Hypercharge Fields and Eötvös-Type Experiments

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It is shown that Eötvös-type torsion-balance experiments performed in the vicinity of a large cliff may be used as sensitive tests for the recently postulated existence of a medium-range hypercharge force. The residual nonzero effect found in the original Eötvös results could be mainly due to terrain irregularities and thus be larger than, but still correlated to, the effects expected from the Earth's rotation and the hypercharge hypothesis.

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The recent reanalysis[1] of the Eötvös experiments[2] shows a striking correlation between the residual values found in these experiments (previously interpreted as giving only upper limits for nonproportionality of inertial and gravitational mass) and the variations in the gravitational constant for different substances expected from a hypothetical medium-range hypercharge potential. The form of this potential was assumed to coincide with the form of a non-Newtonian gravitational potential recently used[3] as a possible interpretation of geophysical determinations of the gravitational constant as a function of depth.[4,5] The magnitude of the non-Newtonian term deduced from the geophysical data and the hypercharge hypothesis is, however, ~16 times too small to account for the conventional interpretation of the Eötvös results.

It is shown here that the presence of a non-Newtonian medium-range force would introduce large uncertainties in the conventional evaluation of the Eötvös experiments, and that a new interpretation of the results could make them compatible with the predictions based on geophysical data[3-5] and the hypercharge hypothesis.[1] Also a new Eötvös-type experiment is proposed to settle the questions of the existence, strength, and range of hypercharge fields.

Consider the torsion balance of Fig. 1 first in its equilibrium position with no torque applied to the wire. Let F_1 and F_2 represent the two uniform force fields with a small angle $\eta = \alpha_2 - \alpha_1$ between them. From the equilibrium conditions for all the forces and their moments around O we see that the wire must be parallel to the vector sum of F_1 and F_2, the bar joining M_1 and M_2 must be in the plane determined by F_1 and F_2, and

$$F_1 \sin\alpha_1 + F_2 \sin\alpha_2 = 0, \tag{1}$$

$$F_1 \cos\alpha_1 R_1 - F_2 \cos\alpha_2 R_2 = 0. \tag{2}$$

Now the wire support is rotated by application of a torque T to the bar such that it comes to equilibrium at 90° with respect to its initial position. Since the direction of the wire will not change,

$$T = -F_1 \sin\alpha_1 R_1 - F_2 \sin\alpha_2 R_2. \tag{3}$$

From (2) and (3) and for very small α_1 and α_2,

$$T = F_1 R_1 \eta. \tag{4}$$

Now let us assume that the forces F_1 and F_2 are due to the superposition of gravity and the centrifugal

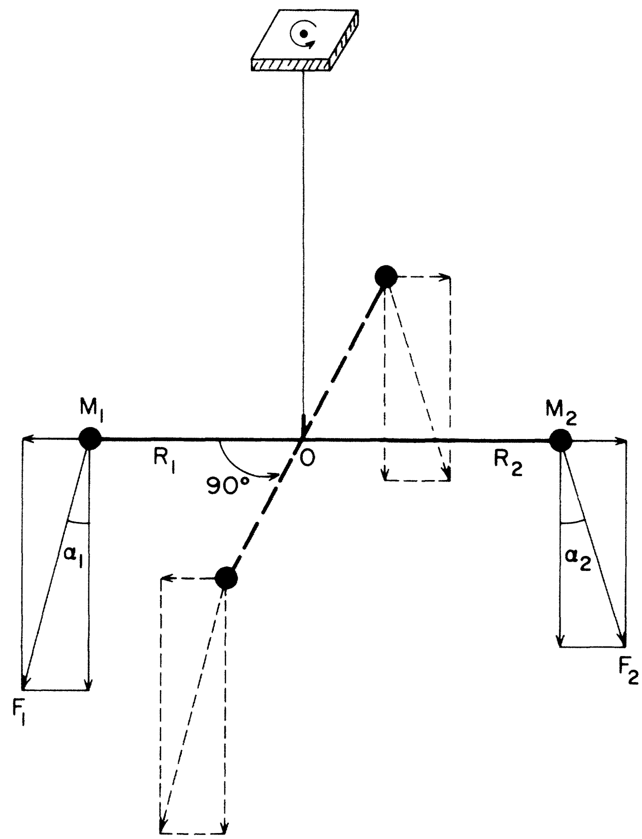

FIG. 1. Schematic representation of two equilibrium positions of a torsion balance. In the first position (solid lines) no torque is applied to the suspension wire and thus the forces F_1 and F_2, the bar joining M_1 and M_2, and the wire must all be in the same plane. In the second position (dotted lines) a torque T has been applied by rotating the wire support such that the balance comes to equilibrium at 90° from the first position. The equilibrium conditions (see text) establish the relation between T, the magnitudes of the forces, and the angle between them.

forces due to the Earth's rotation. Then an angle $\eta \neq 0$ would arise if the gravitational acceleration is different for the two masses, the centrifugal accelerations being the same for both. It can easily be shown[2] that

$$\eta = (G\,\Delta\kappa/g)\sin\epsilon, \tag{5}$$

where G and g are the magnitude of the gravitational and total (gravitational plus centrifugal) accelerations, ϵ is the angle between them, and $\Delta\kappa = \Delta G/G$ corresponds to a possible small difference in the gravitational constant for the two objects.

At 45° latitude for example, $\epsilon \approx 0.1°$ and

$$\eta_{45°} = 1.72\times 10^{-3}\,\Delta\kappa \tag{6}$$

is the angle in the meridian plane between the two forces. Thus a torsion balance pointing east and west will measure a torque given by (4) and (6) and $\Delta\kappa$ can thus be determined.

In Ref. 1 it is suggested that $\Delta\kappa$ may be due to a medium-range hypercharge force with an effective range λ of the order of 200 m. Should this indeed be the case one could perform an Eötvös-type experiment much more sensitive and precise than the original one even without any modern improvement in the instrumentation. This can be done, causing this new force to act in the horizontal rather than in the vertical direction, by performing the torsion-balance experiments close to, and at half the height of, a vertical cliff of height $h > \lambda$. In this case the hypercharge forces would be perpendicular to the cliff and the angle between the total (gravitational plus hypercharge) forces acting on each object would simply be

$$\eta = (\rho_c/\rho_T)\Delta\kappa, \tag{7}$$

where ρ_c and ρ_T represent average densities of the cliff and of the Earth, respectively. This angle is in the vertical plane perpendicular to the face of the cliff. Therefore the torsion-balance experiment would be performed by an alternation between positions parallel and perpendicular to the cliff rather than between the east-west and north-south orientations used by Eötvös. By comparison of (6) and (7) it is seen that for $\rho_c = \rho_T$ a sensitivity ~ 580 times larger should be obtained for the cliff experiment as compared to the conventional Eötvös experiment. It would be possible to deduce the distance dependence of the force by measuring the effect as a function of the distance from the face of the cliff. This could be most easily done in a tunnel penetrating into the cliff to a depth of $d > \lambda$. These experiments could also be performed at the foot or top of the cliff, but with a factor-of-2 loss in sensitivity and with the introduction of possible experimental complications due to vertical field gradients. Strictly speaking one has, in this last case, the superposition of torques caused by the cliff and by the original Eötvös effect due to the rotation of the Earth, but the last one is much smaller and can be neglected.

The effect calculated from the geophysical parameters and the hypothetical hypercharge fields is ~ 16 times smaller than the residual values obtained from the Eötvös experiment. Even if the smaller values are correct, the observations at the foot or top of the cliff should give results $580/(2\times 16) \approx 18$ times larger than the ones obtained by Eötvös. (In addition, the size of the effect could be doubled by utilization of Cu and BeH_2 as test masses instead of Cu and H_2O which gave the largest value in the Eötvös measurements.)

In the analysis of Eötvös's experiments the implicit assumption was made that the gravitational acceleration, even though possibly different in magnitude for different substances, does not differ in direction. As was seen above for the example of the cliff experiments, this assumption is no longer correct in the presence of medium-range forces. Even though Eötvös's experiments were probably not performed in the vicinity of a large cliff, much smaller asymmetries in the surrounding matter could, according to the above considerations, account for sizable effects beyond those mentioned in Ref. 1.

Great care was exercised by Eötvös to cancel through multiple differences and ratios all effects due to finite gravitational field gradients. In doing this, however, it was postulated that the sought-after effect could only be due to forces lying in the meridian plane as had to be the case according to the conventional interpretation of these experiments. But if the hypercharge potentials described in Ref. 1 really exist, the effects caused by them and by terrain irregularities could be larger and of arbitrary orientation. Eötvös residual values would then be mainly due to the north-south component of these forces and would have little to do with the rotation of the Earth.

Thus the proportionality between Eötvös's results and the prediction from the hypercharge hypothesis retains its significance while a plausible explanation has been found for the discrepancy in their absolute values. With the proposed cliff experiment it should be easier than anticipated to settle the question of whether a new force does indeed exist. If the answer to this question is affirmative, one could then use the same type of experiment to characterize the strength and functional distance dependence of this force.

Note added.—After I submitted this paper for publication, it was brought to my attention that Bizetti,[6] Milgrom,[7] Neufeld,[8] and Talmadge, Aronson, and Fischbach[9] were also considering possible effects of terrain irregularities on the results of the Eötvös experiments.

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