Incompatibility of QED/QCD and repulsive gravity, and implications for some recent approaches to dark energy

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Abstract The measurement of the gravitational properties of antimatter is currently a hot research area in experimental physics. Using an outcome of QED calculations by Alves et al. (arXiv:0907.4110), this letter proves that QED and repulsive gravity are *incompatible* by showing that an extension of QED with the assumption of negative gravitational mass for antimatter yields a concrete prediction that is already falsified by the recent Eöt-Wash experiments: if repulsive gravity, and thus negative gravitational mass, would be observed by any of the upcoming experiments, then QED is thus experimentally falsified; the same goes for QCD. An immediate consequence is that virtual particle-antiparticle pairs from contemporary quantum theory cannot be a model for Hajdukovic's virtual gravitational dipoles, nor for the dipolar medium of Blanchet and Le Tiec. There may be ways to reformulate quantum theory to restore consistency with experiment if repulsive gravity would be observed, but these involve a departure from the framework of four dimensions and four forces of nature: an observation of repulsive gravity would thus provide a reason to reject the quantum paradigm in its entirety and to search for new fundamental physics.

Keywords gravitational repulsion; QED; QCD; dark energy; quantum gravity

1 Introduction

Currently, at CERN there are a number of experimental projects (AEgIS, GBAR, ATLAS) ongoing or in the works for a *direct* measurement of the gravitational acceleration of neutral antimatter (antihydrogen) on earth. Amsler *et al.* initially reported that results of the AEgIS project are expected already in 2014-2015 (AEgIS coll. 2013), but the timeline has shifted backwards since: results are now expected in 2015-2016 (M. Doser, personal communication). In addition, there are plans for experiments at the PSI facility in Villingen for measurements with muonium (Kirch 2013), and the construction of a new facility (FLAIR) in Germany for antigravity experiments has been announced (Quint 2013). This indicates that establishing the gravitational properties of antimatter is currently an area of interest in experimental physics. Analysis of preliminary results with ultracold trapped antihydrogen shows with a 95% confidence level that the ratio F of gravitational mass $\overline{m}_g$ and inertial mass $\overline{m}_i$ of antimatter must be in the range $-65 < F < 110$ (ATLAS coll. 2013).

However, it has been argued that the recent results of the Eöt-Wash group rule out that the experiments referred to above will find anything but a confirmation of the weak equivalence principle (WEP), that is, that $\overline{m}_g = \overline{m}_i$ for antimatter (Wagner *et al.* 2012). The underlying quantum-theoretical calculations use the idea that virtual electron-positron pairs must occur inside an atom: the observation that the value of the Eötvos-parameter of Beryllium and Titanium is at most 10^{-13} then compels us to conclude that these pairs must contribute equally to the gravitational and inertial masses of the atoms—a deviation of the WEP for antimatter is then ruled out with a precision of one part in 10^6. This is an important result.

The purpose of this letter is to highlight that this result, interestingly, implies that any detection of a matter-antimatter gravitational repulsion thus constitutes a *direct falsification* of quantum theory. The details of the argument are given in the next section. The final section discusses the implications.

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2 Incompatibility of quantum theory and repulsive gravity

The Eötvos parameter of Beryllium and Titanium is defined in terms of the observable free-fall accelerations a_{Be} and a_{Ti} of Be and Ti atoms; this can be expressed in terms of inertial mass M_i and gravitational mass M_g of the atoms:

$$\eta_{Be-Ti} = \frac{a_{Be} - a_{Ti}}{(a_{Be} + a_{Ti})/2} = \frac{(M_g/M_i)_{Be} - (M_g/M_i)_{Ti}}{((M_g/M_i)_{Be} + (M_g/M_i)_{Ti})/2} \quad (1)$$

The idea is that virtual electron-positron pairs inside the atom will give *different* contributions to the inertial mass and to the gravitational mass if the WEP does *not* hold for antimatter. However, since the ratio M_g/M_i will still be very close to 1 for both Be and Ti, the denominator at the right-hand side of (1) will be approximately 1, so we get

$$\eta_{Be-Ti} = \left(\frac{M_g}{M_i}\right)_{Be} - \left(\frac{M_g}{M_i}\right)_{Ti} \quad (2)$$

In (Alves *et al.* 2009), the QED corrections (E_{Loop}) to the electrostatic self-energy of Beryllium and Titanium nuclei have been calculated to first order in perturbation theory. It was established that the difference in the fractional contribution of E_{loop} to the inertial masses M_i of Be and Ti atoms is approximately 10^{-6}:

$$\left(\frac{E_{loop}}{M_i}\right)_{Be} - \left(\frac{E_{loop}}{M_i}\right)_{Ti} \approx 10^{-6} \quad (3)$$

We now set the gravitational mass equal to the inertial mass minus a fraction of E_{Loop}:

$$M_g = M_i - \alpha \cdot E_{Loop} \quad (4)$$

Note that $\alpha = 0$ if the WEP holds: the virtual pairs then contribute equally to gravitational mass and inertial mass. Now Wagner *et al.* reported (2012) that the absolute value of η_{Be-Ti} has been experimentally established to be at most around 10^{-13}:

$$|\eta_{Be-Ti}| \lesssim 10^{-13} \quad (5)$$

From (2)-(5) we then get

$$\left|\left(\frac{M_i - \alpha \cdot E_{Loop}}{M_i}\right)_{Be} - \left(\frac{M_i - \alpha \cdot E_{Loop}}{M_i}\right)_{Ti}\right| = \alpha \cdot 10^{-6} \lesssim 10^{-13} \quad (6)$$

This yields $\alpha \lesssim 10^{-7}$, so we get the reported result that the Eöt-Wash experiments imply that the WEP should hold for antimatter with a precision of 1 part to 10^6.

The central point is now that the calculated result (3) is not only interesting because one can use it to argue that, from a quantum-theoretical perspective, the Eöt-Wash experiments rule out that the WEP is violated by antimatter: it can, namely, be used in addition to get a concrete prediction from QED that can be compared with experimental results.

Let's assume that, in reality, we have the following relation between the *observable* gravitational masses m_g and $\overline{m}_g$ of an electron and a positron, respectively:

$$\overline{m}_g = -m_g \quad (7)$$

This is the situation that rest-mass-having antimatter would be repulsed by the gravitational field of "ordinary" rest-mass-having matter. Regardless of what gravitation then actually *is*, virtual electron-positron pairs inside an atom would then contribute to its inertial mass, but **not** to its gravitational mass: the factor α in eq. (4) would then thus be 1. Thus speaking, we would then have

$$E_{Loop} = M_i - M_g \quad (8)$$

for both Be and Ti atoms. Substituting eq. (8) in eq. (3) and taking the absolute value gives the following result:

$$\eta_{Be-Ti} = 10^{-6} \quad (9)$$

This is thus a *concrete prediction* of QED extended with the assumption (7); a similar prediction can be made on the basis of QCD when considering virtual quark-antiquark pairs inside the nuclei (Alves *et al.* 2009).

What makes it interesting is that this prediction is *falsified* by the experimental finding (5). By Modus Tollens, that means that the conjunction of assumptions, from which the prediction (9) has been derived, cannot be true. In the present case, that means that quantum theory is **incompatible** with negative gravitational mass for antimatter: if quantum theory is correct then antimatter cannot possibly have negative gravitational mass; conversely, if a matter-antimatter gravitational repulsion—and thus a negative gravitational mass for antimatter—would be observed by any of the ongoing or future experimental projects (AEgIS, GBAR, etc.) then contemporary quantum theory cannot possible be correct. In particular, such an observation would rule out that, *within the framework of three spatial and one temporal dimensions and four forces of nature*, there is any reality to virtual particle-antiparticle pairs, tacitly assumed to exist in the calculations leading to the prediction (9).

It is mentioned that Schiff made a prediction similar to eq. (9), which he compared to the outcome of the Eötvos experiments: that was Schiff's argument against repulsive gravity (1958). However, Schiff's calculation was criticized by Nieto and Goldman (1991). In the present case, the result of the QED calculation by Alves *et al.* is used; the key step is the leap from assumption (7) to eq. (8): the justification is that there is no known argument—within the present ontological setting!—by which the opposite gravitational masses of the particles in a virtual electron-positron pair would add up to a *nonzero* contribution to the atom's gravitational mass.

3 Implications

Blanchet initially showed that a dipolar model for dark matter reproduced the MOND phenomenology at Newtonian (i.e. non-relativistic) level (2007). Later a relativistic model was developed, and it was shown that "the dipolar fluid is undistinguishable from standard dark energy" (Blanchet & Le Tiec 2008). Hajdukovic's closely related approach to the dark energy problem is based on his earlier theory that the vacuum is made up of virtual gravitational dipoles popping in and out of existence (2011). The idea is then "that what we call dark energy is, in fact, the energy of the virtual gravitational dipoles inhabiting the quantum vacuum" (2012). An immediate consequence of the incompatibility of quantum theory and repulsive gravity is then that it is ruled out that virtual particle-antiparticle pairs from contemporary quantum theory can be a candidate for Hajdukovic virtual gravitational dipoles, or for the dipolar medium proposed by Blanchet and Le Tiec[1]. Consequently, these ontological assumptions raise the question which fundamental physical principles have to be in place for such forms of matter to exist.

Now it is known from string theory that there are ways in which QED can remain correct even when the gravitational interactions of matter and of antimatter are not identical, but differ by a small fractional amount. It is also known from quantum gravity research that gravitation can be repulsive if it is an unconventional interaction that has more than one component (gravivector, graviscalar). These results may indicate that virtual pairs from quantum theory could still serve as a model for the above ontological assumptions if quantum theory would be reformulated accordingly, but it should be noted that such entails a drastic departure from the presently accepted framework of four forces of nature in three spatial dimensions plus one temporal dimension. These ideas are therefore not only far from acceptance because of a lack experimental back up: in addition, they lack the required epistemic motivation as to why they can be considered potential 'knowledge' at all—ever.

So the crux is that an observation of a matter-antimatter gravitational repulsion would provide a reason to doubt QED and QCD: this is the cartesian criterion for theory rejection. Such an observation would thus provide enough motivation to reject the quantum paradigm *in its entirety*, and to consider the case that the true foundational principles then find themselves *outside* the framework of the Standard Model plus General Relativity; a candidate theory has already been published in (Cabbolet 2010, 2011), although it remains to be proven that the correspondence principle is satisfied. Alternatively, the fact that the ontological assumptions discussed above provide solutions to problems about the macroscopic world is, in case of an observation of gravitational repulsion, a *motivation* to resolve the problems they raise about the microscopic world—such might lead to new insights, so the inconsistency with QED/QCD is not a bad thing!

Concluding, the incompatibility of the Standard Model and a matter-antimatter gravitational repulsion has been proven: the immediate relevance is that this implies that virtual pairs cannot serve as a model for the ontologies proposed by Hajdukovic and by Blanchet and Le Tiec. But in addition, this incompatibility may spell the demise of the quantum paradigm in case of a detection of gravitational repulsion—the latter may thus open a window to fundamentally new physics.

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[1] In addition, Capozziello *et al.* have developed an approach to a unification of interactions in which the Standard Model is generated from a five-dimensional unification scheme (2011). In this approach, polarization effects could give rise to a vacuum inhabited by pairs of ordinary and "ghost" gravitons, where the latter have negative energy. But it is argued that stability of the vacuum then requires the coupling of all other particles with the ghost gravitations to be *much weaker* than that with the ordinary gravitons. Therefore, while this scenario may lead to interesting predictions, it does **not** predict a matter-antimatter gravitational repulsion: the assumption (7) is thus **not** implied. That means that the incompatibility of the Standard Model and repulsive gravity does **not** imply that this approach to unification can be dismissed a priori as untenable.

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