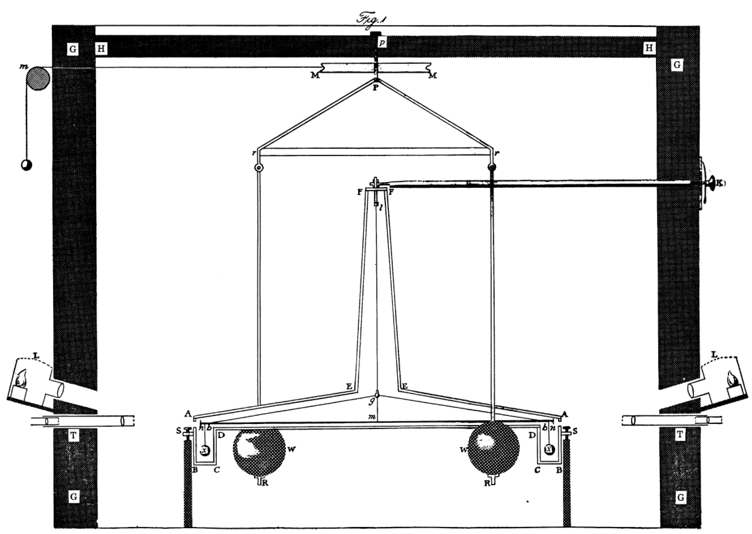
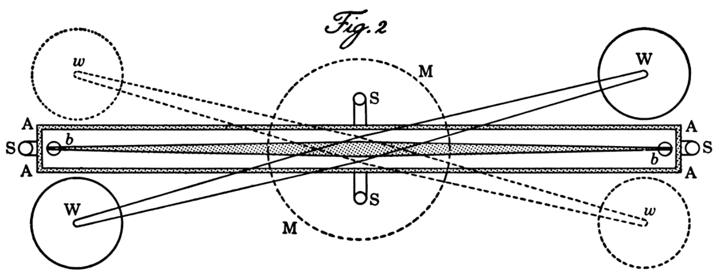
Modified Cavendish Balance for Testing Gravitational Interior Solution

Richard Benish

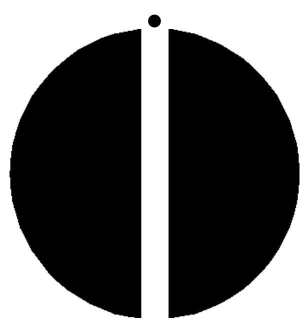
In 1798 Henry Cavendish used a torsion balance to measure the value of Newton's constant, G. Since then hundreds of torsion balance experiments have been conducted to study gravity, mostly as refinements of Cavendish's measurement or as tests of the inverse square law.



Relatively small masses attached to the ends of a suspended arm respond to the gravity of nearby, typically moveable, relatively large masses. The magnitude of deflection of the torsion filament or the magnitude of an applied compensating force needed to prevent deflection are the key data. The force being thus measured between known masses separated by a known distance suffices to determine the value of G. These experiments can be characterized as static measurements. Yet some small amount of motion is obviously involved. A perfect illustration of this was found in a preliminary trial of the original measurement by Cavendish.



To minimize the problem of air convection, his small masses, arm and torsion filament were all enclosed in a tight-fitting case. Cavendish initially tried using as a torsion filament a wire that did not offer enough resistance. When the large masses were brought into place the small masses actually collided with the walls of the case. This fact is part of the inspiration for a new experiment that I have been working on. Before describing my modification of a Cavendish balance, I’ll tell you of another source of my inspiration.



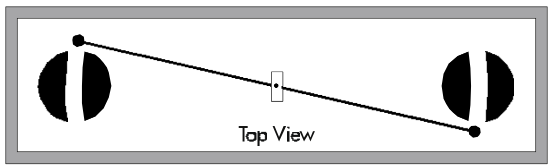
Its a hypothetical scenario commonly presented not only in freshman college textbooks, but also in more advanced contexts. The idea is to imagine, far from any other large masses, a uniformly dense spherical mass with a hole through a diameter. Assuming a perfect vacuum in the hole, what is the pattern of motion that unfolds when a test mass is dropped into it? The question is usually posed in terms of Newtonian gravity, but it has also been posed and solved in terms of Einstein’s General Theory of Relativity. The well-known answer is that the test object harmonically oscillates in the hole. It is not difficult to see why this should be so according to these theories.

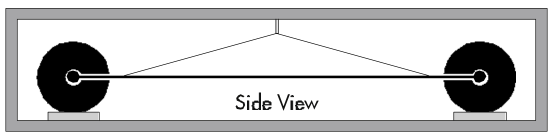
But what of empirical evidence? My research and correspondence with physicists leads to the conclusion that we have no direct empirical support for the prediction. For example, in an email from Bryce DeWitt, of the University of Texas, he writes that, “The experiment you mention has never been done. It might be doable on an asteroid, but the money could be much better spent on other things.” Some of my correspondents argued that the overwhelming support for Newton’s and Einstein’s theories of gravity gleaned from observations of gravity-induced motions outside of gravitating bodies suffices to leave no doubt as to what kind of gravity-induced motion will be found inside gravitating bodies. This confidence is certainly understandable. The validity of Einstein’s theory and of Newton’s theory as an approximation to it is indeed well established.

Yet there is this gap. The interior solution is backed by empirical evidence only by extrapolation, not by a direct, tangible fact. I believe that a proper scientific response to this situation is to investigate possible ways to fill the gap. I myself would like to see the test object oscillate in the hole [if in fact that’s what happens].

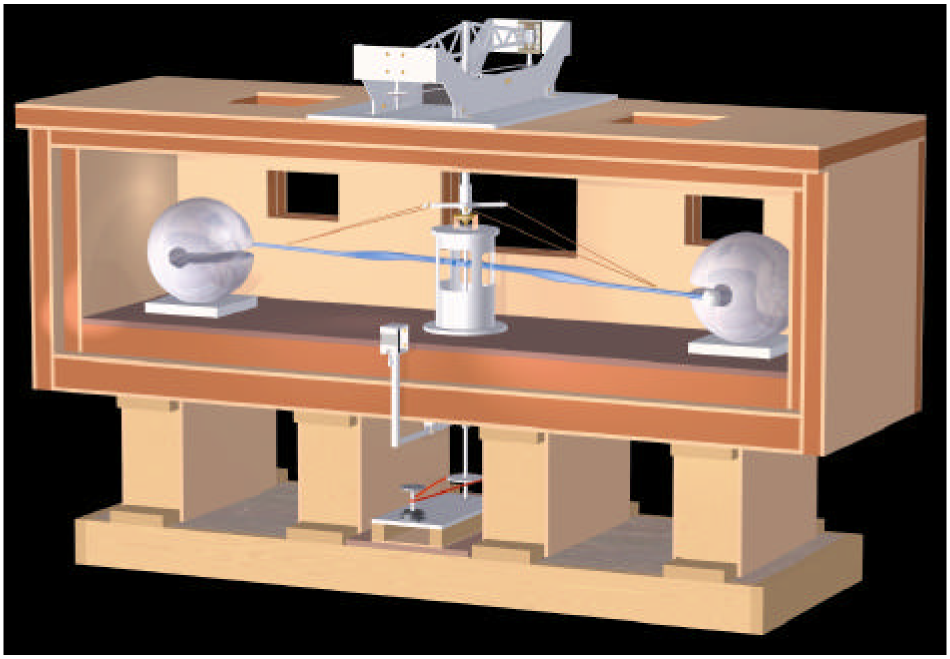
It was once proposed to get an improved measurement of Newton’s constant by arranging such an oscillation in a satellite experiment. The great expense and the technical difficulties involved nixed that idea. My purpose, however, is much more modest. I do not hope to get an especially good measurement of anything; I am not concerned with a number. I want only to demonstrate, as a first approximation, that the test object oscillates in the hole. I don’t think we need an asteroid or a manmade satellite to establish this.

Which brings us back to the experience of Cavendish. Initially, his small masses collided with their enclosure. Why couldn’t we enlarge the enclosure and have the large masses sculpted in such a way as to permit the motion to continue through their centers? Of course we can do this. But then the question becomes whether or not we can sufficiently minimize non-gravitational influences so as to leave the gravity acting between the large and small spheres as the dominant cause of motion.

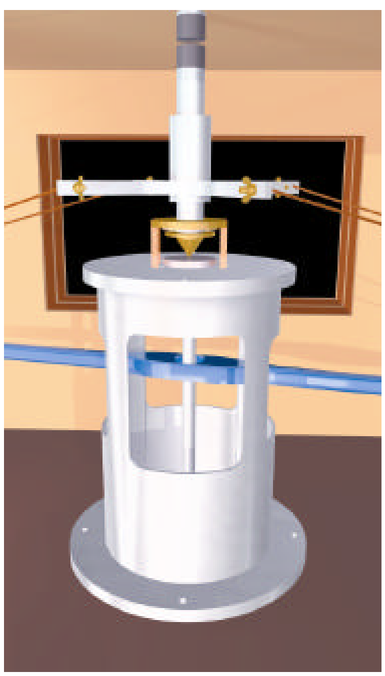


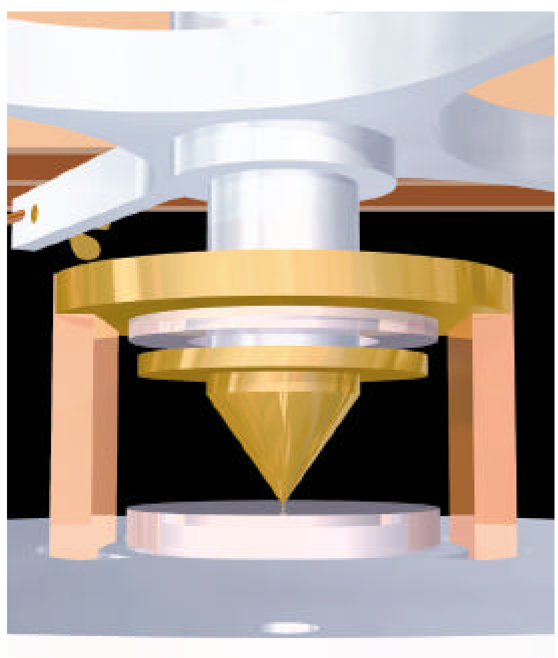


A few of the design considerations for the experiment are as follows: The problem of air convection could be eliminated by having the apparatus enclosed in a vacuum. Since that is beyond my financial and technical means, I have opted for thick and well-insulated walls.

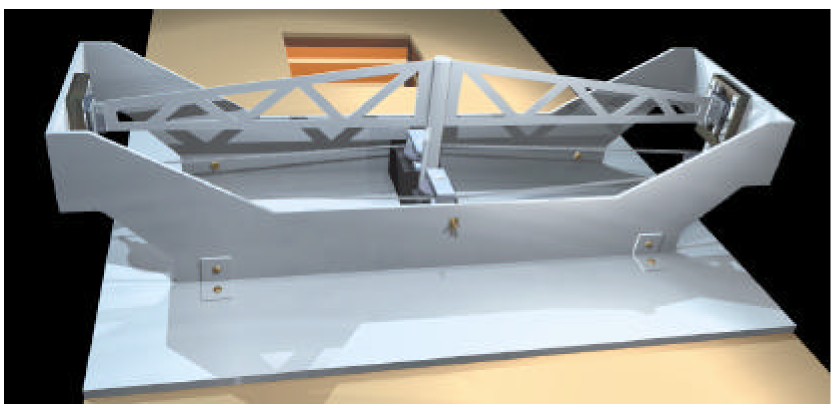


As it was in the original Cavendish experiment, my torsion arm is also six feet long. The large leaden masses have 13 inch diameters and weigh about 400lbs each.



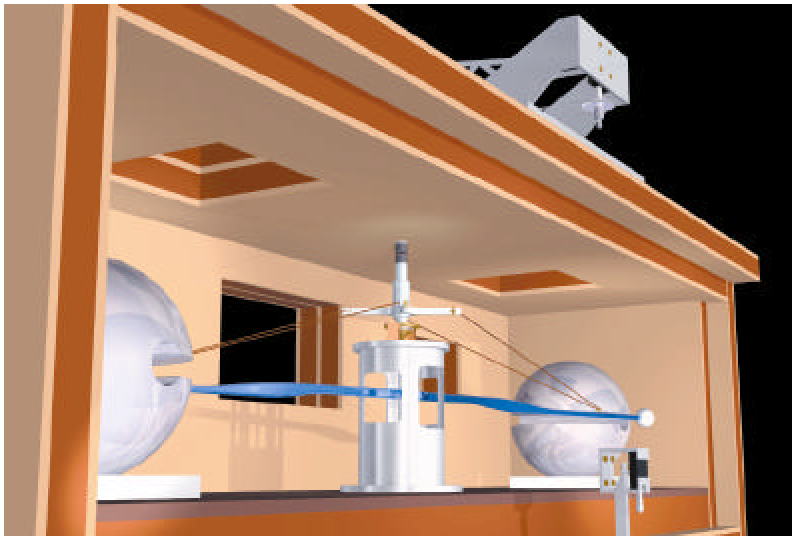


The pivot design is crucial. In the static experiments alluded to earlier a variable resistance to twisting provided by a torsion filament plays the essential role of bringing the arm back to its neutral, untwisted position. Whereas, in the present experiment we need the resistance to be not only very small, but also constant through the full range of motion—about 25°. The design I've come up with to satisfy this need involves a magnetic suspension device. The small masses and the arm are suspended by wires from a superstructure that is attached to a brass conical pivot. This whole assembly, whose pivot point rests on a flat Teflon bearing, weighs about 8 lbs. The small masses are also made of lead and weigh about 2.5 lbs each. A cylindrical magnet is attached to the top of the superstructure. Directly above it another magnet extends along the rotation axis through the top of the box. The vertical position of the latter magnet can be precisely controlled from outside the box.



This is achieved by a pair of translation stages whose micrometers are coupled by gears and a belt, and whose moveable blocks are attached to the arm and shaft to which the magnet is attached. The idea is to lower the upper magnet to the height at which the 8 lb weight of the pivot assembly bearing on the Teflon is reduced to a few grams.

Assuming that this is a viable strategy so far, perhaps the most difficult remaining problem is that of controlling the angular position of the arm from outside the box. Since there is no torsional restoring force, if the arm is moving in some manner that we don’t want or is otherwise out of position, we need to be able to grab it, put it in the proper starting position, and then let it go without giving it any kick.



I hope to achieve this with a set of controls attached to a shaft that extends through the bottom of the box, through the arm and the table, and terminating with a plastic disk brake, positioned just over the disk-like part of the brass cone. The small range of vertical motion of this shaft needed to engage and disengage the brake is provided by linkage through a lever mounted to the underside of the box and another translation stage mounted to the front of the box. For angular positioning there is a gear attached to the bottom of the shaft. The gear is coupled by a belt to a hand-controlled dial.

Each run of the experiment is thus initiated by an operator sitting in front of the box, from where he can easily reach the three controls. After initializing the experiment the position of the arm will be observed through windows in the top of the box. Assuming that extraneous influences have been made negligible, a graph of the position with respect to time would approximate a cosine curve. Even if gravity were the sole influence, the motion would not be quite simple harmonic because the large masses are not perfect spheres and because of the slight arch in the trajectory. The period of oscillation should be about 60 minutes. In about 15 minutes the small masses would thus reach the center, having there a maximum speed of about one half inch per minute.

Multiple runs of the experiment are of course planned, starting an equal number of times from opposite ends of the holes. With some luck, the first run will indicate rough agreement with the theoretical curve. Whereas, if I am not so lucky and the data deviate substantially from the theoretical curve, the cause or causes will be sought and eliminated, if possible. I have resolved to hone the apparatus or overhaul it, if necessary, until I have convinced myself that the primary cause of the observed motion is the gravity of the spheres.