Test of the Inverse Square Law of Gravity at Distances of 5 cm and 1 m

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We report final results of our test of the inverse square law of gravity. A traditional torsion balance is used to compare the torque produced by two 7 kg masses positioned 1 m from a torsion balance with that produced by a 44 gm mass located 5 cm from one arm of the balance.

The Newtonian gravitational force law for two point masses \( m_1 \) and \( m_2 \), separated by a distance \( r \):

\[
F = \frac{G m_1 m_2}{r^2}
\]

is normally assumed to be valid at all distances. However, Fujii and others [1-3] have suggested that the Newtonian gravitational potential be modified by the addition of a Yukawa term:

\[
V(r) = -\frac{G m_1 m_2}{r} \left( 1 + \alpha e^{-r/\lambda} \right)
\]

Here \( \alpha \) is the strength of the Yukawa term and \( \lambda \) is its range.

The gravitational force law associated with this potential would imply a distance dependence for \( G \) of the form:

\[
G(r) = G_0 \left[ 1 + \alpha \left( 1 + r/\lambda \right) e^{-r/\lambda} \right]
\]

Gibbons and Whiting [4] have emphasized that inverse square law tests provide constraints on attempts to unify gravity with other fundamental forces of nature.

Long [5] has reported the results of his experiment in which the gravitational constant at 30 cm is compared to that at 4.5 cm. He found

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that \( G(30 \text{ cm}) > G(4.5 \text{ cm}) \) by \((0.37 \pm 0.07)\% \) and suggested that the Newtonian value of \( G \) be assigned a logarithmic dependence on distance. That is, at laboratory distances:

\[
G(r) = G_0(1 + \varepsilon \ln r)
\]  

(4)

where

\[
\varepsilon_{\text{LONG}} = (20.4) \times 10^{-4}
\]

This result has stimulated a number of clever schemes [7-13] to test the gravitational inverse square law (see Ref. 6 for a review of other activity).

At the University of California at Irvine we have conducted a test of the inverse square law over a range of 5 cm to 1 m. This experiment uses a traditional torsion balance consisting of a 523 gm, 60 cm long copper bar suspended by a 90 \( \mu \)m tungsten fiber. This "detector" compares the change in torque produced by "source" masses at distances of 5 cm and 1 m. At 1 m two 7 kg copper masses (far masses) are cycled between two alternate positions (see figure).

The torque produced by these far masses is nearly cancelled by that produced by the simultaneous cycling of a 44 \( \mu \)m mass (near mass) located near one end of the torsion balance cross arm. By cycling the masses between their respective positions (1 cycle = 30 min) we become relatively insensitive to system drifts and variations in ambient gravitational fields. Also, by choosing the ratio of the near and far masses so that the net torque on the balance is small we obtain the advantages of a null experiment such as insensitivity to system nonlinearity and gain drift.

The experiment exploits numerous symmetries in the placement of near and far masses which make results highly insensitive to uncertainties in the precise location of the torsion balance within its vacuum enclosure. Preliminary results on this experiment were reported last year: in terms of the logarithmic parameterization of eq. (4) we reported

\[
\varepsilon = (-1.3) \times 10^{-4}
\]

These results were deemed preliminary pending a test of the homogeneity of the copper balance bar. Final results based on such measurements will be presented at this conference.
Figure 1. Top view of the apparatus of the 5 cm - 1 m experiment showing the positions of the masses relative to the torsion balance.

References