EXTENDED ABSTRACT

For presentation at the Third International Conference on the
Nature and Ontology of Spacetime

"Inertia and the physical medium pervading Minkowski spacetime"

by
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Galileo uncovered the phenomenon of inertia and Descartes implemented it in his so-called mechanistic philosophy but it was Newton who first formulated it mathematically. Economy of thought required from Newton a simple hypothesis. Newton thus assumed inertia was inherent to mass. For Newton's purposes no further explanations were required. Soon after Berkeley, in his rejection of the Newtonian absolute space concept, questioned this Newtonian hypothesis on the nature of inertia. It was much later that Ernst Mach, in developing what Einstein later called Mach's Principle, did a systematic and critical analysis of the origin of inertia. Mach argued that, contrary to Newton's assertion, inertia is not inherent to mass but that it has to do with the accelerated body interaction with everything else in the universe. We hasten to add that being Mach a positivist, he rejected the idea of the ether. Such concept was devoid of direct empirical basis. So, for an accelerated body in empty space Mach had to search for the origin of inertia in the only other viable alternative available at the time: The long-distance gravitational force which without screening interactions connected the body to the distant stars. Mach thought the stars, by their gravitational pull, conspired to oppose the body's acceleration. Einstein started from Mach's conceptual framework in developing his highly successful theory of general relativity but soon after he realized that general relativity contradicted Mach's Principle. This fact is widely known today (e.g., Rindler) and with only a few exceptions it is viewed as the nemesis of Mach's Principle.

In spite of Mach's Principle shortcomings some of Mach's views are quite valid. Even if the well-localized inertia reaction force is not, as Mach pretended, directly due to the gravitational long range action of astrophysical bodies in distant confines of the universe, Mach's idea that the inertia reaction is due to something outside the accelerated body but that interacts with the body still holds. We all know that the inertial force is instantaneous and most naturally we view it as quite local. And this brings us to the physical medium that pervades Minkowki spacetime and that can be viewed as forming part of it. According to present day views each fundamental interaction of the standard model has its associated quantum vacuum. If we take such vacua seriously and assume they are real, then the assumption of a quantum background medium, made of fluctuating zero temperature boson fields concomitant with fluctuating particle-antiparticle evanescent fermion pairs, becomes fairly natural. Such background medium has been called the physical vacuum (T.D. Lee) and is thought to be pervasive throughout Minkowski spacetime.

In spite of all this, it was only until the nineteen-nineties that it was proposed by several independent researchers that inertia might, one way or another, be related to the presence of such medium. This is what we today call the "quantum vacuum inertia hypothesis". So far the calculations up to this day, only deal with electromagnetic vacuum interactions. There have been a few rather complementary approaches: First we have calculations of zero-point field action on an accelerated body that is electromagnetically interacting (this author and a few collaborators). Second there were rather similar considerations but based instead on radiation reaction (V. Petkov). Zero-point field and radiation reaction are two complementary agents that, as opposite sides of the same coin, play a complementary role when analyzing several vacuum induced phenomena in quantum electrodynamics (P. Milonni). A third approach involving instead the electromagnetic interaction of the accelerated body with the Dirac vacuum of electrons and positrons was proposed also around that time by the late Jean Pierre Vigier.

In order to be able to consider only the gravitational interaction I am going to study here the case of an object that is macroscopic in size and that interacts only electromagnetically. As correctly argued, e. g, by Frank Wilczek and by Robert Laughlin, the inertia reaction is an emergent phenomenon. The object we consider is macroscopic in size because Newton’s laws are not applicable to elementary particles in quantum field theory. It is only when macroscopic aggregates are considered that Newton’s laws emerge. And for simplicity of treatment the body we consider interacts only electromagnetically. Of course, no real body that we know of is exactly like that. But a good approximation however is that of an electromagnetic cavity. This is particularly if for our model we neglect the walls and, making some abstraction, consider only the interior of the cavity. First we discuss in general the electromagnetic modes structure of cavity resonators. The high frequency cut-off is determined by the plasma frequency of the electrons in the conducting metallic walls. The low frequency cut-off is dictated by the cavity geometry, e.g., in a rectangular parallelepiped cavity the lowest frequency is determined by the length of the longest side, and in the case of a spherical cavity by the cavity diameter.

Next we study the exchanges of energy and momentum that take place when an electromagnetic cavity is accelerated in the electromagnetic vacuum by an external agent that applies to it an external force. This is done in two complementary ways. In one approach we see how the electromagnetic vacuum energy and momentum within the cavity grow as the cavity is uniformly accelerated. In a second complementary approach we find how the electromagnetic vacuum exerts a reaction force back on the agent that uniformly accelerates the cavity. For a more thorough analysis we do this also covariantly. We further show that such inertia reaction force in the subrelativistic case is just of the form f = -ma, where m corresponds exactly to the total electromagnetic zero-point energy content within the cavity. In the covariant case one gets the four-force and other features of the ordinary relativistic generalization. Numerical evaluations yield that the electromagnetic contribution to inertial mass is small but what is important is that the inertial force displays the correct f = -ma form and in the relativistic case it yields the exact four-force of the relativistic generalization. As far as the vacua of the other standard model interactions go (namely the weak and specially the strong vacua), we expect them to play an analogous but larger role. This corresponds to the fact that in ordinary matter the gluonic sector displays the lion’s share of the mass of ordinary objects (e.g., F. Wilczek).

Important insights can be gained when we apply the previous analysis to an electromagnetic cavity that is freely falling in a uniform gravitational field and compare it with the more interesting situation when the cavity is externally supported and prevented from falling in the same gravitational field. This analysis shows that the previous inertial mass corresponds exactly to the passive gravitational mass. Some insights on the equivalence principle are gained. This also allows us to see why Newton’s gravitational force has an inverse square dependence on distance. Pending still remains to find the case of active gravitational mass, namely, how is it that massive bodies bend Minkowski spacetime.

Finally we recall that all vacuum fields are usually considered to be Lorentz-invariant in the sense that they should look the same to observers in different inertial frames. This is used to argue why the Minkowski spacetime is the natural reservoir of the physical vacuum. Minkowski spacetime is physically more than just a mathematical four-space where we can place 1+3-dimensional coordinate systems.

Note: Due to space limitations (two pages) we must apologize to authors and readers of this extended abstract for not giving detailed references. We will include all of them with scholarly rigor in the draft of the paper. (November 29, 2007).