this, consider the apparatus as it stood in the lowest floor of NBS: meters away was the building wall, and on the other side a continuous distribution of earth spread away. When the water table rose up to the foundations it permeated the earth beyond the basement wall, introducing a large and changing transverse gravitational gradient, to which the experiment is sensitive. Here we may avoid this potential problem, and we also celebrate the timing of the drought which has caused New Mexico its worst fire season in years: virtually no precipitation fell during the course of my measurements in early 1996.

In summary, these several new advantages inspire hope that the goal of a ten ppm determination of the Newtonian constant of gravitation may be achieved at Los Alamos.

The Matter of This Thesis

I came to Los Alamos in September of 1992, charged with relocating the instrument from a TA-3 space to its current home and with designing and creating the elements of the apparatus which were then lacking. I wrote C-language code which automated the several mechanisms of the apparatus and recorded a variety of data, all by way of a CAMAC crate. To record the rotation of the upper stage, I assembled an angle-measuring interferometer having a microradian resolution and built directional fringe-counting electronics to connect it to the computer. A new pendulum was assembled having a different type of test mass or bob, and a very lightweight mirror by which the angle of the pendulum was monitored. I also became skilled at manufacturing and utilizing quartz fibers six to twelve microns in diameter which were used as the suspension for the torsion pendulum.

Within a year, the device was relocated to its remote site and all the required systems were in place and operative with two exceptions that did not answer to immediate solution. First, the quartz fibers, while convenient to

Taylor

A DETERMINATION OF THE NEWTONIAN CONSTANT

OF GRAVITATION USING THE METHOD OF HEYL

by

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University of Colorado
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$$I\omega_1^2 = \kappa_f + \kappa_g(\phi_{H1});$$
$$I\omega_2^2 = \kappa_f + \kappa_g(\phi_{H2}); \tag{4.4}$$
$$I\Delta(\omega^2) = \kappa_g(\phi_{H2}) - \kappa_g(\phi_{H1}).$$

Therefore, the gravitational constant is given by:

$$G = \frac{I\Delta(\omega^2)}{(\kappa_g(\phi_{H2}) - \kappa_g(\phi_{H1}))/G}. \tag{4.5}$$

Here, $\Delta(\omega^2)$ is measured directly, and it remains to calculate the moment of inertia of the pendulum and the curvatures of its interaction potential with the source masses, $\kappa_g(\phi)$.

Data Analysis: $\Delta(\omega^2)$

Each experiment consisted of a series of Heyl-type measurements in which half-hour data sets ("waves") were recorded alternating between the H1 and H2 positions (crossways and in line). These measurement periods extended over a few weeks and alternated with null measurements in which the identical regimen was repeated with the spheres absent. No Cavendish-type measurement was performed due to the rapid, long-term drift of the tungsten wire's rest angle.

The computer typically recorded forty to ninety such waves in a single data set, lasting up to two days. This rate would have corresponded to one independent determination of G each hour, but in practice the efficiency was not as high. The impulses, described in the first chapter, appeared in the record and occasionally disrupted the sets, at times as frequently as once in an hour or two, at other times as infrequently as to allow twelve undisturbed hours. The frequency of these impulses rose as the ambient temperature climbed in April and May, and the data was almost unusable by the end of the last set, the set taken following Exp. #2, described below, and was not in ready form to attempt a measurement, so the original pendulum was recommissioned.

The Long-Arm Pendulum

In April of 1995, we had been attempting for some time to remove the disruptive impulses which prevented even a low-precision determination and finally decided to switch our approach. A precise measurement of oscillation frequency is required for a Heyl-type determination and in the Cavendish-type in order to measure the torsion constant of the fiber. The periodic disruptions in phase caused uncertainty in my fitting to the oscillation record: in short, we had an insufficient signal-to-noise ratio. It was hoped that a pendulum having a much longer arm would greatly increase the gravitational signal in a Cavendish-type determination without the noise energy increasing, or at least increasing by the same factor.

Calculations showed that a pendulum having ten times the arm length could be constructed with about the same mass as before, allowing the same diameter fiber to be used while the gravitational torque could be increased by enough to allow displacements of a few full rotations. Of course, the pendulum would be kept at the same angle while this twist was taken up by rotation of the upper stage. The expected period of oscillation would be quite large, but if it proved too difficult to measure this period, the torsion constant of the fiber could be determined independently by exchanging the pendulum with a small cylinder of known dimensions having an equal mass but much smaller moment of inertia.

It may be pointed out that such a regimen depends greatly upon the long-term stability of the fiber's torsion constant while its environment is brought back up to atmosphere, serviced, and pumped down once more. This is in contrast to the case in the originally planned experiment, where displacement and frequency information could be measured alternately in short order. Not alone among

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and testing this design, but no usable data were forthcoming. It is believed that irremovable electrostatic effects were to blame.

Eventually the decision was made to employ a tungsten wire suspension having a period of about three minutes, grounding the pendulum unequivocally and squeezing in more cycles between disruptions. The disadvantages to this were tungsten's much greater long-term drift, which prohibited repeatable Cavendish-type measurements, and a decreased sensitivity resulting from the shorter period. In January of 1996, I attempted a trial Heyl-type determination with this arrangement, hoping for a percent number or better.

Unexpectedly, the results showed a statistical scatter of as little as a part per thousand, eventually producing a mean with a standard deviation one tenth as great. Not anticipating this performance, I had not aligned the instrument to such fine tolerances necessary to take advantage of this precise frequency data. After the first experiment (Exp. #1), I reassembled the system with greater care, installing a slightly different fiber for variety, and began another determination (Exp. #2).

These two determinations should be viewed as preliminary to an ongoing project. They only employ half of the instrument's potentiality, both being Heyl-type, and were conceived to work around the problem of the impulses. Nonetheless, the values and their one-to-two-hundred ppm uncertainties should be of some interest as they will be shown to discriminate between past results and to support the conjecture of K. Kuroda.