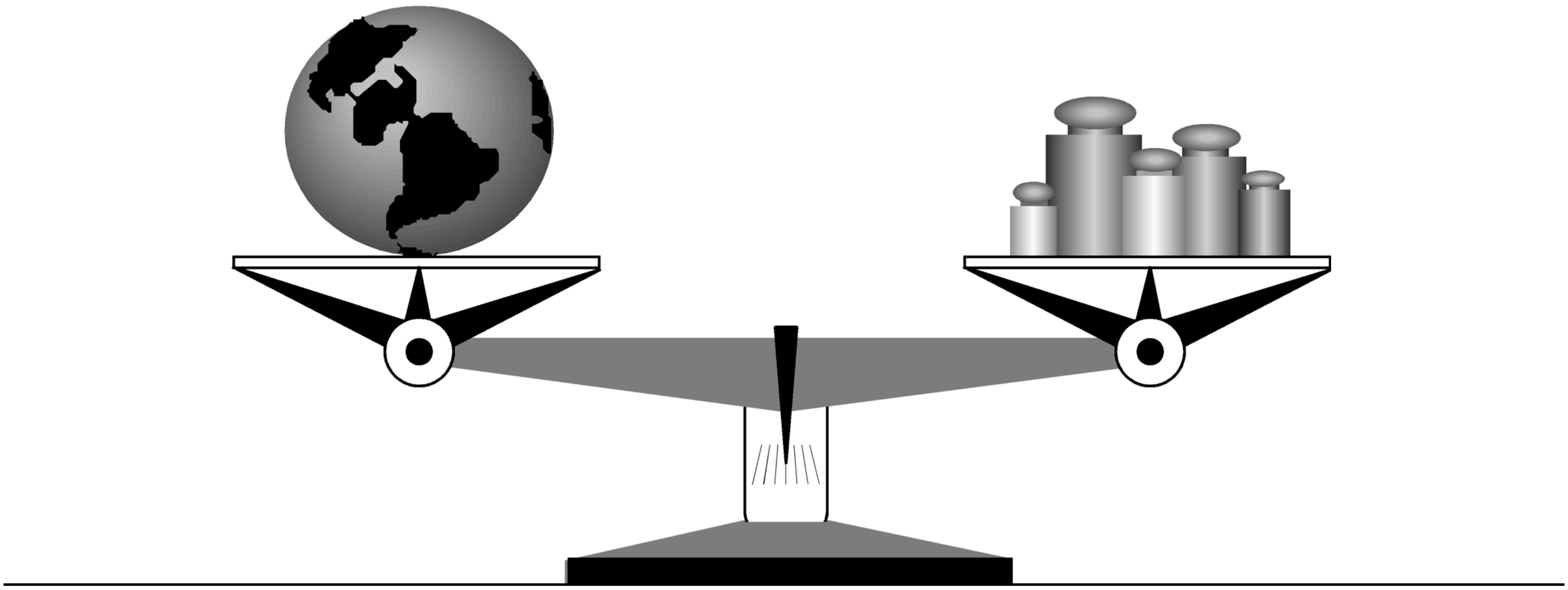
PhyzGuide: Weighing the Earth



IN SEARCH OF "G"

In 1665, 22 year-old Isaac Newton derived the law of universal gravitation. This law can be summarized by the equation that describes the gravitational force of attraction between any two masses.

$$F = G\,\frac{Mm}{R^2}$$

Although Newton was able to verify the validity of the "inverse-square" nature of this formula through calculations involving the orbit of the moon, he was never able to determine the value of the constant G (the universal gravitation constant). The equation could only be used as the proportion $F \propto Mm/R^2$ until the value of G was determined. The problem in determining G was that in order to do so, you needed to know the gravitational force between two known masses separated by a known distance:

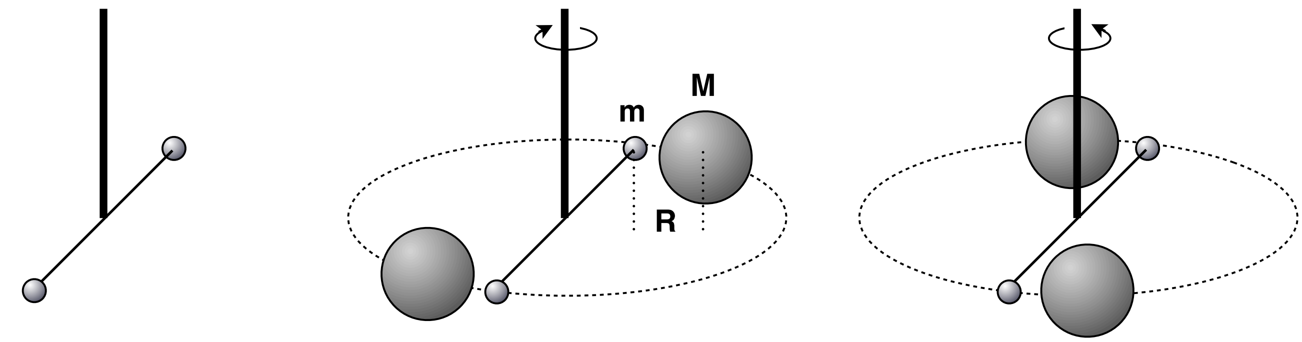
$$G = \frac{FR^2}{Mm}$$

One could easily determine the attraction between an object of known mass and the Earth by weighing it, but the mass of the Earth was not known during Newton's lifetime.

Before the end of the eighteenth century, however, the answer would be found!

THE CAVENDISH EXPERIMENT

In 1798, Henry Cavendish devised an experiment to determine the value of *G*. Instead of involving the gravitational force exerted by the Earth, he measured the gravitational attraction between two known masses in his lab. Measuring this force was difficult because it was exceedingly small (about 10^{-9} N or 0.000 000 001 N). Cavendish was able to accurately measure this force by using a highly delicate torsion balance as shown below. By measuring the force, Cavendish could calculate *G*.

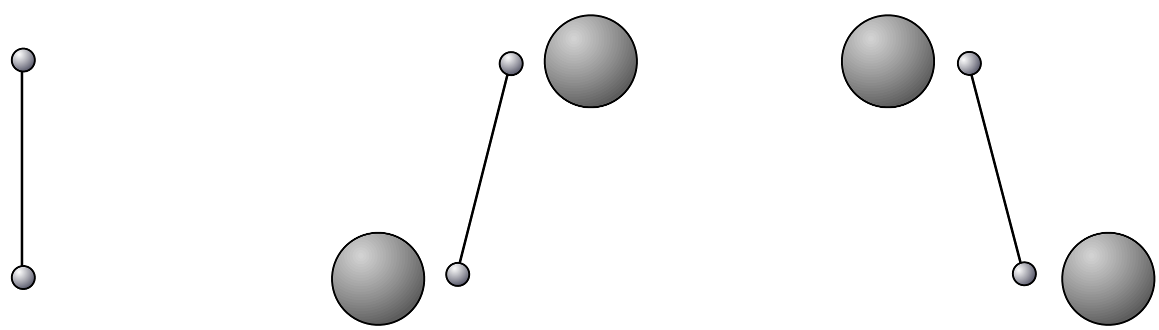


Equilibrium Position: Two small lead masses were balanced on a thin rod that was suspended by a quartz fiber.

Massive lead spheres were then brought near the smaller masses as shown; the gravitational attraction caused the balance to deflect in a clockwise manner.

The massive spheres were then reversed, causing the balance to deflect counter-clockwise.

Viewed from above



Since Cavendish knew how much force was required to make the balance deflect as it did, he could easily calculate the universal gravitation constant *G*. The accepted value for universal gravitation constant is $\mathbf{G = 6.67 \times 10^{-11}\ N{\cdot}m^2/kg^2}$.

By determining the numerical value of the universal gravitation constant, Cavendish made it possible—for the first time in human history—to calculate the mass of the planet on which we live, and the star that supplies it with energy.

And so, within the confines of his laboratory, Henry Cavendish "weighed" the Earth!