Experiment G-8

Measurement of Constant Gravitation

By use of the Cavendish balance, obtain values for the Constant of Gravitational Attraction (a) by means of the initial acceleration of the torsion member of interchanging positions of the large spheres, and (b) by the change in the equilibrium position of the torsion member on interchanging positions of the large spheres.

References:

1. Special Notes for the Leyboldt Apparatus. These are to be kept with the apparatus.
2. 2. Bulletin of National Bur. Standards, Vol. 5, p. 1243 (1930)
3. 3. Bulletin of National Bur. Standards, Vol. 29, P. 1 (1942)

4. Peter F. Michelson, *International Symposium on Experimental Gravitational Physics,* (1987)
5. Venzo deSabbata and V.N. Melnikov, *Gravitational Measurements. Fundamental Metrology and Constants,* Series C, Vol. 230
6. "Physics Leaflets", *The Law of Gravitation and the Gravitational Constant 1 & II,* Sheet Nos. 1/17 and 1/18 (1959)

7. Jesse W. Beams, "Finding a Better Value for G", Phvsics Todav. May 1971

March 11,1994.1

This experiment uses a modified Leyboldt apparatus which will give reasonably good values for G as along as you pay attention to various corrections. (Of course, you will not achieve not the 1% accuracy that Purcell claims he could get in his kitchen). It requires patience in getting the suspended system free of the clamps without imparting too much motion to the apparatus. If it starts swinging as it comes free of the clamps so much that the balls touch the case, enough energy will be acquired during the vibration that the system will almost never come to rest. The best solution would be to reclamp the balls and release them anew.

The apparatus is not in the same condition as when it was retrieved from Leyboldt. We found that with the original glass covers, the deflection should be altered by magnets or a charged plastic comb. We also worried about heating by the illumination system, which should be symmetrical and without torque. We put a small quantity ofCuSO4 in a water cell in the illumination system so that no infrared light could enter. To prevent the possibility of the glass charging or magnet disturbances (since the inner balls are lead, lead is diamagnetic, and they are subject to the earth's magnetic field), we removed the glass covers and replaced them with transformer laminations. The laminations are from the old 300 MeV synchrotron. We shielded the rest of the system with the same material. To avoid the problems connected with differences in contact potential, both the interior balls and insides of the iron cover plates were coated with I! Aquadagl! -a suspension of graphite in water .

If it is necessary to get inside the apparatus to check the alignment, the shielding can be easily removed, just undo the screws and pull off the end pieces. Note that the bevel is at the top and the back of the inside lamination is flared out to make replacing the piece easy. The top pieces can be slid off laterally. These also have a beveled comer to match the end piece and flared comers to slide onto the track. When these pieces are removed, the front and back covers will be free-standing and ready to be lifted out.

The only reason for examining the interior of the apparatus would be to check the alignment should the system not be free -as might be suspected if the light spot on the wall suddenly reverses or if the system is not sensitive enough. In these cases, the system is improperly leveled. Assume that the last experimenter had the apparatus operating satisfactorily and you must simply reset its suspension without imparting any excess motion. Don't change the clamping (i.e. the leveling) until it is obvious from an inspection that this is necessary. Trouble arises when the vertical member interferes with the horizontal bar and the end balls of the moving system and the little plastic baffles (a and b of Fig. 1) which are designed to decrease the convection currents within the housing. (They say that this is the other reason for including the water cell for the lamp). The original baffles were lost and replaced with celluloid cut-outs. Since the celluloid doesn't have the thickness of the original baffles, they were replaced with multiple ones which are not as secure in their slots. There is minimal clearance between the vertical rod and the baffle holes and must be adequate on all sides. The hub connecting the vertical and horizontal bars should be centered over the slightly raised circular boss on the inside of the cavity -lower the surface.

ABOVE ALL: DON'T START THE SUSPENSION SUPPORT KNOB ON THE SUPPOSITION THAT THE ZERO IS WAY OFF -chances are it's close to where it should be.

If it should happen that the system alignment has been disturbed, both in leveling and in the azimuthal position about the support shaft, you may have to start from scratch. The system is clamped by the two semi-cylindrical sheet springs driven by the thumb screws at the bottom of the case. These are pictured in Fig.l. When the system is clamped, the horizontal member fits into the V-notches in the end of the spring and is likewise centered -although the mirror tilt may be off. This may be changed by releasing the clamps a bit. Hopefully the image of the wires will appear somewhere in the plane of the scale on the building column 7 meters to the West. It is easiest to focus the optics up while the swinging system is clamped or at least restricted from movement. The adjustable lens on the lamp housing is set to focus a sharp image through the water filter onto the concave mirror affixed to the vertical member of the moving system. This ensures a maximum throughput of light by the little concave mirror. The sharpest image of the crosswire is then obtained by moving the entire lamp housing on the extended horizontal support rod. The image magnification is large and will not be razor sharp, and the concave mirror doesn't have precision optics. The equipment will allow you to achieve an accuracy of l/2mm.

If the blue circle of light is way off at one end, the apparatus most likely needs to be rotated, case and all. The spot should be moved to the center of the scale, representing the equilibrium position of the free system with no external gravitational torque applied. It should be reasonably near the center of the scale since the total maximum deflection from one extreme to the other is roughly 30 cm. If the clamping for the apparatus must be changed, then it certainly needs to be opened to check the clearance between the vertical member and the baffle openings. The clamping has to be relaxed so that the system can be titled slightly to bring it into proper alignment. Hopefully, this will not affect the azimuthal orientation. Of course, the system has to be completely unclamped to check the alignment when it hangs from the suspension.

Fiber Zeroing

If the equilibrium of the free system (when there are no external torques) does not fall within the limits set with the clamped system, you may have to re-adjust the suspension support at the top. Determine by how much you need to change the 'zero' spot, and calculate the angle of rotation remembering that rotating the mirror by θ degrees shifts the beam by 2θ degrees. A crude scale at the top (as pictured in Fig. 2) of the instrument will help measure the angle the suspension is turned through. The long thumb screw is the clamp for the suspension turning knob, the short, slotted screw, simply a retainer screw and stop. Note the tiny pin projecting across the groove, this limits the range of turning. Don't remove either screw. If, for any reason, you should need to adjust the screws more, seek the help of an instructor. S/He will release the set screw in the knurled knob itself and then turn the shaft which passes through it and is affixed to the fiber. This will all be done very gingerly lest the whole system drop.

The position of the lamp can be adjusted by three thumb screws located the back of its housing. Please remember to turn the lamp off when you're finished. It's not safe to leave the swinging system hanging from the suspension when not attended to. However, this is sometimes unavoidable in between runs. We ask that you take caution to not send shocks through the system.

To release the system from the clamps, back both screws out simultaneously. The light spot will indicate the motion of the apparatus. After a while, the light spot will begin to oscillate with a period of 1/2 second. This means that one clamp is free and the other one is confining it. Wait until the oscillation dies and gradually lower the screw until the oscillation dies. It takes practice to remove the screw without disrupting the system. F or small disruptive oscillations, of 10 cm or less, just wait until the motion dies and take measurements on position vs. time.

It is unnecessary to determine the zero position of the oscillating system although it is ideally the midpoint of the distance between the two extremes of the swing of the outer lead balls.

The oscillations in the system will never completely die out, in part because of the noise fluctuations arising from the temperature of the system. It may even be useful to calculate the expected order of magnitude of T. This should be done after determining the spring constant and the mean square amplitude of the residual oscillation.

You should take three measurements of the equilibrium position. Take the measurements with the balls in one position, in the reverse position, and back again. The measurements may take four hours, with a half hour for the transient oscillation to decay to the residual after the large balls are reversed. The best option would be to do two decays a day for two days and leave the system free in between to save time in getting the system lowered onto the suspension.

Determining Initial Acceleration

Record the displacement at 15 second intervals for 2-3 minutes. This will give the initial acceleration which is also useful for approximating G. You'll want to change the position of the balls rapidly in which case so the pointer may be helpful. Don't forget that the small spheres are undergoing both gravitational and angular acceleration. You should correct for this.

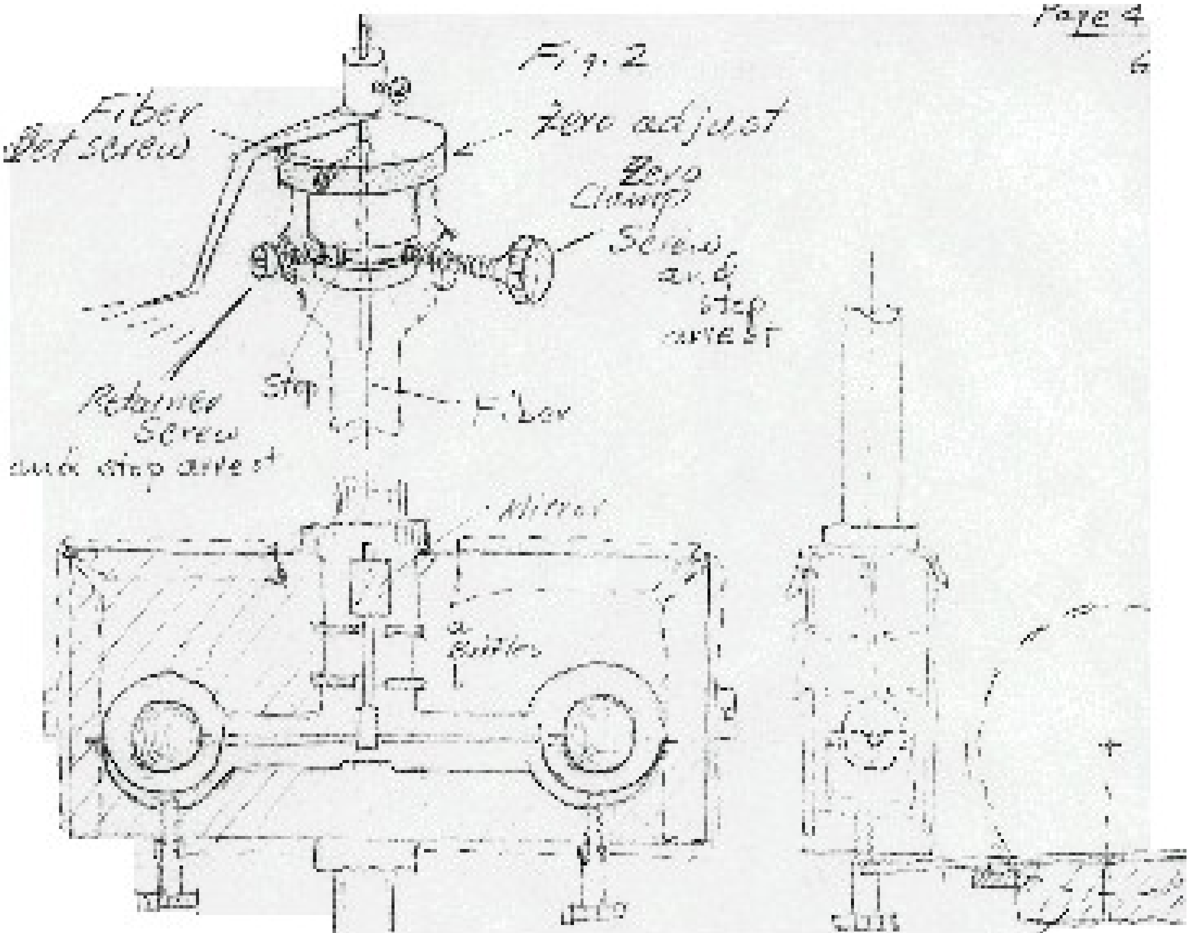
The pointer is attached to the carriage carrying the large balls. Its sole purpose is for switching the large balls, and it may not even aid in that. Before starting the run, you should decide where to position a ball without touching it. Read the pointer and then bring the pointer back to its original position quickly rather than feel your way around. Above all, do not bang the balls against the case causing the spots to bounce and even disturbing the case from its mount.

The sketch on the pillar at the experiment station shows the distance between the internal balls. To measure the mass of the large balls, use the beam balance. The balls weigh approximately 2 kg, but you'll need a higher accuracy for which you can use the smaller brass weights.

Fig.l also illustrates the method of obtaining an equilibrium separation between the large and small balls. The pointer may help again in this situation. With the ball support in position, remove the ball and replace it with a Lucite plug. To measure the distance to the center hole of the plug, use a steel scale with the notch end around the corresponding thumb clamp screw. Because the notch is not centered on the scale edge, you should make 1% correction. Measure the distance at each ball seat in each of the two orientations and average the results. If it should happen that the member is not exactly centered inside the case, it will ultimately make little difference since the error on one side should ultimately cancel the error on the other side.

Making corrections for the attraction of the large ball for the more distant small balls is detailed in the reference by Leyboldt. However, he does not account for the fact that when the suspended member is at its extreme deflection, the separation between the small and large balls is different from when everything is perfectly centered, The deflection can be measured by the angle of deflection which is measured from the spot deflection on the wall. (Don't forget that the angle is twice the deflection angle of the rod connecting the two small balls). At the maximum deflection for the rod, the force is normal to the connecting rod. The fiber spring constant which centers the calculation for G is obtained by measuring the period and moment of inertia although the period may be significantly affected by the large damping. The Q of the system is about 2 or 3.

Fig. 2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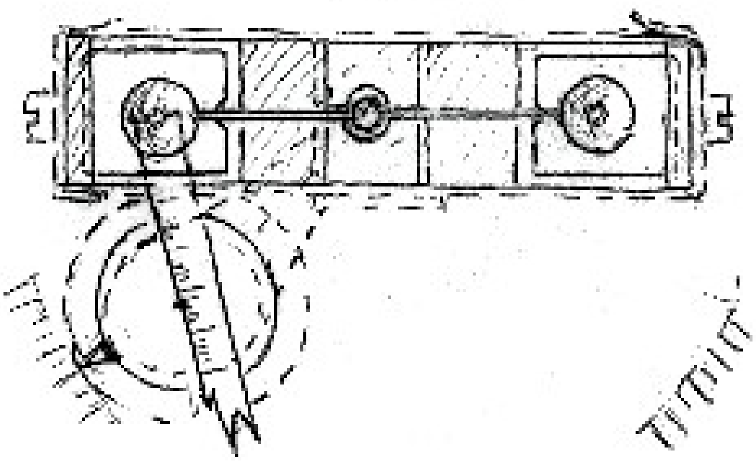

Fig 1