Measurement of the Gravitational Constant with the Cavendish experiment

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Abstract

Between 1788 and 1789 Henry Cavendish (1731 – 1810) effectively weighed the earth using a torsion balance[1]. The experiment was devised by geologist John Michell in 1783. While originally thought of in terms of finding the density of the earth (or specific gravity) the modern experiment is cast in terms of finding the constant of proportionally, G, in the Newtonian law of universal gravitation,

$$\vec{F} = G\frac{m_1 m_2}{r^2}\hat{r}$$

Using a modern version of the torsion balance, we were able to measure G as $5.9 \pm .3 * 10^{-11}\frac{m^3}{sec^2 kg}$. However after correcting for systematic error we got $6.6 \pm .3 * 10^{-11}\frac{m^3}{sec^2 kg}$, placing the known value of $6.674 * 10^{-11}\frac{m^3}{sec^2 kg}$ well within our margin of error.

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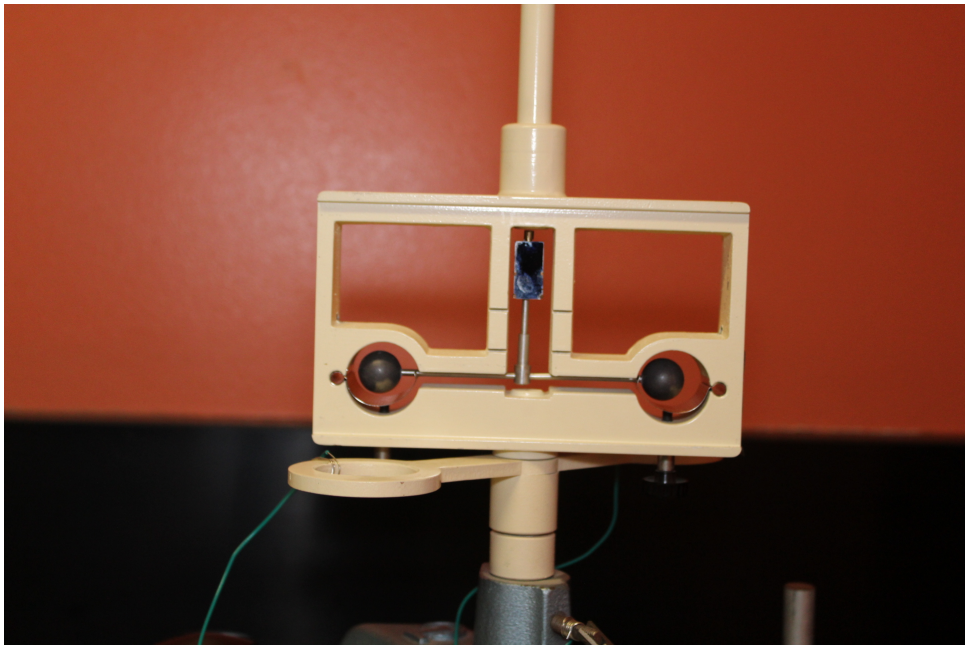

FIG. 1. The open torsion balance

I. INTRODUCTION

Gravity is an extremely weak force compared to other fundamental forces. Any effect it has between daily objects is completely overpowered by the earth's gravity or other forces. In our experiment, the force of gravity between the large and small lead balls can be easily calculated once we know G and is on the order of 10^{-7} times less than that between the small ball and the earth. This ingenious apparatus can detect incredibly small forces.

The torsion balance uses a very thin tungsten wire (about $\frac{1}{1000}$ of an inch thick) to support the dumbbell as seen in Figure 1. We shift large lead balls from one side of the dumbbell to the other (Figure 2). By observing the reflection of a laser off of an attached mirror onto a scale (Figures 3 and 4), we can calculate the restoring torque of the wire and the angular deflection of the dumbbell. From these and a few other easily measured quantities we can calculate G.

A. Theory

For simplicity we will neglect smaller effects at first and then introduce them in the next section. We begin by considering the dumbbell in equilibrium where the sum of torques is