New Force or Thermal Gradient in the Eötvös Experiment?

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Recently, Fischbach *et al.* suggested that the accelerations of various materials to the Earth may be different depending on their compositions, on the basis of their reanalysis of the results of the experiment of Eötvös, Pekár, and Fekete. We find that systematic effects due to thermal gradients can account for the experimental data.

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In a recent Letter,[1] Fischbach *et al.* reanalyzed the results of the experiment of Eötvös, Pekár, and Fekete,[2] and suggested that the accelerations of various materials to the Earth may be different depending on their compositions. They interpreted this possible dependence as evidence for the existence of a new force. An alternate explanation, that thermal gradients may be responsible for the observed effect, had been proposed. Fischbach *et al.* considered and excluded this possibility.[3] We have carried out a detailed analysis and found that the systematic effects due to thermal gradients can give an adequate description of the data from the Eötvös experiment.

There were nine sets of measurements in the Eötvös experiment,[4] listed in Table I. Each set compared the acceleration of two different materials to the Earth. The Ag-Fe-SO_4 measurement, which compared the accelerations of the reactants before and after the chemical reaction $Ag_2SO_4 + 2FeSO_4 \rightarrow 2Ag + Fe_2(SO_4)_3$, and the magnalium-Pt measurement were made with the "single balance." The most critical thermal-gradient effect for a measurement with the Eötvös balance is that of differential gas pressures associated with the gradients. The differences in pressure set up convection currents which exert forces on the weights suspended from the balance. The magnitude of the force on a given weight should be approximately proportional to its cross-sectional area. The Eötvös paper gives the length and diameter of the variuos weights. The cross-sectional area $S = \text{length} \times \text{diameter}$ is calculated and listed in Table I. From the above discussion, we use the following functional form for the apparent difference in acceleration due to thermal gradients:

$$\Delta\kappa = a + bS_1 - cS_2, \tag{1}$$

where the parameter b refers to the suspended weight B, the parameter c to the fixed (platinum) weight C, the parameter a represents the bias due to the lack of symmetry in the balance, and S_1 and S_2 are the cross-sectional areas of the weights B and C.

The results in Table I are differences of two such measurements, with the weight B being changed between the sets of measurements. Thus the expected thermal effect should be

$$\Delta\kappa = \Delta\kappa_1 - \Delta\kappa_2 = b(S_{B_1} - S_{B_2}), \tag{2}$$

where B_1 and B_2 now refer to the two different values of the suspended weight B.

The next two measurements, snakewood-Pt and Cu-Pt, were made with the same technique, but with balance 1 of the "double-balance" instrument replacing the "single balance." Except for the effect of the unused balance 2 of the double balance on the mount, these first four measurements should be equivalent, and we tentatively group them together (see below).

The remaining five measurements were made with the double balance with B_1 and B_2 simultaneously suspended from the top balances for the first measurement, and interchanged for the second measurement. This technique is quite different. It measures the difference $\Delta\kappa = \Delta\kappa_1 - \Delta\kappa_2$ directly, in constrast to the first four measurements where $\Delta\kappa_1$ and $\Delta\kappa_2$ were measured separately. The effects due to thermal gradients for these five measurements may be quite different from those for the first four measurements, and will be described by a different coefficient b. To take such a difference into account, the functional form

$$\Delta\kappa = [b_1(1-\lambda) + b_2\lambda](S_{B_1} - S_{B_2}) \tag{3}$$

is used where λ is the "window function": $\lambda = 0$ for the first four pairs and $\lambda = 1$ for the remaining five pairs.

The two-parameter fit, by Eq. (3), yields

$$b_1 = (0.017 \pm 0.007) \times 10^{-8}\ \text{cm}^{-2}$$

TABLE I. The observed values of $\Delta\kappa$ from the Eötvös experiment are compared with the calculated values of $\Delta\kappa$, from the best fit using Eq. (3). Also listed are the differences in the areas of the weights B_1 and B_2.

Materials compared	Observed $10^8\,\Delta\kappa$	Values calculated from Eq. (3) $S_1 - S_2$ (cm^2)	$10^8\,\Delta\kappa$	Residual	Contribution to χ^2
Ag-Fe-SO_4	0.0 ±0.2	0.0	0.00	0.00	0.0
Magnalium-Pt	0.4 ±0.1	9.0	0.15	0.25	6.2
Snakewood-Pt[a]	−0.1 ±0.2	21.2	0.36	−0.46	5.2
Cu-Pt	0.4 ±0.2	1.9	0.03	0.37	3.4
Water-Cu	−1.0 ±0.2	11.4	−0.93	−0.07	0.1
$CuSO_4 \cdot 5H_2O$-Cu	−0.5 ±0.2	5.8	−0.47	−0.03	0.0
$CuSO_4$(Solution)-Cu	−0.7 ±0.2	6.4	−0.52	−0.18	0.8
Asbestos-Cu	−0.3 ±0.2	5.8	−0.47	0.17	0.7
Tallow-Cu[a]	−0.6 ±0.2	8.8	−0.72	0.12	0.4

[a]These two measurements were not included in the reanalysis of Fischbach *et al.* in Ref. 1.

and

$$b_2 = (-0.082 \pm 0.011) \times 10^{-8}\ \mathrm{cm}^{-2}$$

with a χ^2 of 16.8 for 7 degrees of freedom. The calculated values of $\Delta\kappa$ are listed in Table I, and compared with the observed $\Delta\kappa$ in Fig. 1. The values of b_1 and b_2 turn out to be quite different. If one insists on a single-parameter fit, by Eq. (2), then one gets $b = (-0.012 \pm 0.006) \times 10^{-8}\ \mathrm{cm}^{-2}$, with a χ^2 of 71.3 for 8 degrees of freedom.

As can be seen from Table I, the largest contributions to the χ^2 of the two-parameter fit come from the three measurements of magnalium-Pt, snakewood-Pt, and Cu-Pt. It is possible that the effect of the unused balance 2 on the mount is not negligible. Perhaps the single balance is not equivalent to $\frac{1}{2}$ of the double balance and we should not group the first four measurements together. If the first four points are omitted, the single-parameter fit, by Eq. (2), gives

$$b = (-0.082 \pm 0.011) \times 10^{-8}\ \mathrm{cm}^{-2},$$

with a χ^2 of 2.0 for 4 degrees of freedom.

It had been suggested earlier,[3] as an approximation, to substitute $1/\rho$ for the area S in Eq. (3). The best fit in this case gives

$$b_1 = (0.64 \pm 0.22) \times 10^{-8}\ \mathrm{gm/cm}^3,$$

and

$$b_2 = (-0.92 \pm 0.13) \times 10^{-8}\ \mathrm{gm/cm}^3,$$

with a χ^2 of 17.2 for 7 degrees of freedom. If the first four points are omitted, the best fit for the remaining five points, using Eq. (2), gives

$$b = (-0.92 \pm 0.13) \times 10^{-8}\ \mathrm{gm/cm}^3,$$

with a χ^2 of 5.1 for 4 degrees of freedom.

The overall conclusion is that the thermal-gradient hypothesis is capable of giving a reasonably good description of the data.

Editorial note.—A Comment on this Letter by Fischbach *et al.*[5] appears in this issue.

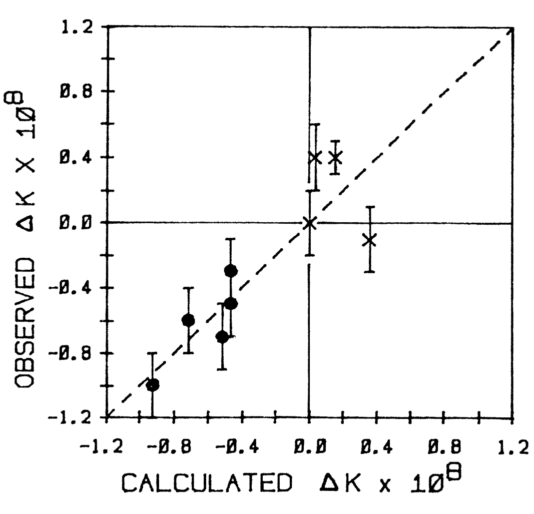

FIG. 1. Comparison of the calculated $\Delta\kappa$ from the best fit using Eq. (3), and the observed $\Delta\kappa$. Crosses denotes the first four points and the solid circles denote the remaining five points.

[1]E. Fischbach, D. Sudarsky, A. Szafer, C. Talmadge, and S. H. Aronson, Phys. Rev. Lett. **56**, 3 (1986).

[2]R. V. Eötvös, D. Pekár, and E. Fekete, Ann. Phys. (Leipzig) **68**, 11 (1922).

[3]See "Note added" in Ref. 1.

[4]Because of the heat generated by the radioactivity and its effect on the balance, the data point with $RaBr_2$ should not be treated on the same basis as the other data points and is therefore omitted.

[5]E. Fischbach, D. Sudarsky, A. Szafer, C. Talmadge, and S. H. Aronson, this issue [Phys. Rev. Lett. **57**, 1959 (1986)].