. It is only in the lengthening of the average lifetime of radioactive cosmic rays traveling practically at the speed of light that this change has been observed directly on the earth. It is primarily the more indirect features of the theory which follow from the field equations which are amenable to observation and experimental verification.

Our purpose in taking this long road through the present theory of gravitation was to explore every possible access it might afford to new and useful effects such as the shielding , reflection, or absorption of the gravitational field. We have found that in dealing with masses even up to the size of the earth and with velocities such as can be obtained in the laboratory by whirling for example a massive flywheel until it flies to pieces the Einstein theory reduces for our purposes to the Newtonian theory. Our hope of finding some especially promising nook or cranny in the structure of the theory of general relativity has been frustrated. This is important, for it means that the most reliable scientific judgement available at the present time as to the possibility of finding something new in this category of phenomena can be obtained from the old Newtonian theory alone.

There are two very serious difficulties which this theory indicates lie in the way of finding the gravity devices listed above. They are, using somewhat technical terms, 1)weak coupling and 2)lack of sinks. Both are basic features of the physical world and are so ingrained in our everyday existence that it is difficult to see how they could ever be found to be basically incorrect. The first refers to the weak coupling between matter and the gravitational field, compared for example to the coupling between electrically charged particles and the electromagnetic field of force. A graphic illustration is the violent repulsion of two pith balls when they are given like charges. When they are now neutralized their residual gravitation attraction is much too feeble to measure. Or again, it requires the entire mass of the earth to produce the moderate downward attraction which we experience as the "force of gravity". This accidental disparity in the strengths of the electrostatic and gravitational fields is probably not entirely unfortunate. For it is well to remember that our muscular strength, the resistance of materials such as steel girders to deformation, and countless other things important in our daily life depend in the last analysis on the strong electrostatic forces holding the atom together (as well as certain quantum mechanical effects which give stability to these forces). Cell growth and the evolution of life would be impossible if indiscriminate gravitation attraction predominated over the highly selective electrostatic and chemical forces which knit together in very special arrangement the atoms of the astoundingly complex organic molecules.

The efficiency of matter in producing a gravitational field depends on the right hand sides of equations (A) and (B) and is proportional to ρ, the mass density. Remembering that energy also has mass according to $E/c^2=m$, we might do well to investigate its corresponding mass density in forms other than matter itself. Consider the energy radiated from a 100 watt light bulb in the form of eletromagnetic waves (light and heat). At a distance of about 10 inches or 25 centimeters from the filament there streams through the surface a flux of energy per square centimeter of $\frac{100 \times 10^7 \text{ erg/sec}}{7{,}860 \text{ cm}^2} = 1.27 \times 10^5 \frac{\text{erg}}{\text{cm}^2\text{ sec}}$, with a mass flux of $\frac{1.27 \times 10^5 \text{ erg/cm}^2\text{ sec}}{(3 \times 10^{10})^2 \text{ cm}^2/\text{sec}^2} = 1.41 \times 10^{-16} \frac{\text{grams}}{\text{cm}^2 \cdot \text{sec}}$

Since the mass which passes during one second gets stretched over a distance of 3×10^{10} cm, we see that the actual mass density is 4.7×10^{-27} grams per cubic centimeter--incredibly small. This is only raised by a factor of about 10^3 if we calculate the density of mass corresponding to the radiation built up inside a furnace at about 1,400 F. Thus matter is truely a condensed form of energy, having a density of usually about one gram per cubic centimeter. Energy in the form of radiation is much too dilute to produce a useful gravitational field.

The second point allows us a greater play of imagination. The lack of sinks for the field means that no negative masses exist which can "pull in the field" that emanates from the other positive masses. The ease with which electrostatic fields can be shielded depends on the existence of both positive and negative electric charges. Excess electrons can appear on the surface of a conductor to neutralize a field due to positive charges, or electrons can be carried away, leaving the positive protons to neutralize some external field produced by electrons. Although highly speculative, negative masses can be treated according to the usual equations. They however have to be extrapolated beyond the known range of validity and may lead us astray. But we should expect that such particles would accelerate in a direction opposite to the force applied to them. Thus they would move toward positive and away from negative masses. Furthermore a positive mass would be repelled and would recede from the negative. Thus a sort of chase begins, with the positive running away from the negative mass. As the velocity of both increases the positive mass gains kinetic energy ($\frac{1}{2}mv^2$) while at the same time the negative mass increases its negative kinetic energy. Thus total energy is conserved and likewise with momentum. It would seem that the pair accelerates until it reaches the velocity of light, then assumes the role of perhaps the neutrino. This speculation could be made more quantitative and may perhaps be fruitful in the field of elementary particle research. In any case it shows that we cannot expect to be able to use large amounts of negative mass to absorb the gravitational field. Such a unit would immediately desintegrate due to the mutual repulsions, and its individual particles would flee in all directions in the merry chase after ordinary positive mass particles.

In view of the evidence presented above we must conclude that there is nothing we can do to appreciably alter the earth's gravitational attraction for bodies at its surface. It requires the whole mass of the earth to set up this field, which can only be modified by a body of comparable mass. Negative mass offers the only possibility of shielding this field, but such material has never been found in nature and theoretical treatment indicates that if it did exist it would soon render itself useless to us. In any case a tremendous quantity would be needed for any measurable effect. We are forced to the conclusion that shields, absorbers, or reflectors of gravity, as we would expect to know them from an analogy with electromagnetics, are not to be expected to be found.

This does not mean that new effects are not likely to be discovered. However these future effects will surely be rather subtle to have gone unnoticed for so long. Such for example was the case with the discovery of the laws of electromagnetism by Faraday and Maxwell. Only much later did these slight and previously unnoticed phenomena become the basis for dynamos, electric motors, radio, etc. At present the expectation of a self-consistent unified field theory which will describe both gravitation and electrodynamics is quite optimistic. Einstein's latest theory has not yet reached this stage but is considered as the most promising attempt in this direction. Such a theory should give many predictions of completely unsuspected phenomena depending on the interaction of electric charges and the gravitational field. The great difficulty involving laboratory experiments in general relativity is the extreme smallness of the effects. However if coupled with the much stronger electrical effects, general relativity might be made an experimental field of investigation and be brought into the laboratory for the first time. Work in both the theoretical and, hopefully, later the experimental aspects of this subject should be strongly encourage as it could be very fruitful. But history shows that a frontal attack in science is not likely to be the most successful. Endeavors guided primarily by the desire to know and understand the laws of nature have usually been the ones which have ultimately resulted in the most benefit to humanity.