DETERMINING THE GRAVITATIONAL CONSTANT USING A CRYOGENIC TORSION PENDULUM

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We report progress in measurements of G using a cryogenic torsion pendulum in the 'dynamic' (time-of-swing) mode. We have collected about 550 hours of data which should yield a G measurement with statistical uncertainty less than 20 ppm.

We determine G by measuring the change in oscillation frequency of a thin-plate torsion pendulum due to a pair of ring-shaped source-masses positioned alternately as indicated in figure 1. The pendulum is in an evacuated chamber within a dewar filled with liquid helium; the source-mass rings are suspended outside the dewar at room temperature. The pendulum's suspension point is maintained at ~ 2.4K, controlled to $\pm 30\mu$K. The high Q afforded by the low temperature operation minimizes bias due to fiber anelasticity[1]. Details of this apparatus are reported elsewhere[2,3].

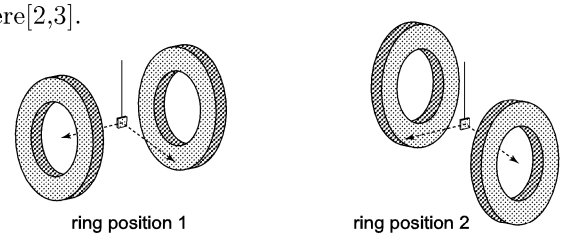

Figure 1. The pendulum and source-mass rings. The pendulum is an 11 gram fused silica square plate 40x40x3 mm, suspend by a copper-beryllium fiber 20 μm diameter and 24 cm long. Each copper ring is 60 kg with dimensions: 52 cm OD, 32 cm ID, 5 cm width.

The frequency shift due to the source-mass rings may be expressed as: $\omega_1^2 - \omega_2^2 \cong KG\, J_1(2A)/A$, where ω_1 and ω_2 are the pendulum's frequencies for the ring positions as indicated in figure 1, K is a geometric factor determined by the mass and dimensions of the pendulum and rings, G is the gravitational constant, J_1 is a Bessel function, and A is the oscillation amplitude of the pendulum. Thus by measuring the frequencies and amplitude of the pendulum, KG may be determined. By restricting our knowledge of K as we analyze our data, we are able to conduct a "blind" experiment minimizing the danger of bias.

We operate the pendulum at an oscillation amplitude near an extremum of $J_1(2A)/A$: 2.57, 4.21, 5.81, 7.40 radians. Data runs were made by setting the pendulum's amplitude to about 50 mrad above one of the extrema, then allowing the pendulum to 'ring down' while alternately moving the source-mass rings every 20 pendulum cycles (figure 2). We made 26 data runs with durations varying from 10 to 50 hours. For each of these runs, a value and uncertainty of KG was determined (figure 3). Between sets of several runs, we flipped and/or rotated our source-mass rings to average out possible asymmetries; four unique ring configurations were used. Occasional 'glitches' appearing in the pendulum's measured period (see figure 2) were removed in the determination of KG values.

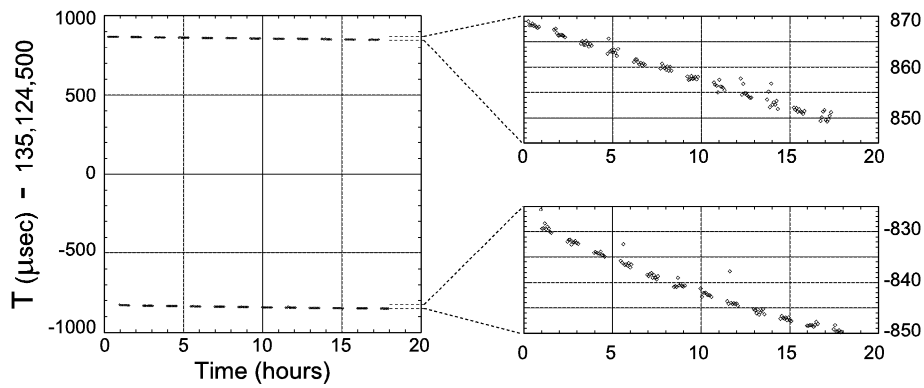

Figure 2. Typical data run (day 39) showing the period shift due to the source-mass rings. The rings are moved every 20 pendulum cycles, at about 45 minutes intervals. Every two pendulum cycles a period **T** is determined and plotted; expanded plots are shown at right.

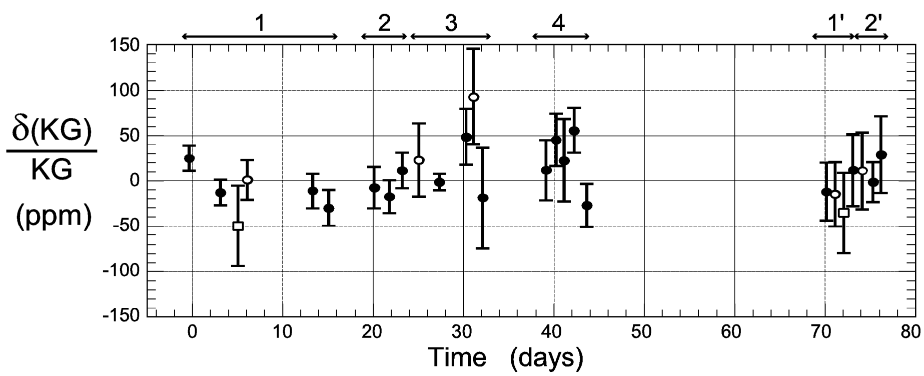

Figure 3. Determined KG values for data runs from October to December 2000. For each run, the pendulum's oscillation amplitude was one of three nominal values: 2.57-solid circle, 4.21-open circle, and 7.40-open square. Regions 1,2,3,4 correspond to different ring configurations. After day 45 the as-drawn fiber ($Q \sim 80,000$) was replaced with a heat treated fiber of the same material ($Q \sim 120,000$). Outliers, about 2% of the data, were excluded in the determination of KG values.

Acknowledgments

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References

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