Comment on "Does Antimatter Fall with the Same Acceleration as Ordinary Matter?"

In a series of Letters [1,2] the Eöt-Wash Collaboration has reported on their equivalence-principle experiment. In a summary article [3] they stated that their experiment limited an anomalous acceleration of antimatter to $10^{-5}g$ from quantum-gravity models. Reference [2] expanded on Ref. [3], now claiming a limit of $2\times10^{-6}g$.

However, what they have actually shown is that, since their [2] vector coupling is proportional to a conserved charge (e.g., baryon number), a precise cancellation by a scalar requires its coupling to be effectively proportional to this charge to a high accuracy; cancellations more precise than Ref. [2] envisions can occur naturally in many theories (see below and Ref. [4]). Further, they give no detailed long-range topographic or geologic error analysis [1-3]. Independently, it is important to measure gravity on antimatter [4,5] just as it is important to test the principle of equivalence [1].

In Ref. [2] there is much discussion about the experimental conclusion that Witteborn and Fairbank (WF) observed the Schiff-Barnhill "electron-sag" effect in their electron gravity experiment. However, for a quarter century this result has remained an object of experimental and theoretical controversy, involving the Dessler-Michel-Rorschach-Trammell-Herring "ion-sag" and patch effects [4,6]. (Eventually, Schiff came to accept ion-sag dominance, concluding that WF "cannot be understood" given the "usual picture of the metallic surface" [7]). In any event, surfaces have been developed which should allow gravity to be measured on ions [8]. This would culminate in the original experimental proposal [4] to measure $g(\bar{p})/g(\mathrm{H}^-)$.

The analysis of Ref. [2] considers a possible anomalous acceleration of antimatter due to "quantum gravity." However, of the three cases discussed, only the first two are based upon a Lagrangian scalar interaction density. The other case is a phenomenological parametrization. Further, the analysis, especially in case (1), depends heavily on details of only one example in the quantum-gravity framework [4]. One is simply *not* restricted to the forms in Ref. [2]. For example, all three cases in Ref. [2] assume $\mathcal{L}_V=(a)^{1/2}V_\mu J^\mu$, with J^μ a dimension-three operator. Such a dimension constraint is found in renormalizable gauge-field theories, but does not generally apply to gravitational theories [4].

The scalar coupling of case (1) of Ref. [2] also assumes $\mathcal{L}_S=(b)^{1/2}\phi T^\mu{}_\mu$. However, there exist other couplings of the graviscalar field to either the gauge fields and/or other sources that reduce the differences between the vector and scalar couplings above. For example, $\mathcal{L}_{S2}=(b)^{1/2}\phi U$, where $U=\sum_j (b_1^j)/4)[F_j{}^{\mu\nu}F^j{}_{\mu\nu}]$, has a $j=0$ QED component which is closely related (by a virial) to a constant fraction of the binding energy, whatever its Z dependence. When added to $\mathcal{L}_S$, the resulting effective coupling of the scalar is more closely proportional to the vector coupling. (A similar argument can be made for the $j=1,\dots,8$ QCD couplings [4].)

Case (2) is superfluous as it is equivalent to changing the vector coupling in case (1) from B to $(1-\varepsilon)B$ (for [2] $\lambda_V=\lambda_S$).

Case (3) generates an *ad hoc* phenomenological dependence of the scalar coupling on $|B|$ and B^2 (and perhaps μ—see Fig. 3 of Ref. [2]). However, again the vector coupling is assumed proportional to B/μ, so cancellation simply requires the scalar to vary similarly. A more revealing assumption would have been a case "orthogonal" to case (1), that is, to assume $q_S=\varepsilon\mu+|B|$. However, then the Eöt-Wash constraint is satisfied for reasonable values of ε.

Thus, while we agree that the precise cancellation described in Ref. [2] is ruled out for the very specific cases discussed there, it is neither excluded nor unnatural in the more general case. A precise cancellation is "natural" only if it is due to some (approximate) symmetry; however, that symmetry may not be immediately apparent. Matter experiments can only lead us to conclude that *either* there are no new effects *or* they cancel as if enforced by a symmetry. An antimatter experiment can decide between the two. Therefore, although strong constraints can be set on some theories by present experiments [1-3], they alone cannot rule out all anomalous gravitational forces.

Finally, and most importantly, independent of any particular theoretical motivation [4], be it quantum gravity, *CPT* violation, or something else, the measurement of gravity on the antiproton would be unique among all fundamental gravity and particle-physics experiments. Fortunately, a consensus now exists to this effect [5]. Even if one obtains the Newtonian value one expects, one will have learned something new and important.

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