AN ELECTROMAGNETIC BASIS FOR INERTIA AND GRAVITATION: WHAT ARE THE IMPLICATIONS FOR 21st CENTURY PHYSICS AND TECHNOLOGY?

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Abstract

The basis of most modern technology is the manipulation of electromagnetic phenomena. Haisch, Rueda and Puthoff (1994a) published a controversial but substantive formulation of a concept proposing an explanation of inertia of matter as an electromagnetic phenomenon originating in the zero-point field (ZPF) of the quantum vacuum. This suggests that Newton's equation of motion can be derived from Maxwell's equations of electrodynamics, in that inertial mass is postulated to be not an intrinsic property of matter but rather a kind of electromagnetic drag force (which temporarily is a place holder for a more general quantum vacuum reaction effect) that proves to be acceleration dependent by virtue of the spectral characteristics of the ZPF. Moreover the principle of equivalence implies that in this view gravitation would also be electromagnetic in origin along the lines proposed by Sakharov (1968). A NASA-funded research effort has been underway at the Lockheed Martin Advanced Technology Center in Palo Alto and at California State University in Long Beach to develop and test these ideas. An effort to generalize the 1994 ZPF-inertia concept into a proper relativistic formulation has been successful. With regard to the goals of the NASA Breakthrough Propulsion Physics Program we can, on the basis of the ZPF-inertia concept, definitively rule out one speculatively hypothesized propulsion mechanism: matter possessing negative inertial mass, a concept originated by Bondi (1957). The existence of this is shown to be logically impossible. On the other hand, the linked ZPF-inertia and ZPF-gravity concepts open the conceptual possibility of manipulation of inertia and gravitation, since both are postulated to be electromagnetic phenomena. Whether this will translate into actual technological potential, especially with respect to spacecraft propulsion and future interstellar travel capability, is an open question. The (possibly comparable) time scale for translation of Einstein's $E = mc^2$ mass-energy relation into nuclear technology was approximately four decades. A key question is whether the proposed ZPF-matter interactions generating the phenomenon of mass might involve one or more resonances. This is presently under investigation.

INTRODUCTION

In spite of the success of special and general relativity, which embody our best understanding of the relationship between mass and energy, the fundamental nature of mass has remained a complete mystery. There are four characteristics of matter that involve some aspect of the property of mass. (1) *Inertial mass:* the resistance to acceleration known as inertia, defined in Newton's equation of motion, $\mathbf{F} = m\mathbf{a}$, and its relativistic generalization. (2) *Active gravitational mass:* the ability of matter to attract other matter via Newtonian gravitation, or, from the perspective of general relativity, the ability to curve spacetime. (3) *Passive gravitational mass:* the propensity of matter to respond to gravitational forces. (4) *Relativistic or rest mass:* the relationship of mass and energy expressed in the $E = mc^2$ relation of special relativity. These are very different properties of matter, yet for some reason they are quantitatively represented by the same parameter. One can imagine a universe, for example, in which inertial mass, m_i, and passive gravitational mass, m_g, were different...but then objects would not all fall with the same acceleration in a gravitational field and there would be no principle of equivalence to serve as the foundation of general relativity. One can imagine a universe in which active and passive gravitational mass were different...but then Newton's third law of equal and opposite forces would be violated, and mechanics as we know it would be impossible. Another fundamental characteristic of mass is that objects that possess mass (i.e. matter) are limited to speeds less than the speed-of-light, c, whereas massless entities such as photons cannot move at any speed other than c.

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It is also instructive to consider the concept of *negative mass*, hypothetically proposed by Bondi (1957). This would not be the same as antimatter. A positron is the anti-matter version of an electron, but while it has the opposite charge, the mass of the positron and the electron are identical: all four types of mass (inertial, active and passive gravitational, and rest) are "positive". Real anti-matter has positive mass, whereas the hypothetical negative matter would be stuff whose mass is the negative of conventional matter.

> If an object made of negative matter could be obtained and coupled by elastic, gravitational, or electromagnetic forces to an object containing an equal amount of positive matter, the interactions between the two objects would result in an unlimited amount of unidirectional acceleration of the combination without the requirement for an energy source or reaction mass. In this paper, it is shown in exhaustive detail that, despite their unbelieveable propulsive capabilities, negative matter propulsion systems do not violate the Newtonian laws of conservation of linear momentum and energy. Thus, logical objections to the existence of negative matter must be found elsewhere than in Newtonian mechanics. (Forward 1990)

We propose that we have indeed found a new insight into the nature of mass, and while this immediately rules out the possibility of negative matter discussed above and its consequent hypothetical propulsion capabilities, it opens an equally revolutionary opportunity: the chance that inertia and gravitation, as electromagnetically-based phenomena, may be subject to modification.

WHY DOES F=ma?

Newton's second law, his equation of motion **F**=m**a**, is arguably regarded as the origin of physics. Forces and accelerations are perceptible phenomena, and from the equation of motion one infers that matter possesses a property called inertial mass. Note that it is impossible to directly perceive this mass, m. The only thing one ever perceives with the senses or measures with instruments is either **F** or **a** or both. That matter must possess mass, m, is an inference: one could say it is a matter of bookkeeping.

While it is difficult to imagine what such a universe would be like, it is possible to imagine a universe in which $\mathbf{F} \neq \mathrm{m}\mathbf{a}$, e.g. $\mathbf{F} = m\mathbf{a}^2$. However it appears that Newton's third law is somehow deeper and in a sense more fundamental than the second. Newton's third law states that for every force there must be an equal and opposite reaction force, i.e. $\mathbf{F} = -\mathbf{F}_r$. For stationary or static phenomena it is impossible to even conceive of an alternative: If the right hand is pressing against the left hand with force **F**, then the left hand must press back against the right hand with the equal and oppositely-directed reaction force, $\mathbf{F}_r$. How could one hand press against the other without the other pressing back? It would violate a fundamental symmetry, since who or what is to say which hand is pressing and which is not. Thus for static or stationary situations the balance of forces is the only imaginable circumstance.

If an agent exerts a force on a non-fixed object, experience tells us that a reaction force also manifests against the agent. But why is this so? The traditional explanation is that matter possesses inertial mass which by its nature resists acceleration. The discovery that appears to have been made is that, on the contrary, there is a very specific origin for a reaction force, $\mathbf{F}_r$. Accelerated motion through the electromagnetic zero-point field (ZPF) of the quantum vacuum results in a reaction force. If one analyses the ZPF using Maxwell's equations of electrodynamics, one finds that $\mathbf{F}_r = -m\mathbf{a}$. An electromagnetic reaction force (somewhat like a drag force) arises that happens to be proportional to acceleration. In other words, if one begins with Newton's third law of equal and opposite force and carries through an analysis using Maxwell's equations, one winds up *deriving* $\mathbf{F} = m\mathbf{a}$. That being the case, one can, in principle, dispense with the concept of inertial mass. Matter, consisting of charged particles (quarks and electrons) interacts with the electromagnetic ZPF and this yields a reaction force whenever acceleration takes place.

WHAT IS THE ELECTROMAGNETIC ZERO-POINT FIELD?

Statistical mechanics was developed by Boltzmann, Maxwell, Gibbs and others towards the end of the 19th century to yield a deeper understanding of the physics underlying the empirical laws of thermodynamics. Matter is treated as consisting of ensembles of oscillating particles. This approach was used to analyze the heat flows of thermodynamics and the blackbody radiation of heated objects (cf. Milonni 1994). The simplest representation of an atom in a solid is to regard it as an idealized point harmonic oscillator. This tells us nothing about the structure or intrinsic nature of an atom, but does allow one to analyze the energetics of a macroscopic object (e.g. a perfectly radiating solid at temperature T) on the basis of energy exchange between microscopic oscillators comprising the object. The laws of quantum mechanics tell us that there is a non-zero minimum energy for any oscillator. Calculating the minimum energy of such a quantum oscillator is one of the obligatory fundamental problems solved in most any textbook on Quantum Mechanics. Couching this in quantum language, one states that the lowest eigenvalue, E, of the oscillator Hamiltonian is not zero, but rather $E = h\nu/2$. The oscillators comprising matter have a minimum quantum energy.

The electromagnetic field inside a cavity can be represented as an expansion, i.e. a linear superposition of the characteristic modes of the cavity, each one oscillating at its characteristic frequency. It can also be shown after second quantization that the individual cavity modes behave in mathematically exactly the same way as ordinary mechanical harmonic oscillators. The volumetric density of modes between frequencies ν and $\nu + d\nu$ can be represented by means of the density of states function $\rho_\nu d\nu = (8\pi\nu^2/c^3)d\nu$. The ground state energy of each one of these harmonically oscillating modes is then $h\nu/2$.

It is instructive to write the expression for blackbody radiation including this additional zero-point energy:

$$\rho(\nu, T)d\nu = \frac{8\pi\nu^2}{c^3}\left(\frac{h\nu}{e^{h\nu/kT} - 1} + \frac{h\nu}{2}\right) d\nu. \tag{1}$$

The first term (outside the parentheses) represents the mode density, and the terms inside the parentheses are the average energy per mode of thermal radiation at temperature T plus the zero-point energy, $h\nu/2$, which has no temperature dependence. Take away all thermal energy by formally letting T go to zero, and one is still left with the zero-point term. The laws of quantum mechanics as applied to electromagnetic radiation force the existence of a background sea of zero-point-field (ZPF) radiation.

There is a discipline within physics known as stochastic electrodynamics (SED) which assumes that the ZPF may be treated as a real field no different from any other radiation field (de la Peña and Cetto 1996). The extent to which this is an accurate representation of reality is the subject of lively debate (see Michel 1996 and the reply of Haisch and Rueda 1997a). We have — so far — relied upon the techniques of SED to calculate the electromagnetic reaction force that we propose accounts for inertia.

TWO DERIVATIONS OF INERTIA

The key to understanding the relationship between the ZPF and inertia is to recognize that while the ZPF, as represented above, is perfectly uniform and isotropic in stationary or uniform-motion frames, certain asymmetries appear in the ZPF when viewed from an accelerating frame. (There is an important distinction between accelerating and constant-motion frames: If the ZPF were detectable in a constant-motion frame the laws of special relativity would be violated.) The original analysis of Haisch, Rueda and Puthoff (1994a) concerned itself with interactions between an idealized charged particle forced to undergo a uniform acceleration and the ZPF. A new analysis (Rueda and Haisch 1997) arrives at the same result — in fact it extends the result to a relativistically correct form of the equation of motion, $\mathcal{F} = d\mathcal{P}/d\tau$ — by examining only the ZPF radiation pattern as viewed from an accelerated frame. The new analysis is thus both more general and at the same time not dependent on simplified particle-field interaction models.

In the 1994 analysis, HRP assumed that matter, consisting of quarks and electrons, could be represented as an ensemble of oscillating point charges. Following a terminology of Feynmann, such an idealized quark or electron was called a parton. Protons are believed to consist of three quarks (uud) whose charges sum to +1. Neutrons are believed to consist of three quarks (udd) whose charges sum to zero. Electrons are — to the best of our current knowledge based on scattering experiment — point-like. It was simply assumed that the interactions between matter and the ZPF take place at the quark or electron level, so that the parton analysis would apply equally to protons and neutrons. (If the interactions take place at sufficiently high frequencies, the gluon-mediated binding between quarks can justifiably be ignored.) Following a technique first developed by Einstein and Hopf the partons were driven to oscillate ($\mathbf{v}_{osc}$) by the electric component of the ZPF, $\mathbf{E}^{ZP}$. The oscillating parton was forced to accelerate in a direction perpendicular to the oscillations. The average Lorentz force between the oscillating charge and the magnetic component of the ZPF, $\mathbf{B}^{ZP}$, was calculated. It was found that

$$\mathbf{F}_L = < (q/c)(\mathbf{v}_{osc} \times \mathbf{B}^{ZP} > = -\frac{\Gamma \hbar \omega_c^2}{2\pi c^2}\mathbf{a}. \quad (2)$$

The Lorentz force, $\mathbf{F}_L$, is seen to provide a reaction force, $\mathbf{F}_r$, having the appropriate dependence on acceleration to account for inertia. The interpretation is that the electromagnetic and ZPF parameters constitute inertial mass (see HRP for definitions of the quantities):

$$m_i = \frac{\Gamma \hbar \omega_c^2}{2\pi c^2}. \quad (3)$$

The recently completed relativistic analysis (Rueda and Haisch 1997) is no longer dependent on matter behaving as oscillating partons. Instead we have investigated the Poynting vector (energy flow) of the ZPF in an accelerating frame using standard relativistic transformation formulae. The Poynting vector is found to be non-zero, whereas it is precisely zero in constant-motion frames. From the Poynting vector one may calculate the electromagnetic momentum flux transiting a given object, which is also non-zero for an accelerating object. All an object need do is scatter a tiny amount of the ZPF radiation flux to generate a reaction force that turns out to be proportional to acceleration. An accelerating object "sees" a flux of electromagnetic radiation coming toward it; scattering some fraction of that radiation (by dipole scattering, say) will generate a drag force that is necessarily directed against the accelerated motion. From this picture it is immediately obvious why the hypothesized Bondi negative inertial mass conjecture becomes impossible: the resistance comes from the object moving into a flux of radiation, and there is no way to "turn this around" into a negative inertial mass, i.e. no way to turn a resistance into an attraction.

GRAVITATION

One of the first objections typically raised against the existence of a real ZPF is that the mass equivalent of the energy embodied in eq. (1) would generate an enormous spacetime curvature that would shrink the universe to microscopic size. The resolution of this dilemma lies in the principle of equivalence. If inertia is an electromagnetic phenomenon involving interactions between charge and the ZPF, then gravitation must be a similar phenomenon. The mere existence of a ZPF would not necessarily generate gravitation or spacetime curvature. Indeed, preliminary development of a conjecture of Sakharov (1968) by Puthoff (1989) indicates that the ZPF in and of itself *cannot* be a source of gravitation.

Expressed in the simplest possible way, all matter at the level of quarks and electrons is driven to oscillate (*zitterbewegung* in the terminology of Schrödinger) by the ZPF. But every oscillating charge will generate its own minute electromagnetic fields. Thus any particle will experience the ZPF as modified ever so slightly by the fields of adjacent particles... and that is gravitation! It is a kind of long-range van der Waals force.

A ZPF-based theory of gravitation is only in the exploratory stage at this point. The Puthoff (1989) analysis that resulted in the calculation of a proper Newtonian inverse-square law of attraction has since been shown to be problematic. Moreover at this time there is no accounting for the gravitational deflection of light other than to invoke a variable permittivity and permeability of the vacuum due to the presence of charged matter. However if it can be shown that the dielectric properties of the vacuum can be suitably modified by matter so as to bring about light deflection, this may be a viable alternative interpretation to spacetime curvature. There is no way even in principle to distinguish between true spacetime curvature and deflection of light beams in Euclidean (flat) spacetime, since light propagation serves to define the metric.

SUMMARY AND CONCLUSIONS

A mathematically rigorous but still to be verified concept has been proposed that attempts to account for the inertia of matter as an electromagnetic reaction force. A preliminary version of a parallel gravitation concept along lines proposed by Sakharov also exists, and is consistent with the proposed origin of inertia as demanded by the principle of equivalence. On the basis of this ZPF-inertia concept, we can definitively rule out one speculatively hypothesized propulsion mechanism: matter possessing negative inertial mass, a concept originated by Bondi (1957) is shown to be logically impossible.

We speculate that the charged particle-zero point field interactions giving rise to inertia may take place at one or more resonance frequencies rather than at the Planck frequency used in the analysis of Haisch, Rueda and Puthoff (1994). De Broglie was the first to propose that there exists a specific mass-dependent internal frequency for an elementary particle. If the inertia resonance frequency for the electron should prove to be the annihilation frequency (512 keV in energy units), it may be possible to devise some method for modifying inertia and gravitation.

Is it proper to regard the ZPF as a real electromagnetic field? The measurements by Lamoreaux (1997) of the Casimir force show excellent agreement — at the five percent level (much better than previous experiments) — with theoretical predictions. One interpretation of the Casimir force is that it represents the radiation pressure resulting from the exclusion of certain ZPF modes in the cavity between the (uncharged) conducting plates. There are alternate ways of looking at this (cf. Milonni 1994). We suggest that it is fruitful at this stage to continue exploring the ramifications of a real-ZPF paradigm and that just as a real, measureable Casimir force results upon construction of an uncharged parallel-plate condenser, so too does a real, measureable reaction force result upon acceleration thereby creating the inertial properties of matter.

The Propulsion Directorate of the USAF Phillips Laboratory commissioned a study in 1995 to investigate the possibility of defining and carrying out tests of the ZPF-inertia concept (Forward 1996). This resulted in a ranked list of possible experiments. The highest priority was given to measuring the Casimir Force more precisely, which has now been done (independently) by Lamoreaux (1996). Inside a Casimir cavity the ZPF-inertia theory would seemingly predict — though more calculations need to be done — a slight anisotropy in inertial mass, i.e. inertial mass would become slightly tensorial. Unfortunately attainable Casimir cavity experiments would yield changes of mass as a function of direction of only on the order of 10^{-24}; still, this is conceivably measureable using a Hughes-Drever technique (see Forward 1996).

On the basis of an astrophysical model by Rueda, Haisch and Cole (1995) one would expect to be able to measure the stochastic acceleration of particles in extreme vacua. While not directly testing the inertia concept, such an experiment would demonstrate the reality of ZPF-matter interactions. In fact, in principle such an experiment would demonstrate extraction of energy from the quantum vacuum, which is, perhaps surprisingly, not a thermodynamic impossibility (Cole and Puthoff 1993). Forward also discusses the possibility of directly probing for the reality of the ZPF "by focussing laser light on a vacuum containing a magnetic field." Unfortunately this experiment appears to be impossible given current technology.

Additional theoretical investigations would also serve to test the ZPF-inertia and ZPF-gravitation concepts. NASA-funded studies are underway at Lockheed Martin Advanced Technology Center in Palo Alto and at California State University in Long Beach. Recently Ibison and Haisch (1996) proposed a modification of the SED representation of the quantum vacuum in a way that makes the classical and quantum statistics of the field identical. The more one can show that SED and QED (quantum electrodynamics) yield identical results, the more credible are analyses based on SED techniques. Naturally a QED analysis yielding the inertia and gravitation results needs to be carried out. For overview articles see Haisch, Rueda and Puthoff (1994b, 1997) and Haisch and Rueda (1996, 1997b, 1997c).

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