Did 20th century physics have the means to reveal the nature of inertia and gravitation?

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Abstract

At the beginning of the 20th century the classical electron theory (or, perhaps more appropriately, the classical electromagnetic mass theory) - the first physical theory that dared ask the question of what inertia and mass were - was gaining momentum and there were hopes that physics would be finally able to explain their origin. It is argued in this paper that if that promising research path had not been inexplicably abandoned after the advent of relativity and quantum mechanics, the contemporary physics would have revealed not only the nature of inertia, mass, and gravitation, but most importantly would have outlined the ways of their manipulation. Another goal of the paper is to try to stimulate the search for the mechanism responsible for inertia and gravitation by outlining a research direction, which demonstrates that the classical electromagnetic mass theory in conjunction with the principle of equivalence offers such a mechanism.

1 Introduction

According to an eastern proverb the darkest place is beneath the lantern. The meaning of a proverb could hardly be more profound and more suitable for fundamental concepts: Nature has given us her greatest secrets as self-evident phenomena. Everyone "knows" what existence, space, time, mass, inertia, gravitation, etc. are; we even have complex theories dealing with those concepts. If, however, we want to explain their nature we find ourselves in the same situation in which St. Augustine found himself when tried to explain the nature of time: "What then is time? If no one asks me, I know; if I wish to explain it to one that asketh, I know not" [1].

We are about to enter the 21st century but our understanding of the origin of inertia, mass, and gravitation still remains what has been for centuries - an outstanding puzzle. All theories constituting the contemporary physics are concerned mostly (if not only) with the description of those phenomena. Even the modern theory of gravitation, general relativity, which provides a consistent no-force explanation of gravitational interaction of bodies following geodesic paths, is helplessly silent on the nature of the very force we identify as gravitational - the force acting upon a body deviated from its geodesic path being at rest on the Earth's surface.

The classical electromagnetic mass theory appears to have been gradually forgotten and now many physicists believe that physics cannot say anything about the origin of inertia, mass, or gravitation. Even scientists directly involved in the efforts to discover the Higgs boson [2] (believed to be responsible for endowing particles with mass) such as Claude Detraz, one of the two research directors at CERN, think that "Mass is a very important property of matter, and we have nothing in our current theory that says even a word about it". In what follows we will see whether this is really the case.

Here we shall follow the tradition established by the classical electron theory (i.e. the classical electromagnetic mass theory) and will study the inertial and gravitational properties of the simplest charged particle - the classical electron. There are two reasons why the classical electron is studied:

- (i) There is no quantum mechanical model of the electron quantum mechanics describes only its state not the electron itself (later we will make an attempt to outline the basis of the quantum electrodynamical formulation of the electromagnetic mass theory), and
- (ii) It is quite natural to complete the classical electromagnetic mass theory first before making the transition to a quantum description of the electron inertial properties. This has never been done since the classical electromagnetic mass theory was virtually abandoned when the theory of relativity and quantum mechanics were formulated. To abandon a promising theory that has never been proven wrong is an unprecedented case in physics. This unforgivable neglect is truly beyond one's comprehension because the electromagnetic mass theory is even now the only theory that addresses the origin of inertia and inertial mass in accordance with the experimental evidence of the existence of electromagnetic inertia and of the electromagnetic origin of some of the mass of charged particles. Moreover, the classical electromagnetic mass theory predicted that the (electromagnetic) mass increases with the increase of velocity (yielding the correct expression) and that the relationship between energy and mass is $E = mc^2$ (see [3]) all this before the theory of relativity.

2 Classical electromagnetic mass theory

In 1881 Thomson [4] first realized that a charged particle was more resistant to being accelerated than an otherwise identical neutral particle and conjectured that inertia can be reduced to electromagnetism. Due mostly to the works of Heaviside [5], Searle [6], Lorentz [7], Poincaré [8], Abraham [9], Fermi [27], Mandel [11], Wilson [12], Pryce [13], Kwal [14], and Rohrlich [15] this conjecture was developed into a theory (the classical electromagnetic mass theory of the electron) in which inertia is a local phenomenon originating from the interaction of the electron charge with itself (i.e. with its own electromagnetic field) [16].

According to the classical model of the electron its charge is uniformly distributed on a spherical shell. Such a model, however, cannot explain why the electron is stable since the negatively charged spherical shell tends to blow up due to the mutual repulsion of the different "parts" of the charge. This difficulty, known as the stability problem of the electron, has two sides - computational and conceptual. In the beginning of the century it appeared that the stability problem did lead to a computational difficulties with the famous 4/3 factor stubbornly appearing in the different expressions for the electromagnetic mass. Several authors [10]-[15] independently showed that the 4/3 factor had been caused by incorrect calculations, not by the model itself. This implies that there is no real problem with the stability of the electron. We do not know why. What we do know, however, is that if there were such a problem it would inevitably show up in all calculations of the electromagnetic mass which is not the case.

The conceptual difficulty with the classical model of the electron - its failure to explain what prevents the electron charge from blowing apart - has never been satisfactory resolved by the classical electromagnetic mass theory [18]. This is viewed as an indication that that model is not entirely correct. There are three reasons, however, which demonstrate that the classical model of the electron works. (i) The very existence of the radiation reaction force is evidence that there is interaction (repulsion) between the different parts of the electron charge. "The radiation reaction is due to the force of the charge on itself - or, more elaborately, the net force exerted by the fields generated by different parts of the charge distribution acting on one another" [19] (in the case of a single radiating electron the presence of a radiation reaction implies interaction of different parts of the electron). This may indicate that the charge of the real electron can indeed be modeled by a small spherical shell which, but the electron charge should be not *continuously* existing as smeared out on the shell; only if the electron charge were occupying the whole shell at every instant the stability problem would arise [20]. (ii) The calculations of the electron electromagnetic mass (assuming a spherical distribution of its charge) yield the correct expression for the mass. (iii) A more important indication that the classical model of the electron cannot be discarded as inadequate is that the classical electromagnetic theory is the *only* theory that correctly predicts the experimental fact that at least part of the electron's inertia and mass are electromagnetic in origin. As Feynman put it: "There is definite experimental evidence of the existence of electromagnetic inertia - there is evidence that some of the mass of charged particles is electromagnetic in origin" [3, p. 28-10], [23].

At the beginning of the century many physicists recognized "the tremendous importance, which the concept of electromagnetic mass possesses for all of physics: It is the basis of the electromagnetic theory of matter" (E. Fermi [24]). Therefore, it would have been natural to develop further the theory of electromagnetic mass by taking into account the relevant new results in physics achieved in this century. Instead, it had been inexplicably abandoned: "The state of the classical electron theory reminds one of a house under construction that was abandoned by its workmen upon receiving news of an approaching plague. The plague in this case, of course, was quantum theory.

As a result, classical electron theory stands with many interesting unsolved or partially solved problems" (P. Pearle [25]).

It is clear that what Fermi, Feynman, and Pearle are saying is important but not crucial (one can always find favourable quotes). What is crucial is what the classical electromagnetic mass theory itself is saying on inertia, mass, and gravitation when the principle of equivalence is taken into account.

The mechanism responsible for the electron's inertia and mass according to the classical electromagnetic mass theory is the following. The repulsion of the charge elements of an electron in uniform motion in flat spacetime cancels out exactly and there is no net force acting on the electron. If, however, the electron is accelerated the repulsion of its volume elements becomes unbalanced and as a result it experiences a net self-force \mathbf{F}_{self} which resists its acceleration - it is precisely this resistance that we call inertia (for a detailed description of why the repulsion of the different parts of an accelerating electron becomes unbalanced see [3, p. 28-5]). The self-force is opposing the external force that accelerates the electron (i.e. its direction is opposite to the electron's acceleration \mathbf{a}) and turns out to be proportional to \mathbf{a} : $\mathbf{F}_{self} = -m\mathbf{a}$, where the coefficient of proportionality m represents the inertial mass of the electron and is equal to E/c^2 where E is the energy of the electron field (therefore the electron inertial mass is electromagnetic in origin). This is an amazing result for three reasons: (i) it reveals that both inertia and mass have electromagnetic origin; the mass m in the expression for the self-force is electromagnetic since it is simply the mass that corresponds to the energy of the electron's electric field through the relation $E = mc^2$; (ii) it demonstrates that inertia is a local phenomenon (contrary to Mach's hypothesis that the local property of inertia has a non-local origin [26]) and (iii) it constitutes the first derivation of Newton's second law $\mathbf{F} = m\mathbf{a}$ [20] - a law that is considered so fundamental that after Newton postulated it no one has attempted to derive it.

Therefore, the classical electromagnetic mass theory does say not only a word, but offers a detailed mechanism explaining the origin of inertia and mass of charged particles: it is the *unbalanced* repulsion of the volume elements of the charge of an accelerating electron that gives rise to the electron's inertia and inertial mass.

An observer at rest in an accelerating reference frame will see that the electric field of an electron also at rest in the frame is distorted. Unlike uniform velocity, acceleration is absolute and the distorted electric field of the electron is one of the means by which the observer can detect the frame's acceleration. Therefore, in terms of the distorted electric field of an accelerating electron and avoiding the use of the controversial concept "parts of an elementary charge", one can equivalently say that an electron's inertia and inertial mass originate from the interaction of its charge with its own distorted electric field. The interaction of the charge of an uniformly moving electron with its own Coulomb (not distorted) field produces no net force acting on the electron as a whole; that is why an electron moving with constant velocity offers no resistance to its uniform motion [28].

The electromagnetic mass theory has been not only gradually forgotten; its status is now even more awkward those who mention it regard the electron mass as electromagnetic only in part as if the 4/3 factor in the expression for the electromagnetic mass has not been accounted for. It is that factor that was considered an indication that not the entire electron mass was electromagnetic. Feynman's objection against regarding the entire electron mass as electromagnetic was that the 4/3 factor leads to a contradiction with special relativity [3, p. 28-4]. Now, after the removal of that factor, it clearly follows from the classical electromagnetic mass theory that the entire mass of the electron should be electromagnetic in origin [29].

3 Electromagnetic mass theory and the principle of equivalence

The classical electromagnetic mass theory offered a mechanism accounting for the origin of inertia and inertial mass, but before the formulation of the equivalence principle by Einstein it appeared that that theory does not explain the origin of the passive gravitational mass and does not affect gravitation at all. The equivalence principle, however, postulated that the inertial mass (the measure of resistance that a body offers when accelerated) is equal to the (passive) gravitational mass (the measure of resistance that a body offers when being prevented from falling in a gravitational field); L. von Eötvös' experiments had already confirmed that equality. The equivalence principle requires that inertial and gravitational mass be equal but it was not initially clear how the electromagnetic mass theory could explain the origin of the gravitational mass in a gravitational field. The answer to this question is that it is a spacetime anisotropy around massive bodies that is responsible for the force acting upon an electron on the Earth's surface and for its gravitational mass. It manifests itself in the anisotropy in the velocity of electromagnetic signals (for short - the velocity of light). To explain what is the origin of the passive gravitational mass according to the electromagnetic mass theory and to shed some light into the basis of the equivalence principle here is a brief description of what happens to an electron in an accelerated reference frame and a frame of reference supported in

3.1 An electron in an accelerated reference frame N^a

For an observer at rest in an inertial reference frame I the electromagnetic field of an accelerating electron is distorted due to the electron's accelerated motion. As the accelerated motion is absolute the electron's electric field will be also distorted for an observer at rest in the accelerating (non-inertial) reference frame N^a in which the electron is at rest. The distortion of the electron's field for the inertial observer in I is caused by the electron's accelerated motion. For the non-inertial observer in N^a , however, the electron is at rest and therefore there is no (accelerated) motion of the electron that can account for the distortion of its field as determined by the observer in N^a . What causes the deformation of the electron's field in N^a is the anisotropic velocity of light there; N^a is an accelerating frame and it is the anisotropy in the propagation of light (and its manifestations such as the distorted electron field) which allow an observer in N^a to determine from within N^a that it is an accelerating (non-inertial) frame (for a more detailed discussion why the velocity of light in a non-inertial frame is anisotropic see [29] and [30]).

3.1.1 An electron falling in N^a

Imagine that an inertial observer I is observing an electron floating inside a spacecraft which moves with a constant velocity with respect to I (so both the spacecraft and the electron move by inertia offering no resistance to their motion). Let's now assume that the spacecraft starts to accelerate with an acceleration \mathbf{a} , i.e. it becomes a non-inertial frame N^a (an observer in the spacecraft will be also called N^a). For the inertial observer I nothing happens to the electron - it continues to move by inertia until the spacecraft's floor reaches it. For an observer in the spacecraft, however, the electron is falling toward the floor with an acceleration \mathbf{a} (for I it is the spacecraft's floor that approaches the electron). Obviously, there is a problem here - as the non-resistant motion by inertia is absolute, both observers (I and N^a) should agree that the electron is moving by inertia inside the spacecraft which does not appear to be the case since for N^a the electron is accelerating toward the floor (which implies that there is a force that accelerates it). Despite the fact that today's physics regards the force accelerating the electron inas fictitious, it has never explained why the accelerated motion of the electron as viewed in N^a should be considered inertial in N^a as well.

When the anisotropic velocity of light in N^a is taken into account in the calculation of the electric field of the falling in N^a electron it turns out that at every instant the electron field is the Coulomb (not distorted) field (here the instantaneous field is considered in order to separate the Lorentz contraction of the field and the distortion due to acceleration) [29]. Therefore, for an observer in N^a the motion of the falling (accelerating) electron will not be resistant since its electric field is not distorted. This means that the free electron in N^a falls with an acceleration a in order to compensate the anisotropy in the propagation of light in N^a and to prevent its field from being distorted; in other words, the falling electron offers no resistance to its accelerated motion in N^a and therefore moves by inertia while falling in N^a . In such a way, as expected, both the inertial observer I and the non-inertial observer N^a agree that the electron in N^a is moving by inertia offering no resistance to its motion.

3.1.2 An electron at rest in N^a

Now consider the moment when the spacecraft's floor reaches the floating electron as seen by the inertial observer I. The electron starts to accelerate and its motion is no longer non-resistant; its field gets distorted and a self-force $\mathbf{F}_{self} = -m\mathbf{a}$ originating from the unbalanced repulsion of the electron's charge "elements" (caused by the accelerated motion of the electron) starts to oppose its acceleration (i.e. the deformation of its field); here again m is the electromagnetic mass of the electron which is the mass corresponding to the energy of the electron field E ($m = E/c^2$).

What can an observer in N^a (in the spacecraft) say about the electron on the spacecraft's floor? At first, it appears that the electron field is not distorted with respect to N^a since it is at rest in N^a which would mean that no force is acting on the electron. If this were the case, there would be a problem again: the inertial and the non-inertial observers would differ on whether the electron is subjected to a force; as the existence of a force is an absolute fact all observers should recognize it. That problem disappears when the anisotropic velocity of light is taken into account in the calculation of the electron field in N^a . Due to an unnoticed up to now Liénard-Wiechert-like contribution to the potential of a charge in a non-inertial reference frame [29], [30] (caused by the anisotropic velocity of light in such frames) the electric field of the electron in N^a is as distorted as the field seen by the inertial observer I.

Therefore, the non-inertial observer N^a will also find that the electron is subjected to the purely electric self-force $\mathbf{F}_{self} = -m\mathbf{a}$, originating from the anisotropic velocity of light in N^a which disturbs the balance of the mutual repulsion of the "elements" of the electron charge. As seen from the expression for the self-force it coincides with what we call the inertial force; hence it follows that the inertial force is electromagnetic in origin.

The non-inertial observer in N^a sees that when the falling electron reaches the floor of the spacecraft it can no longer compensate the anisotropy in the propagation of light in N^a (by falling with an acceleration **a**), its field gets distorted which gives rise to the self-force \mathbf{F}_{self} .

3.2 An electron in a gravitational field

Consider now an electron at rest in the Earth's gravitational field. The Newtonian theory of gravitation tells us that the electron is subjected to a gravitational force - its weight $\mathbf{F} = m\mathbf{g}$. What does general relativity say about that force? Nothing. The gravitational field in general relativity is a manifestation of spacetime curvature and (unlike the electromagnetic field) is not a force field (which means that "there is no gravitational force in general relativity" [31]). A body falling toward the Earth is represented by a geodesic worldline which means that no force is acting on it. If a body is on the Earth's surface, however, its worldline is no longer geodesic and it is subjected to a force whose nature is an open question in general relativity [30]. This fact alone (not to mention the issue of the represented by a pseudo-tensor energy and momentum of the gravitational field [32]) is a sufficient reason for a thorough re-examination of the foundations of general relativity. And this is urgently needed since, as we shall see bellow, there are strong arguments indicating that the correct interpretation of the formalism of general relativity should be in terms of anisotropic, not curved spacetime.

3.2.1 An electron at rest in the Earth's gravitational field

One of the formulations of the equivalence principle states that what is happening in a non-inertial reference frame N^a which accelerates with an acceleration \mathbf{a} also happens in a non-inertial reference frame N^g at rest in a gravitational field characterized by an acceleration $\mathbf{g} = -\mathbf{a}$. One of the results Einstein obtained by analyzing the principle of equivalence is that in two elevators - one accelerating (frame N^a) and another at rest in the Earth's gravitational field (frame N^g) - light bends when propagating perpendicularly to the accelerations \mathbf{a} and \mathbf{g} , respectively. If one considers light propagating parallel and anti-parallel to \mathbf{a} and \mathbf{g} , it turns out that the average velocity of light in N^a and N^g is anisotropic: the velocity of a light ray from the elevator's ceiling toward the floor is slightly greater that the velocity of light propagating in the opposite direction [29], [30]. Interestingly, the expression for the average anisotropic velocity of light follows from the expression of the velocity of light in a gravitational field obtained by Einstein in 1911 but abandoned when the calculations of the deflection of light by the Sun (based on that expression) predicted a wrong value for the deflection angle. A careful analysis of the propagation of light in the Einstein thought experiment involving the two elevators demonstrates that his 1911 expression for the velocity of light in a gravitational field has been prematurely discarded [29].

Due to the anisotropic velocity of light in N^g the electric field of an electron at rest in N^g distorts, the balance of the mutual repulsion of the electron charge "elements" is disturbed which in turn gives rise to a self-force \mathbf{F}_{self} which tries to restore the balance in the mutual repulsion. The self-force turns out to be $\mathbf{F}_{self} = m\mathbf{g}$, where $m = E/c^2$ represents the passive gravitational mass of the electron and E is the energy of its field. As the electric self-force \mathbf{F}_{self} is precisely equal to the gravitational force $\mathbf{F} = m\mathbf{g}$, the classical electromagnetic mass theory predicts that the gravitational force acting on an electron on the Earth's surface is purely electromagnetic in origin which means that its passive gravitational mass is also electromagnetic in origin.

This is an important result since it demonstrates that the self-forces $\mathbf{F}_{self} = -m\mathbf{a}$ in N^a and $\mathbf{F}_{self} = m\mathbf{g}$ in N^g have precisely the *same* origin: in both cases it is the anisotropic velocity of light (electromagnetic signals) that gives rise to the electric force \mathbf{F}_{self} by distorting the electric field of the electron at rest in N^a and N^g which in turn disturbs the balance in the repulsion of its charge "elements". What we call the inertial mass m (in $\mathbf{F}_{self} = -m\mathbf{a}$) and the passive gravitational mass m (in $\mathbf{F}_{self} = m\mathbf{g}$) are precisely the *same* thing: m is the measure of the resistance an electron offers when its field is being distorted. In the case of an accelerating electron it is its acceleration (i) that distorts its field as seen by an inertial observer and (ii) that causes the anisotropy in the propagation of light in N^a which in turn distorts the electron field as observed by a non-inertial observer in N^a . Similarly, the distortion of the field of an electron at rest on the Earth's surface (i.e. at rest in N^g) is caused by the anisotropic velocity of light in N^g .

3.2.2 An electron falling in the Earth's gravitational field

The self-force \mathbf{F}_{self} acting on an electron at rest on the Earth's surface arises on account of its distorted electric field (caused by the anisotropic velocity of light in N^g) which disturbs the balance in the mutual repulsion of the electron charge "elements". \mathbf{F}_{self} tries to prevent the electron field from distorting and to restore the repulsion balance. If we allow \mathbf{F}_{self} do its job by removing the obstacle beneath the electron, it will start to fall and it will fall in such a way that the distortion of its field is eliminated, the repulsion balance is restored and the self-force \mathbf{F}_{self} ceases to exist. The calculation of the electric field of an electron left on itself in a gravitational field shows that the only way for the electron to compensate the anisotropy in the propagation of light in the gravitational field and to prevent its field from being distorted is to fall with an acceleration \mathbf{g} [29]. Therefore, a free electron in a gravitational field will move by inertia (without resistance) only if it falls with an acceleration \mathbf{g} . This result sheds light on the fact that in general relativity the motion of a body falling toward a gravitating center is regarded as inertial (non-resistant) and is represented by a geodesic worldline. Therefore, the electromagnetic mass theory gives an elegant answer to the question why an electron is falling in a gravitational field and no force is causing its acceleration.

The result that the electric field of an electron falling in the Earth's gravitational field at any instant is the Coulomb field, which means that no self-force is acting on the electron, also demonstrates that a falling electron does not radiate - its electric field is the Coulomb field and therefore does not contain the radiation r^{-1} terms [29].

If the electron is prevented from falling its electric field distorts, the self-force \mathbf{F}_{self} appears and tries to force the electron to move (fall) in such a way that its field becomes the Coulomb field; as a result of the free fall of the electron the self-force disappears.

3.2.3 The electromagnetic mass theory explains the behaviour of an electron in a gravitational field

The behaviour of the classical electron in a gravitational field is *fully* accounted for by the classical electromagnetic mass theory and the equivalence principle: the anisotropic velocity of light in N^g (in an elevator at rest in the Earth's gravitational field)

- (i) gives rise to a self-force acting on an electron at rest in N^g (whose worldline is deviated from its geodesic status) by distorting the electric field of the electron which in turn disturbs the balance in the mutual repulsion of its charge "elements", and
- (ii) makes a free electron fall in N^g with an acceleration \mathbf{g} in order to preserve its Coulomb field and therefore to balance the repulsion of its charge "elements". No force is acting upon a falling electron (whose worldline is geodesic) but if it is prevented from falling (i.e. deviated from its geodesic path) the mutual repulsion of the "elements" of its charge becomes unbalanced which results in a self-force trying to force the electron to fall.

General relativity does not provide an explanation of the nature of the force acting on a body at rest in a gravitational field whose worldline is not geodesic. It appears that general relativity cannot provide such an explanation at all since "there is no gravitational force in general relativity" [31]; this fact constitutes not only an open question but a crisis in general relativity. The classical electromagnetic mass theory in conjunction with the principle of equivalence provides a natural answer to the questions (i) why a free electron in a gravitational field is falling by itself (with no force acting upon it) and why its worldline is geodesic, and (ii) why an electron at rest in a gravitational field is subjected to a force and why its worldline is not geodesic: the worldline of an electron which preserves the shape of its Coulomb field is geodesic and represents a free non-resistantly moving electron; if the field of an electron is distorted, its worldline is not geodesic and the electron is subjected to a self-force on account of its own distorted field.

The anisotropic velocity of light in both N^a and N^g is responsible for the fall of a free electron and the appearance of a self-force when the electron is prevented from falling in N^a and N^g . Therefore, it is the anisotropy in the propagation of light in N^a and N^g that makes the two non-inertial reference frames N^a and N^g equivalent. In such a way, the equivalence principle is a straightforward corollary of the anisotropic propagation of light in N^a and N^g . The anisotropy in the velocity of light in the accelerating reference frame N^a is caused by the frame's acceleration. What is the origin of the anisotropic velocity of light in the non-inertial reference N^g (at rest on the Earth's surface) will be discussed bellow.

3.3 Toward a general theory of motion and gravitation?

In a spacetime region where the propagation of light is isotropic a free electron does not resist its motion only if it moves with uniform velocity (which means that its electric field is not distorted - it is the Coulomb field [34]); in this case the electron's worldline is a straight geodesic line. If the electron is prevented from moving with constant speed

its field distorts and the electron resists its acceleration (i.e. it resists the distortion of its field); in this case the worldline of the accelerating electron is neither geodesic nor straight. In a spacetime region where the propagation of light is anisotropic (i.e. in an elevator on the Earth's surface) the motion of a free electron is non-resistant (preserving the Coulomb shape of its field) only if it falls with an acceleration \mathbf{g} ; in this case the electron's worldline is geodesic but not a straight line. If the electron is prevented from falling (i.e. from moving by inertia in an anisotropic region of spacetime) its field distorts and the electron resists the deformation of its field; in this case its worldline is neither geodesic nor straight.

The electromagnetic mass theory provides an amazingly elegant and consistent description of the motion of the classical electron in open space (far from massive objects) and in a gravitational field. If it turns out that a quantum electrodynamical formulation of the electromagnetic mass theory reproduces the same elegant picture of the motion of charged particles we will realize that the basis for a general theory of motion and gravitation has been available for a century now.

4 Spacetime curvature or spacetime anisotropy?

We have seen that the anisotropy in the propagation of light and the electromagnetic mass theory fully account for the behaviour of the classical electron in a gravitational field. It appears that no curvature of spacetime is needed. In order to see whether this is really the case let us first consider what causes the gravitational attraction of two electrons.

We have seen that the electron inertial and passive gravitational mass are entirely electromagnetic in origin. As it is believed that all three masses - inertial, passive gravitational, and active gravitational - are equal, it follows that the electron active gravitational mass is fully electromagnetic in origin as well. And since it is only the charge of the electron that represents it (there is no mechanical mass), it follows that the active gravitational mass of the electron is represented by its charge. Therefore it is the electron charge that causes its gravity and the anisotropic velocity of light in the electron's neighborhood. The question now is: "Is the electron's gravitational field a manifestation of a spacetime curvature around the electron?" or more precisely: "Does the electron's charge create a curvature which in turn causes the anisotropic velocity of light in the electron's vicinity?"

We have seen that it is the anisotropy in the velocity of light and the electromagnetic mass theory that fully and consistently explain the fall of an electron toward the Earth and the self-force acting on an electron at rest on the Earth's surface. Let us now see whether the (gravitational) attraction between two electrons can be explained in the same way.

In addition to the electric repulsion of two electrons (e_1 and e_2) in open space, they also attract each other through the anisotropy in the velocity of light around each of them: e_1 falls toward e_2 in order to compensate the anisotropy caused by e_2 and vice versa. Therefore, the anisotropy in the propagation of light in the electrons' vicinity and the electromagnetic mass theory are completely sufficient to explain the electrons' (gravitational) attraction. No additional spacetime curvature hypothesis is necessary. This is an indication that, according to the classical electromagnetic mass theory, what the electron's charge creates is not a spacetime curvature; it is a spacetime anisotropy which causes the anisotropic velocity of light. In such a way, an electron's gravitational field according to the electromagnetic mass theory turns out to be the spacetime anisotropy in the neighborhood of the electron originating from its charge.

An anisotropic-spacetime re-interpretation of general relativity appears more trouble-free than its current curved-spacetime interpretation: (i) there is no problem with the force acting on a body whose worldline is not geodesic; (ii) the problem with the existence of gravitational energy is solved (there is energy, but electromagnetic); (iii) the equivalence of an accelerating frame and a frame at rest in a gravitational field is explained along with the equivalence of inertial and passive gravitational mass; (iv) it is also explained what tells a body to move non-resistantly (by inertia) or to offer resistance: a free body moves by inertia if the electric field of each of its charges is the Coulomb field; if the body's charges' fields are distorted, the body's motion is with resistance - it resists the deformation of its charges' electric fields.

5 Toward a quantum electrodynamical formulation of the electromagnetic mass theory

Although the lack of a quantum model of the electron makes it impossible to formulate the classical electromagnetic mass theory in terms of quantum mechanics, it appears that its quantum electrodynamical formulation may be possible.

According to the electromagnetic mass theory the inertial and gravitational force acting on the classical electron originate from its self-interaction through its distorted field. In quantum electrodynamics (QED) the quantized electric field of a charge is represented by a swarm of virtual photons that are constantly being emitted and absorbed by the charge. The distorted field of a non-inertial electron in QED is represented by the anisotropy in the velocity of the virtual photons comprising the electron field. The recoil that an electron experiences every time it emits or absorbs a virtual photon depends on the photon's velocity. Therefore, the anisotropy in the virtual photons' velocity disturbs the balance of the recoils to which a non-inertial electron is subjected (all recoils cancel out exactly if there is no anisotropy). This means that in QED too the interaction of a non-inertial electron with its own distorted field also gives rise to a self-force which may completely coincide with the inertial force in the case of an accelerating electron and with the gravitational force in the case of an electron supported in a gravitational field.

It turns out that in the QED formulation of the electromagnetic mass theory it does not matter whether an electron will be regarded as a point or a sphere - in both cases the self-force acting on a non-inertial electron originates from the *unbalanced* recoils of the virtual photons being absorbed by the electron; the recoils of the emitted virtual photons cancel out since the photons are always emitted with initial speed = c.

The QED formulation of the electromagnetic mass theory makes it possible to compare the electromagnetic mass approach to inertia with a recently proposed zero-point field (ZPF) approach to inertia [35] according to which the inertia of an (accelerating) electron originates from the interaction of its charge with the virtual photons of the zero-point fluctuation of the electromagnetic vacuum. A careful analysis of the two approaches demonstrates that they are regarding different mechanisms as the origin of inertia: the self-force acting on a non-inertial charge (according to the electromagnetic mass theory) originates from the disturbed balance of the recoils from the virtual photons comprising the charge's own electric field while the reaction force an accelerating charge is experiencing (according to the ZPF approach) is caused by the ZPF fluctuations of the entire electromagnetic vacuum. There are two reasons which seem to indicate that the ZPF inertia may be only a small contribution to the electron's inertia caused by the unbalanced recoils from the virtual photons of its field:

- (i) The ZPF approach appears unable to explain gravitation and the origin of gravitational mass. The electromagnetic resistance offered by an accelerating charge as explained by the ZPF approach can be viewed as caused by the Lorentz force which originates from the interaction of the magnetic component of the electromagnetic ZPF with the charge. This addresses the charge inertial mass only. When the charge is at rest on the Earth's surface, however, there is no magnetic component of the electromagnetic ZPF which can interact with the charge and therefore there is no ZPF contribution to the charge gravitational mass. One may speculate that inertial and gravitational mass are not equal at the quantum level which is, of course, something that should be studied. It becomes clear from here, however, why the ZPF contribution to inertia will be a small correction at best if there is no ZPF contribution to the gravitational mass: a ZPF contribution to the inertial mass should be extremely small since a greater contribution will result in a greater difference between the two masses which would have been observed by now.
- (ii) As the classical electromagnetic mass theory is the only classical theory (supported by experimental evidence) that deals with inertia it is natural to expect that it should be the QED version of that theory that accounts for inertia in QED. On the other hand, the ZPF approach to inertia does not have a classical analog which seems to disqualify it as a theory describing the major contribution to inertia.

As inertia and gravitation have predominantly macroscopic manifestations it appears certain that these phenomena should possess not only a quantum but a classical description as well. This expectation is corroborated by the fact that such a description already exists - the electromagnetic mass theory which yields the correct expressions for the inertial and gravitational mass of the classical electron. Therefore, the chances of any modern theory of inertia (and gravitation) can be evaluated by seeing whether it can be considered a quantum generalization of the classical electromagnetic mass theory.

6 Is all the mass electromagnetic?

We have seen that both the inertial and the passive gravitational mass of the classical electron are fully electromagnetic in origin. If we now ask what about the inertial and gravitational mass of the real electron? Are they electromagnetic in origin as well?

An argument against regarding the entire mass as electromagnetic is that strong and weak interactions should also contribute to the mass. This argument, however, does not apply to the electron for two reasons: (i) the electron does not participate in strong interactions, and (ii) a free electron does not participate in any weak interactions either.

This argument, however, is quite relevant when the nature of mass of the other elementary charged particles is discussed. As the issue of the strong and weak contributions to the mass is an open one and needs a separate study, let us outline an argument demonstrating that at least the strong interaction does not contribute to the mass. As we have seen the unbalanced repulsion of the charge "elements" of the classical electron gives rise to its inertia and mass. Therefore the unbalanced repulsion of two like charges increases the mass of the two-charge system. Unbalanced attraction of opposite charges results in the reduction of the charges' mass [29]. This is true not only for electric forces. Early attempts by Poincaré [8] to resolve the stability problem in the classical electromagnetic mass theory resulted in the introduction of unknown attraction forces (called Poincaré stresses) that balance the repulsion of the charge "elements" of the classical electron. As it turned out that those attraction forces had a negative contribution to the mass the problematic 4/3 factor was reduced to 1. Therefore, due to (i) the fact that the forces of strong interaction are attraction forces and (ii) the strength of strong interaction (over two orders of magnitude greater than the electromagnetic interaction) one can expect a significant negative contribution to the mass of a charged particle (compared to the electromagnetic contribution). If it turns out that the strong interaction does contribute to the mass, we will face a major crisis in physics - it will not be clear what compensates the negative contribution to the mass that originates from the strong interaction.

On the other hand, however, the strong and weak interactions as fundamental forces should make a contribution to the mass (as the electromagnetic interaction does) [36] and if they do not, then we might be forced to re-examine their very nature as separate fundamental interactions.

If it turns out that the strong and weak interactions make no contribution to the mass then the mass of all particles will prove to be entirely electromagnetic in origin. It should be noted, however, that a fully electromagnetic mass implies that there are no elementary neutral particles (with non-zero rest mass) in nature. A direct consequence from here is that only charged particles or particles that consists of charged constituents possess inertial and passive gravitational mass. Stated another way, it is only elementary charges that comprise a body; there is no such fundamental quantity as mass. It is evident that in this case the electromagnetic mass theory predicts zero neutrino mass and appears to be in conflict with the apparent mass of the Z^0 boson which is involved in the weak interactions. The resolution of this apparent conflict could lead to either restricting the electromagnetic mass theory (in a sense that not the entire mass is electromagnetic) or re-examining the facts believed to prove (i) that the Z^0 boson is a fundamentally neutral particle (unlike the neutron), and (ii) that it does possess inertial and gravitational mass if truly neutral.

Another argument that the mass of a particle is fully electromagnetic in origin comes from the velocity dependence of the mass. It is a corollary of the classical electromagnetic mass theory that the electromagnetic mass rises with velocity inversely as $(1-v^2/c^2)^{1/2}$ [3, p. 28-3]. And instead of viewing the result that all the mass depends on velocity discovered by the special theory of relativity as a serious indication that all the mass is electromagnetic, inexplicably the whole issue of electromagnetic mass has been practically abandoned. If we assume that the mass of a body consists of several kinds of masses (electromagnetic, mechanical, strong and weak) we have to answer the question how all of them obey the *same* law of velocity dependence?

7 Conclusions

We have seen that inertia, inertial mass, gravitation, passive gravitational mass, and the equivalence of the two masses of the classical electron are fully accounted for by the electromagnetic mass theory. The self-force to which a non-inertial electron is subjected on account of its own distorted electric field unambiguously indicates that the inertial and passive gravitational mass of the classical electron are electromagnetic in origin. This result provides a straightforward explanation of the equivalence of inertial and gravitational mass. The inertial and passive gravitational mass of the electron are the *same* thing - the mass that corresponds to the energy of its electric field.

However, the inertial and passive gravitational mass of the electron manifest themselves as such - as a measure of the electron's resistance to being accelerated - only if it is subjected to an acceleration (kinematic or gravitational). This resistance originates from the unbalanced mutual repulsion of the volume elements of the electron.

According to the electromagnetic mass theory it is the electron charge that causes the anisotropy in the propagation of light in the electron's vicinity. That anisotropy completely accounts for the (gravitational) attraction of two electrons. This is an indication that the Riemann curvature tensor in general relativity should be regarded as describing an anisotropy (not curvature) of spacetime. An important open question of the electromagnetic mass theory is how a charge causes the anisotropy of spacetime around itself. The study of this question may have important implications for the possibility of controlling gravitational interaction one day.

It should be stressed that the electromagnetic mass theory is not just a hypothesis; it is a valid physical theory since (i) it is based on firm experimental evidence (the experimental fact that at least part of the mass of charged particles is electromagnetic in origin; there is no other theory that accounts for this fact), and (ii) it is a further natural development of the classical electron theory in conjunction with the principle of equivalence.

It should be also specifically emphasized that even if it turns out that only part of the mass is electromagnetic in origin it still follows from the electromagnetic mass theory that inertia, inertial mass, gravitation, and gravitational mass (passive and active) are in part electromagnetic in origin.

The fact that a valid physical theory predicts that inertia and gravitation are entirely or at least partly electromagnetic in origin should have received the attention this incredible result deserves. The prediction that it is electromagnetic phenomena that cause (fully or partly) inertia and gravitation means that they can be in principle manipulated since we know how to deal with electromagnetic phenomena.

All results discussed here could have been obtained at least eighty years ago when Fermi [10] initiated the approach of studying the classical electromagnetic mass theory in conjunction with general relativity (more specifically, with the equivalence principle). Unfortunately, he later turned to atomic physics and perhaps deprived our century from solving the mystery of inertia and gravitation.

I believe that the answer to the question posed in the title is now clear - Yes, the 20th century physics did have the means to reveal the nature of inertia and gravitation.

References

- [1] St. Augustine, Confessions, Book 11(11.14.17); http://ccat.sas.upenn.edu/jod/augustine.html (see the Section "Texts and Translations").
- [2] See: http://press.web.cern.ch/Press/Releases00/PR08.00ELEPRundelay.html
- [3] R. P. Feynman, R. B. Leighton and M. Sands, The Feynman Lectures on Physics, Vol. 2, Addison-Wesley, New York, 1964, p. 28-4.
- [4] J. J. Thomson, Phil. Mag., 11, 229 (1881).
- [5] O. Heaviside, The Electrician, 14, 220 (1885).
- [6] G. F. C. Searle, Phil. Mag., 44, 329 (1897).
- [7] H. A. Lorentz, Proceedings of the Academy of Sciences of Amsterdam, 6, 809 (1904); Theory of Electrons, 2nd ed. (Dover, New York, 1952).
- [8] H. Poincaré, Compt. Rend., 140, 1504 (1905); Rendiconti del Circolo Matematico di Palermo 21, 129 (1906).
- [9] M. Abraham, The Classical Theory of Electricity and Magnetism, 2nd ed. (Blackie, London, 1950).
- [10] E. Fermi, Nuovo Cimento, 22, 176 (1921); Phys. Zeits., 23, 340 (1922); Rend. Acc. Lincei (5), 31, 184; 306 (1922); Nuovo Cimento, 25, 159 (1923).
- [11] H. Mandel, Z. Physik, 39, 40 (1926).
- [12] W. Wilson, Proc. Phys. Soc., 48, 736 (1936).
- [13] M. H. L. Pryce, Proc. Roy. Soc., A168, 389 (1938).

- [14] B. Kwal, J. Phys. Rad., 10, 103 (1949).
- [15] F. Rohrlich, Am. J. Phys., 28, 639 (1960); Classical Charged Particles, (Addison-Wesley, New York, 1990).
- [16] On the historical development of the classical electromagnetic mass theory see [15] and [1].
- [17] J. W. Butler, Am. J. Phys. 37, 1258 (1969).
- [18] In order to account for the stability of the classical electron Poincaré [8] assumed that part of the electron mass (regarded as mechanical) originated from forces (known as the Poincaré stresses) holding the electron charge together and that it was this mechanical mass that compensated the 4/3 factor (reducing the electron mass from 4/3m to m). However, the 4/3 factor, as discussed above, turned out to be an error in the calculations of electromagnetic mass as shown in [10]-[15]. As there remained nothing to be compensated (in terms of mass), if there were some unknown attraction forces (the Poincaré stresses) responsible for holding the electron charge together, their negative contribution to the electron mass would result in reducing it from m to 2/3m. This made the stability problem even more puzzling on the one hand, a spherical electron tends to disintegrate due the repulsion of the different parts of the spherical shell; on the other hand, however, an assumption that there is a force that prevents the electron charge from blowing up leads to a wrong expression for its mass. Obviously, there is an implicit assumption in the classical model of the electron that leads to such a paradox it is assumed that at every instant the electron charge occupies the whole spherical shell (see [20]).
- [19] D. J. Griffiths, Introduction to Electrodynamics, 2nd ed., Prentice Hall, New Jersey, 1989, p. 439.
- [20] It is not impossible for an elementary charge to have a spherical but not continuous distribution. Such a possibility follows from a work [21] which has received little attention so far. By bringing the idea of atomism to its logical completion (discreteness not only in space but in time as well - 4-atomism), it is argued in that work that a quantum-mechanical description of the electron itself (not only of its state) is possible if the electron is represented not by its worldline (as deterministically described in special relativity) but by a set of fourdimensional points (modeled by the energy-momentum tensor of dust - in this case a sum of delta functions) scattered all over the spacetime region in which the wave function of the electron is different from zero. The 4-atomism hypothesis gives an insight into two questions: (i) how an elementary charge can have "parts" and still remain an elementary charge, and (ii) why there is no stability problem despite that the "parts" of an electron repel one another: since for 1 second an electron is represented by 10²⁰ four-dimensional points (according to the 4-atomism hypothesis) at one instant the electron exists as a single point carrying a greater (bare) charge, but for one second, for example, there will be 10^{20} such points occupying a spherical shell that manifest themselves as an electron whose effective charge is equal to the elementary charge. The 4-atomistic model of the electron appears to overcome the difficulties of both a purely particle and a purely wave models of the quantum object and may be a candidate for what Einstein termed "something third" (neither a particle nor a wave). For a brief description of why neither the purely particle nor the purely wave models of the quantum object can be accepted see reference [22].
- [21] A. H. Anastassov, "The Theory of Relativity and the Quantum of Action (4—Atomism)", Doctoral Thesis, Sofia University, 1984 (unpublished); "Self-Contained Phase-Space Formulation of Quantum Mechanics as Statistics of Virtual Particles", Annuaire de l'Universite de Sofia "St. Kliment Ohridski", Faculte de Physique, 81, 1993, pp. 135-163.
- [22] Here are two of the most serious problems with a purely particle and purely wave models of the electron. (i) If the s-electron in the hydrogen atom is regarded as a particle, i.e. as localized (its charge being localized) somewhere above the proton, then the hydrogen atom should possess a dipole moment in its s-state. Both quantum mechanics and the experiment show that this is not the case. One may picture the electron in the s-state as so rapidly orbiting the proton that what is experimentally measured is the average value of the dipole moment over the measurement time. And since there is a spherical symmetry in the s-state all dipole moments cancel out exactly the average value is zero. To verify that hypothesis Madelung calculated the orbital velocity of the electron that would ensure that all dipole moments during the measurement cancel out. It turned out that the electron orbital velocity should be several orders of magnitude greater than the velocity of light. This shows that the electron charge should be somehow uniformly distributed around the proton. (ii) A system of n "particles" cannot be represented by a pure wave since that wave cannot be a real wave in the real space it is a wave in a space of 3n dimensions.

- [23] The Feynman Lectures on Physics is not the only physics textbook that stresses that experimental fact; see, for example, R. Stevenson and R. B. Moore, Theory of Physics, W. B. Saunders, Philadelphia and London, 1967 (p. 590: "there is experimental evidence for the existence of electromagnetic mass").
- [24] E. Fermi, Z. Physik, 23, 340-346 (1922), quoted by P. Moylan, Amer. J. Phys., 63, 818 (1995).
- [25] P. Pearle, in D. Teplitz, ed. Electromagnetism: Paths to Research, Plenum Press, New York, 1982, p. 213.
- [26] E. Mach, Science of Mechanics, 9th ed., Open Court, London, 1933. Around 1883 Mach argued that inertia was caused by all the matter in the Universe (no matter how distant it may be) thus assuming that inertia had a non-local cause.
- [27] The self-force $\mathbf{F}_{self} = -m\mathbf{a}$ is traditionally called inertial force. According to Newton's third law the external force \mathbf{F} that accelerates the electron and the self-force \mathbf{F}_{self} have equal magnitudes and opposite directions: $\mathbf{F} = -\mathbf{F}_{self}$. Therefore $\mathbf{F} = m\mathbf{a}$ which means that Newton's second law is derived on the basis of Maxwell's electrodynamics and Newton's third law.
- [28] Strictly speaking, in the framework of classical electrodynamics the explanation of the self-force acting on an accelerating charge appears possible only in terms of repulsion of charges, not in terms of interaction of a charge and a distorted electric field.
- [29] V. Petkov, Ph. D. Thesis, Concordia University, Montreal, 1997; for an account of why all arguments against regarding the entire mass of the classical electron as electromagnetic in origin have been answered see also: "Acceleration-dependent electromagnetic self-interaction effects as a basis for inertia and gravitation" (http://xxx.lanl.gov/abs/physics/9909019)
- [30] V. Petkov, What is general relativity silent on? (http://xxx.lanl.gov/abs/gr-qc/0005084).
- [31] J. L. Synge, Relativity: the general theory, Nord-Holand, Amsterdam, 1960, Ch. III. Sec. 3.
- [32] The formalism of general relativity refuses to yield an appropriate mathematical (tensor) expression for the energy and momentum of gravitational field; instead a pseudo-tensor to model gravitational energy and momentum is used. The problem with a pseudo-tensor is that it cannot represent a real physical quantity; this implies that there is no gravitational energy and momentum. Such a conclusion appears to be fully in line with the way general relativity describes gravitation - as a manifestation of spacetime curvature, not as a force field which possesses energy and momentum; gravitational filed in general relativity can be regarded as an energy-less and momentum-less geometric field. However, some people think that there is a real problem with such a conclusion since the experimental evidence seems to demonstrate the existence of gravitational energy and momentum it is sufficient to mention only the tidal electric power stations converting what appears to be gravitational energy into electric energy. That experimental evidence looks completely differently from the viewpoint of the electromagnetic mass theory which reveals that gravitation is electromagnetic in origin (at least in part) - the tidal electric power stations convert electric energy into electric energy (as in the cases in which mechanical energy is converted into mechanical energy). There are attempts to explain the fact that a pseudo-tensor is used for modeling gravitational energy and momentum: "At issue is not the existence of gravitational energy, but the localizability of gravitational energy. It is not localizable" [33]. Howeve, those attempts appear to be a result of a confusion because it is essentially claimed that two mutually excluding things are true: (i) there is gravitational energy, and (ii) there is no (force) gravitational field which means that there is no gravitational energy.
- [33] C. W. Misner, K. S. Thorne and J. A. Wheeler, Gravitation, Freeman, San Francisco, 1973, p.467.
- [34] An inertial observer with respect to whom an electron moves with constant speed will see its field deformed (Lorentz-contracted), but this does not mean that the electron resists its motion with uniform velocity. The observed deformation of the electron field gives rise to the increase of the electron mass as seen by the inertial observer.
- [35] B. Haisch, A. Rueda and H. E. Puthoff, Phys. Rev. A 49, 678 (1994); A. Rueda and B. Haisch, Phys. Lett. A 240, 115 (1998); A. Rueda and B. Haisch, Found. Phys. 28, 1057 (1998).
- [36] H. Stephani, General Relativity, 2nd ed., (Cambridge University Press, Cambridge, New York, 1990), p. 69.