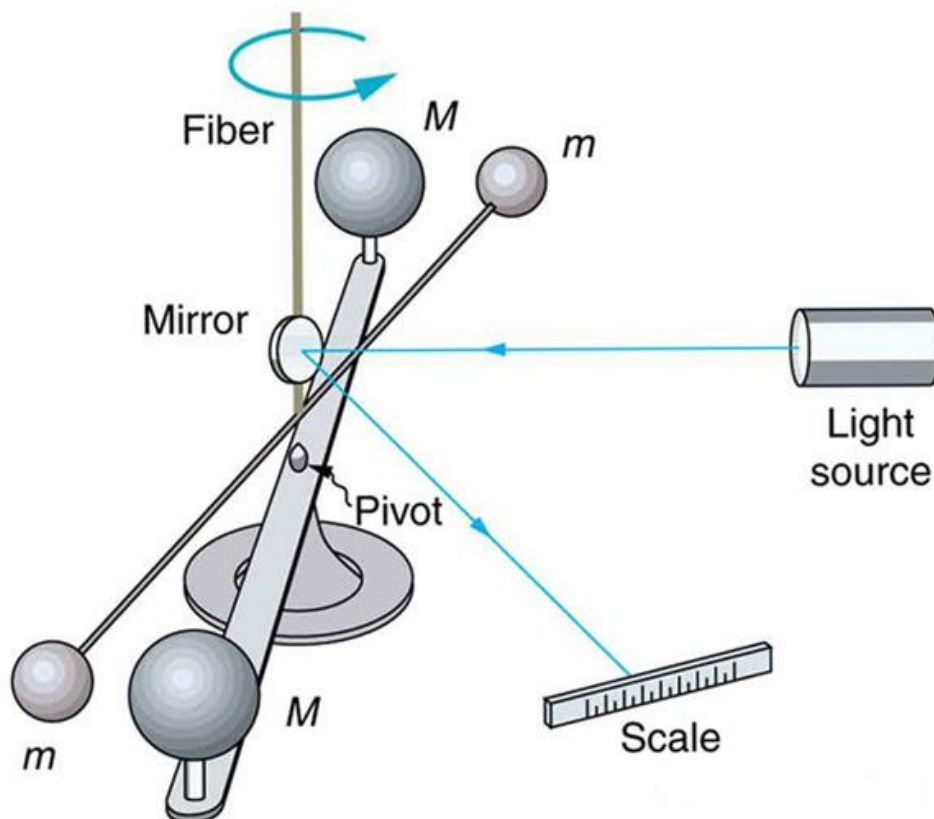


## The Cavendish Experiment: Then and Now

As previously noted, the universal gravitational constant  $G$  is determined experimentally. This definition was first done accurately by Henry Cavendish (1731–1810), an English scientist, in 1798, more than 100 years after Newton published his universal law of gravitation. The measurement of  $G$  is very basic and important because it determines the strength of one of the four forces in nature.

Cavendish's experiment was very difficult because he measured the tiny gravitational attraction between two ordinary-sized masses (tens of kilograms at most), using apparatus like that in the figure below. Remarkably, his value for  $G$  differs by less than 1% from the best modern value.



Cavendish used an apparatus like this to measure the gravitational attraction between the two suspended spheres ( $m$ ) and the two on the stand ( $M$ ) by observing the amount of torsion (twisting) created in the fiber. Distance between the masses can be varied to check the dependence of the force on distance. Modern experiments of this type continue to explore gravity.

One important consequence of knowing  $G$  was that an accurate value for Earth's mass could finally be obtained. This was done by measuring the acceleration due to gravity as accurately as possible and then calculating the mass of Earth  $M$  from the relationship Newton's universal law of gravitation gives

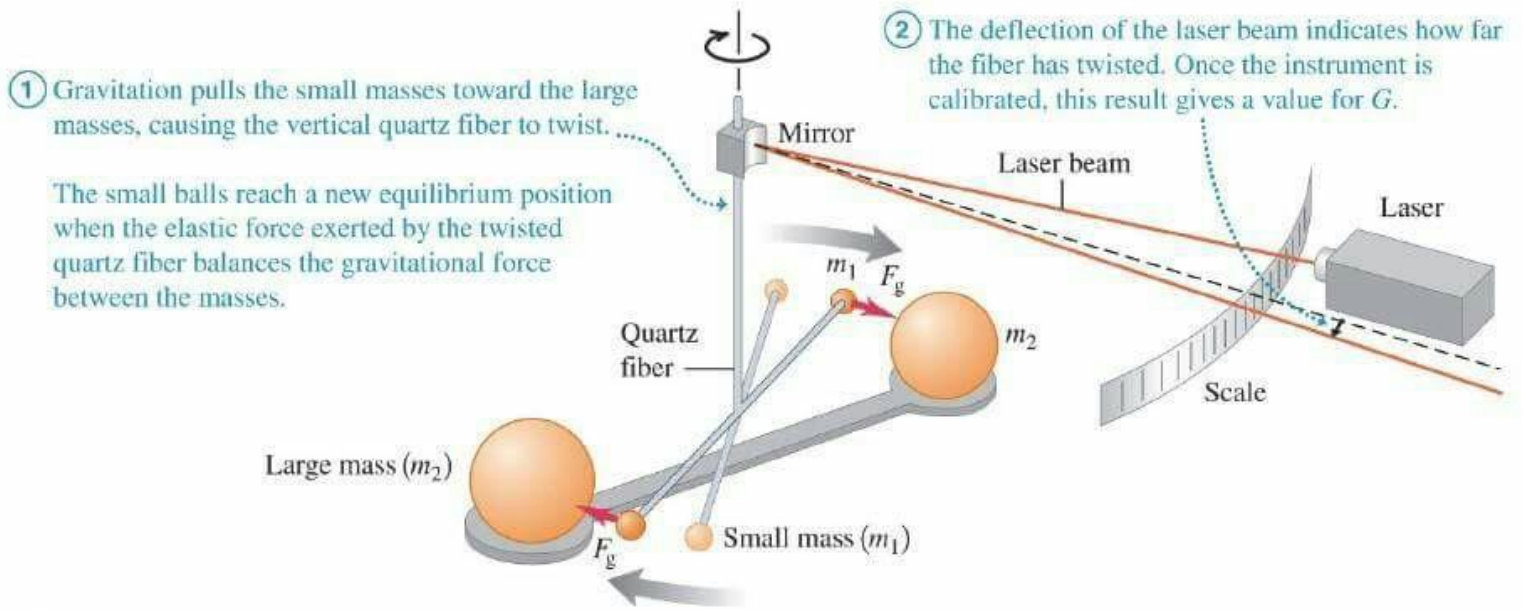
$$mg = G \frac{mM}{r^2},$$

where  $m$  is the mass of the object,  $M$  is the mass of Earth, and  $r$  is the distance to the center of Earth (the distance between the centers of mass of the object and Earth). See the figure above. The mass  $m$  of the object cancels, leaving an equation for  $g$ :

$$g = G \frac{M}{r^2}.$$

So  $M$  can be calculated because all quantities on the right, including the radius of Earth  $r$ , are known from direct measurements. We shall see in the next lesson on Satellites and Kepler's Laws: An Argument for Simplicity that knowing  $G$  also allows for the determination of astronomical masses. Interestingly, of all the fundamental constants in physics,  $G$  is by far the least well determined.

The Cavendish experiment is also used to explore other aspects of gravity. One of the most interesting questions is whether the gravitational force depends on substance as well as mass—for example, whether one kilogram of lead exerts the same gravitational pull as one kilogram of water. A Hungarian scientist named Roland von Eötvös pioneered this inquiry early in the 20th century. He found, with an accuracy of five parts per billion, that the gravitational force does not depend on the substance. Such experiments continue today, and have improved upon Eötvös' measurements.



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**Figure 2** – The apparatus used by Cavendish to measure the magnitude of the universal gravitational constant.