GRAVITY

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When NEWTON discovered that the motion of astronomical bodies could be forecast with extraordinary precision using simply the assumption that they attracted each other in accord with his famous law, neither he nor his contemporaries imagined that the issue was exhausted. In spite of its elemental simplicity, his explanation of astronomical motion by cause of a force propagated without an intervening medium, or what amounts to the same thing: instantaneously, was for people at that time both highly unlikely and repugnant. The rejection of [instantaneous] action-at-a-distance, as prevails still today, can not be spared a psychological rationalization: it issues from a deep sense of the essence of physical force, which, in all its variation, always needs a certain interval of time to propagate its effect; and, when this force exists between two bodies immersed in a medium, this medium is in a real sense, modified[1]. However, in GALILEO'S times, light was considered an exception; nevertheless, he never doubted that this was only an apparent fact; subsequent experiments have substantiated his doubts. The desire to fathom the structure of the medium and propagation, has led from HUYGENS, NEWTON and FRESNEL to the laws of optics. Also for electrical forces, experiments have tended not to support [instantaneous] action-at-a-distance. Only gravity is an exception. It is difficult to believe, that in this case the situation is more than just an illusion, and many experiments were done, the majority of which reveal a finite propagation velocity and call for no changes in NEWTON's law, that are amenable to empirically verification. We shall discuss them below; by use of well chosen categorization, those few archetypes can be identified, from which real effects can be expected.

One should not imagine that the velocity of gravity can be experimentally observed as was the case for electric interaction. But indirect consequences of each hypothesis usually suffice to make some determination thanks to the high precision of astronomical observations. Such indirect alterations, which eventual new hypotheses introduce, must not exceed tolerances set by observation. But there are exceptions. A hundred years of astronomical observations and calculations have revealed several discrepancies between them, which so far have not been explained using NEWTONian mechanics, but which a new law must be able to reconcile. Among these anomalies, surely the largest pertains to Mercury, for which the effect of gravitation from other planets on its elliptical orbit is to cause it to rotate in its plane: observations show a precession of 42 arc-seconds per century in excess of the calculated value. This difference is small, but beyond doubt and unexplained. It is possible that the next nearest planets, Venus and Earth, also exhibit

[1]A hundred years ago, when gravity in general was formulated as an action-at-a-distance, the then current sensibilities pertaining to the unity of natural forces, led to regarding all such forces, e.g., molecular, as action-at-a-distance. That nowadays, contemporary sensibilities weigh against such artificial concoctions, can be credited to the success of FARADAY AND MAXWELL.

similar, if 5 to 10 time smaller, anomalies. The eccentricity of their orbits is very small, approximately 0.01%; they are virtually circular. Although it is obviously impossible to observe the rotation of a circle in itself, it is sufficient to observe the cycle time of the planet to detect this effect. In this case, the very small changes caused by this anomaly, were their orbits very eccentric, would be reduced by one part in a hundred, if the cycle time were changed even in an insignificant way. For Mars, for which the eccentricity is 0.09%, a similar, small anomaly should be expected, and it is in fact observed.

Other anomalies concern lunar motion and the ENCKER comet; which we shall not further consider.

Observation shows that for gravity, in contrast to electric forces, there is no shielding effect; further, there is no evidence of influence from a medium. Were a part of the matter of a planet partially shielded against the pull of the Sun, then the total force would not be proportional to the full masses, which would cause significant abberations; as LAPLACE calculated, in order to estimate the largest such aberration allowed by observations, one would have to assume that at most the force of gravity on passage through the Earth could be reduced by one part in a million.

These facts are of the greatest importance for all theories, especially those, which in one way or another do not seek to give a "mechanical explanation" in the usual sense, rather seek to reduce gravity to a side effect of the electric force, so that, for example, the gravitational constant would be determinable from electrical and magnetic measurements. This would represent a reformulation of the problem of very great significance for Physics.

To date the explanations suggested for gravity can be categorized in two groups: static and dynamic.

In the first of these, matter is taken to deform surrounding aether, a deformation that is assumed to expand outwards onto other bits of matter such that the effect is to create the appearance of an attraction. When *ponderable matter is in equilibrium, so also is the aether*, at least after a suitable interval. Such an assumption is the most obvious and goes back to NEWTON. Gravitational energy is here the potential energy of the aether. This assumption, however, as MAXWELL noted, is itself sufficient to undermine the theory from the start. This is so according to a very general principle of statics, which states that energy must be greater *after* a deformation than before, that is, in the absence of ponderable matter, or else the equilibrium of the material would be unstable. In this case, however, the opposite must take place, in so far as gravitation is an attractive force, so that its potential energy should be smaller when the masses in a system are larger causing an aether deformation to be larger. For electric forces, the sign of the force is the opposite so energy under similar circumstance increases. It was on the basis of this principle that MAXWELL expected to be able to formulate his explanation of static electric forces, a task at which, however, he was not successful. Thus, one sees that an "aether" in which deformation is to effect gravity, would be, even in the absence of ponderable bodies, unstable; so that such an explanation is precluded from the start.

We are then necessarily led to introducing hidden motions in order that *kinetic* energy is involved, even when the material bodies which are detectable by our senses themselves appear at rest. In this the principle of minimum energy is not determinant, and the problem becomes resolvable in principle.

The oldest of the *kinetic* theories is that from LASAGE, which was taken up later by ISENKRAHE and others. The fundamental premise of their theory takes it that that space is replete with ultramicroscopic particles, *corpuscles ultramondains*, propagating in all directions with very high velocity. When a material body, *A*, is exposed to the impacts of

this flow, it remains at rest because the average impulse is zero, but should a second body, *B*, be located at some distance from *A*, it shades *A* from the stream coming toward it from *B*'s location, and then the total impulse is the average of the non-shaded flow, which leads directly to a net attraction of the two bodies.

Careful consideration shows[2], that these corpuscles must undergo more or less only *inelastic* scattering, so that the impacts would cause an increase in temperature, otherwise body *A* would reflect just as many particle toward *B* as it shaded from *B* so that the total effect would cancel out. Moreover, in so far as for gravity there is no neutralization by cause of negative mass, the atoms of a material body must be located at distances from each other that are large in comparison to their size, they must be composed of identical elements that are much larger than the *corpuscles ultramondains.* For particles at rest this leads to the law of gravitation. For particles in motion, as in a gas for example, friction must arise. The effect of gravity must have a finite propagation speed at most that of the corpuscles, and the effect on material bodies can depend only on their relative speed with respect to these corpuscles. LAPLACE, considered such a theory, which, as mentioned, should lead to friction that would have the long term effect on planets of slowing them down. Such an effect would be detectable with great accuracy from solar and lunar eclipses, for which there is quite good historical data. The absence of observations of this effect puts a lower limit on the propagation speed of gravity, which must, on this basis, be a hundred million time greater than light! The corpuscules themselves have an even more unbelievable velocity, for which POINCARÉ calculates after taking into account all perturbations, a value of 24×10^{17} times the velocity of light. Simultaneously the friction would be cause of a temperature increase for the Earth alone per unit time 10^{26} times larger than that due to solar insolation!

Such considerations, in spite of all modifications, torpedo this theory definitively. This pertains especially to a hypothesis from HOOKE, a contemporary of NEWTON's, which recently was revived and developed by LORENTZ. It replaces the corpuscles with waves that are presumed to traverse the aether in all directions. Such waves are taken to be partially adsorbed by material, otherwise they would have no effect at all.

For this variant too, a temperature increase should result. On the other hand, no noticeable adsorbtion of gravity should take place. These waves on traversing through the Earth lose at most one part in a million of their strength. This is highly improbable, and for this reason LORENTZ abandoned his hypothesis. Again, according to POINCARÉ's calculations, the deposited heat would be horrendously high, that is about 10^{13} degrees per second.

In these theories, gravitation was dependant on irreversible processes. This is not the case for the attempts at *hydrodynamical* paradigms from BJERKNES and RIEMANN.

The first of these shall be only briefly mentioned. If one considers a system comprised of spheres that simultaneously and uniformly periodically pulsate by expanding and contracting, and that are immersed in an incompressible and frictionless fluid, and if the intensity of the pulsation is set proportional to and identified with the atoms of the spheres, one gets the NEWTONian expression for the forces these spheres have on one another through the fluid. The simultaneity is crucial, however, and even more incomprehensible than NEWTON's law itself, and quite distant from all that we see in Nature elsewhere. WEBER has found, on the other hand, that if one attempts to induce synchronization, should it not exist at the start, it quickly and spontaneously establishes itself by means of the mutual effect

[2]See, e.g.: POINCARË, H., *Science et Méthode,* (Paris, 1908) p. 263; ZENNECK, J. *Gravitation,* in: *Enzklop. de math. Wissenshaft.* **V**, (Leipzig, 1903) p. 57.

of the spheres on each other. This transpires, however, only by cause of friction, which plays a role in all realistic fluids, and leads to the deleterious effects considered above for irreversible processes.

One may replace the pulsation of the spheres with alternating in- and exhalation of aether, for which, if the period of alternation is allowed to increase, one eventually reaches the conceptions of BERNOULLI and RIEMANN, which were actually more thoroughly researched by A. BRILL. In this paradigm, each atom is considered a persistent source (or sink) for aether. This aether substance is supposed to be incompressible outside an atom, while in an atom it must therefore be continuously created or annihilated, in other words, it is not subjected to the principle of conservation of matter. In order to retain NEWTON's Law, it is then necessary that atoms, or sources whatever they be, are small with respect to their separation. The velocity of aether emission then plays the role of a *cyclic coordinate*, for which the appropriate moment, according to the laws of mechanics must remain constant; this moment (but not the emission velocity) must be set equal to the mass of the atom. Under these assumptions, atoms would attract each other in accord with NEWTON's Law of gravitation, and, on account of the incompressibility of this aether, the effect would be instantaneous, there would be neither propagation velocity nor perturbations, nor friction.

This is, of course, not a *mechanical explanation* of gravity. Even in a generalized mechanics, indestructibility of matter would be an axiom, that we would surrender only with great regret. Further, there is the additional difficulty, that an aether of this character, could not be reconciled with the discipline of Optics.

With these considerations, we have been acquainted with all current notions for a *mechanical explanation* of gravity. This survey shows, I hold, that this problem can not be resolved within today's overly narrow conceptions; but, perhaps, better fortune could be had still with some wider generalization. What's important for a *mechanical explantation*, so that it can satisfy our vaguely formulated desiderata for a view of Nature, is not that mechanical principles known to us today are directly applicable, rather, that the uniquely variable quantities are space and time, while otherwise all quantities that arise, namely the total quantity of material[3], or energy[4], electric charge, etc. are invariants.

A *mechanics of energy*, in which it is considered as a constantly moving fluid, perhaps would lead to a solution of this problem.

In stead of seeking a mechanical explanation, one can pose the judicious, and seemingly more promising, question whether gravitation is an ancillary effect which is due to electric interaction. In this case, gravity would propagate with the speed of light, and NEWTON's Law would have to be extended with terms depending on the velocity and acceleration divided by c. If in these terms c appears in the denominator with the power n, one speaks of a term of the n-th order. For the solar system, first order terms have a magnitude of three parts in $10,000$, and second order terms of 10^{-7}, etc.

First we must ask ourselves, how this supposition contrasts with that of LAPLACE, according to which the velocity of gravitation is 10^8 times that of the speed of light. Now, we know from aberration, that the direction of a gravity wave is not the same for fluid and fixed situations, and that the difference is of the first order. This is the LAPLACE assumption, and it is probable that he attributed aberration to it. Only detailed examination

[3]The term "substance," would capture the same sense of indestructibility, however, nowadays it has been loaded with metaphysical significance that renders it unusable in the physical sciences.

[4]The *unity of all energy*, as it is sought, for example, in HERTZian mechanics, should be one of the most important postulates toward which Physics strives. To date, gravitational theories have considered energy only in its usual kinetic variant, which is, no doubt, too narrow.

can show, that this result in Optics is conditioned by the wavelength being small with respect to separation distances. For planets and their satellites, however, the periods (year lengths) are of such a nature, that the wavelengths are large with respect to the dimensions of the solar system. Calculations show that changes in the direction of emission, that is, aberration, through changes in intensity and in the distance from the source are such that the first order terms cancel. The new gravity law would differ from NEWTON's only by very small terms of second and higher order. Moreover these terms, to the extent that they give detectable effects at all, are not friction terms; so that the LAPACEian calculation is not applicable and one can from the consequences see that *nothing prevents attributing the velocity of light to gravity*, but likewise nothing requires it either, in so far as this hypothesis, to date at least, doesn't lead to any clarification of Mercury's anomaly.

In an attempt to attribute gravity to the electric interaction, MOSSOTTI, ZÖLLNER and lately even LORENTZ, suggested that the attractive force between unlike charges somewhat outweighs the repulsive force of like charges. In so far as nowadays a hydrogen atom is seen as two unlike charges bound together, then according to the usual electrostatic laws, two such atoms at a distance from one another which is large with respect to their size, no longer exert a force in exact proportion to the inverse square of their separation. By this hypothesis, the combination of attraction and repulsion no longer compensate, rather the attraction dominates. Since the charge and masses in a hydrogen atom are known approximately, one can estimate to what percent the attraction dominates. This is extraordinarily small, it is about 10^{-34}%. That is, gravitational force is vastly weaker than electric force that would result were the positive and negative charges of an atom completely separated. Such separation is successfully achieved (through friction, for example) only to a very small extent.

Such a small dissymmetry, were its existence beyond doubt, would scarcely correspond to our physical-ascetic instincts. In reality, even a very small alteration in the relationships[5], suffices to realize a superposition of the *ordinary* electric with the gravitational force. There is then in this hypothesis from MOSSOTTI, just an altered relationship; for which the positive aspect is, that the laws for electric force are to be applied to gravity simply in that one replaces charge with mass. Moreover, one must attribute a certain conduction capacity so that in principle a shadow or screening effect can diminish gravity. By consequence of appropriately chosen ancillary assumptions, as shown by GANS, one can reduce this effect; but, to get an absorption of one part in million through the Earth's diameter, which experience seems to require, appears impossible. This then constitutes a serious objection to this theory.

What effect would this theory predict for planetary motion? To answer this question, we must distinguish among the various electrodynamic theories. One has already used formulas from WEBER and RIEMANN for gravitation. The only significant deviation was the precession of the perihelion of Mercury, which per WEBER, amounted to $7''$ per century[6], and according to RIEMANN, $14''$, while for other planets it is vanishingly small. The general magnitude and direction agree with observations, which is already a remarkable achievement. But the observed anomaly is actually $42''$, i.e., substantially larger. As far as the mutual influence of the planets on each other, it is so weak — it is a correction of second order of approximately one part in $10,000$ — that it has no observable effect.

[5]See: GANS, R., *Jahresber. deutsch. Math.-Vereinigung,* **XIV,** 578 (1905).

[6]TISSERAND obtained the double of this figure, namely $14''$; he set WEBER's constant equal to the reciprocal of the square of the speed of light, when it actually has only half this value. This he then repeated everywhere that this issue arose.

LORENTZ also applied his equation to planetary motion. As is well know, LORENTZ considered absolute velocity with respect to an aether. Detailed examination shows, that the particular source of deviations could be the following:

(1) the translation velocity of the Sun in space: LORENTZ finds discrepancies between the motion of the Sun relative to the fixed stars as observed in astronomy, and as identified with the motion of the Sun relative to aether, a not unreasonable identification, that in fact even for Mercury are not evident.

(2) the change in mass with the absolute velocity: If one takes it that mass for all matter, as is done for the electron, is of a purely electromagnetic origin (the assumption of a "true" mass, would reduce the discrepancy), then one finds that precession of the perihelion of Mercury would be several arc-seconds per century[7], regardless whether one uses formulas from ABRAHAM, BUCHERER-LANGEVIN or LORENTZ for the calculation of mass.

Finally, in recent times LORENTZ has reformulated his theory so that absolute velocity no longer plays a role at all in it. Thus, the effect of translation of the solar system, vanishes; since however, it resulted in no corrections in any case, this consideration has no influence on our conclusions.

In summary we can conclude, that it is possible to apply the laws of electrodynamics to gravity, but that this does not give a clarification of either the magnitude of the gravitational constant from electrical and magnetic measurements, nor of the precession of the perihelion of Mercury.

As the laws of electromagnetism themselves, however, are rather provisional, one can pose the question whether further developments might in fact allow the extraction of gravity from them in a satisfactory manner. We shall ague that, this very likely is indeed the case.

To make this argument, it is necessary to know exactly within which boundaries one can modify the expression for the force that two charges exercise on each other without introducing a conflict with empirical experience. Exactly this the writer has done[8]. It is probably *impossible* to provide a general solution; one wins, however, satisfactorily general conclusions if one introduces certain accessory hypotheses, in particular the assumption of the relativity of motion in its classical sense (not in the sense that EINSTEIN and LORENTZ introduced)[9], and its application to light propagation [10].

The force mentioned above between two arbitrary charges or electrons depends on their position, velocity and acceleration as well as on the laws governing propagation. From experiment, one finds, that terms of second order even, are not completely determined, rather contain an arbitrary constant. Terms of higher order play a role only in KAUFMANN's experiments on the variability of mass and for the most part remain undetermined. Under these conditions, there remains two ways to unify gravitation and electric forces so as to derive the gravitational constant and calculate the precession of the perihelion of Mercury.

According to current understanding, the atom consists of a given number of positive charges which are fully compensated by negative electrons. Magnetic effects seem to require that one attribute rotation or gyration to these charges. Let us assume, in order to

[7] WILKENS, *Physik. Zeitschr.* **VII**, p. 846 (1906).

[8] RITZ, W., "L'Electrodynamic Général, *Annales de Chimie it de Physique,* **XIII,** 145-275 (1908).

[9] According to the Principle of Relativity, a uniform translation of a system has no influence on the processes taking place within it. LORENTZ and EINSTEIN, on the other hand introduce new definitions for 'time,' 'velocity' and so on.

[10] For details see: RITZ, W., "Du rôle de L'Éther en Physique", *Rivista di Scientia,* **III** (6) (1908).

have a particular vision as basis, that the electrons are at rest while the positive charges are in uniform and very rapid rotation. If two such atoms at large distance interact on each other, the following will transpire.

Electrostatic interaction vanishes, or rather, interact as small dipoles according to an entirely different law than that of NEWTON. For a system of a large number of such atoms, the total force of this interaction is null. But, those forces dependant on the velocity and acceleration, of which the former are proportional to the inverse square of the separation and the latter to the inverse distance itself, must be taken into account. The first category includes, for example, the effects studied by AMPÈRE, that two constant currents exercise on each other, and therefore also two moving charges. The latter includes the electric forces that emanate from a HERTZian oscillator, as well as those from light, such as light pressure.

In order that these forces could lead to a gravitational force, it must be the case that their average does not vanish when the axes of rotation take on all possible orientations, which must occur in a block of material comprised of a large number of atoms. Neither in the original nor in the revised version of LORENTZ' theory are there terms that satisfy these stipulations. But must this inevitably always be the case? Close examination shows that in the original theory, this arrises by effect of the existence of absolute velocities, whereas in the revised theory it arrises because the principle of kinematics and universal time were surrendered. Precisely these features, however, are the least secure points in the current understanding of electrodynamics. As soon as one retains classical kinematics, and considers *relative* motion, there appear terms that give a finite average contribution. Such terms arise even in the second order, the resulting force is proportional to the average of the square of the velocity of a charge[11] and depend on an arbitrary constant. Thermal molecular motion already suffices in any case (maintaining the general views as described above), in order to get an significant force between two bodies, *A* and *B*, that is proportional to temperature, which conflicts with experience, so that it becomes necessary to so chose the constant, that this force vanishes. But higher, fourth and sixth order terms, with still unknown coefficients, would not be vulnerable to this objection if the motion in the interior of atoms is large compared to thermal motion, which is very likely the case. In this way one would get a force that is proportional to the inverse of the square of the separation distance, and directly proportional to the number of rotating charges contained in *A* and *B*, even while the coefficients remain undetermined. It suffices to assume that the number of charges in each atom is proportional to the mass of the atom, and the coefficients can be obtained by retaining NEWTON's law[12]. Naturally, a future theory must determine these coefficients *a priori* or derive them from electrical and (or) magnetic measurements. The so calculated gravitational constant must be identical to the measured value. In so far as the relevant terms are of high order, it is clear, that gravitational forces would be much weaker than the electric forces directly between the charges themselves.

Besides the term of fourth (or sixth) order, from which we deduced gravitation, the next term, the sixth (or eighth) is also to be exploited for second order gravitational forces. Of its coefficients, we know knowing. It would again determine a rotation of the perihelion, as

[11] See: RITZ, W., "L'electrodynamic Général, *Annales de Chimie it de Physique,* **XIII,** §2.17 (1908).

[12] If rotating charges are unadaptabley bound to the atom, then there can be no screening effect for gravity. Electrical screening arises by effect of rearrangements of charges within a block of material; likewise, magnetic forces are screened by rearrangements of the axes of rotation of charges by cause of forces imposed from the exterior of the material. Neither of these effects would occur for gravity.

in the cases treated above, and it is sufficient, that coefficient be larger than in those cases, in order to get the anomaly seen fir Mercury.

Thus far we have considered only electromagnetic terms that depend on the velocity and fall off in inverse proportion to the square of the separation. Other terms depend on the acceleration and some power of the relative velocity, they are of third or higher order and fall off in proportion to the inverse of the separation. But for a rotating electron, the acceleration of one part will be compensated by the other part, and in fact more so as the separation of the two electrons is larger than their diameter, a. An exact calculation, using an expansion in terms of a/r, shows that the term in $1/r$ vanishes, and that in general a term with a/r^2 survives, for which the average value over all possible positions of the axis of rotation, is different from zero. That is, we get a force proportional to the inverse of the square of the separation for which the coefficient, a, that is, one proportional to the the dimension of the electron and a power of the reciprocal of the speed of light, usually "3", all of which again corroborates the observed weakness of gravity relative to electric force. The coefficient of this term, just as for the other terms of order higher than second (with the exception of light pressure, which is here not an issue), is obviously unknown, so we again obtain the same result: extraction *of the force of gravity from electromagnetic measurements, along with a calculation of the gravitational constant and a clarification of Mercury's anomaly will be possible only after the laws of electrodynamics are sufficiently precisely known.*

In any case, gravity will depend on the dynamical constitution of atoms.

If after two centuries of intense research, still no connection between gravity and another, especially electrical, force is developed, and if no limit on its propagation velocity is revealed, then it most likely will be due to our ignorance of the electric interaction. We can hope, however, that in the foreseeable future, if not a "mechanical explanation," still a reduction of gravity to electrodynamics will be achieved. Towards a unified view of our universe, such will constitute a step of great significance.