Gravity

Gravity is the force with which people are most familiar, but it’s also by far the weakest of the four natural forces. We’re aware of it because mass causes gravity, and we’re standing on an object with a very high mass (Earth).

\[ F = \frac{G m_1 m_2}{d^2} \]

This is Newton’s Universal Law of Gravity. It says that there is an attractive force between any two objects that have mass. The masses of the two objects are \( m_1 \) and \( m_2 \), and \( d \) is the distance between their centers of mass. \( G \) is called the gravitational constant. It’s a very small number, \( G = 6.673 \times 10^{-11} \text{ Nm}^2/\text{kg}^2 \), which tells you that gravity is a very weak force.

Looking at the equation, we see that the bigger \( d \) is, the smaller \( F \) is. In other words, the farther the two objects are from each other, the weaker the attractive force.

Also, it should be pointed out that every object that has mass attracts every other object that has mass. So you can think of each atom in object 1 attracting each atom in object 2. But if we compute all these trillions of forces and add them up, the answer we get is the same as if we use the entire masses of the objects and \( d \) is the distance between their centers of mass.

Let’s calculate the gravitational attractive force between two ordinary objects to see how strong it is. Suppose each object in the drawing above has a mass of one kilogram (about 2.2 pounds), and the distance between their centers of mass is one meter (about 3.3 feet). Then the equation becomes

\[ F = \frac{6.673 \times 10^{-11} \text{Nm}^2/\text{kg}^2 (1\text{kg})(1\text{kg})}{(1\text{m})^2} \]

\[ F = 6.673 \times 10^{-11} \text{N} \]

The attractive force is only 6.673 one hundred billionths of a Newton, which 2.4 ten billionths of an ounce. That’s a force that no one would notice, and it would be very difficult to measure even in a very carefully performed experiment.

But now let’s calculate the Earth’s attractive force on one of these kilograms. Now object 1 is the Earth, and its mass is very large. Our one kilogram object is sitting on the surface of the Earth, and so \( d \) is the radius of the Earth, the distance between the two attracting objects’ centers of mass.

\[ F = \frac{6.673 \times 10^{-11} \text{Nm}^2/\text{kg}^2 (5.97 \times 10^{24} \text{kg})(1\text{kg})}{(6.38 \times 10^6\text{m})^2} \]

\[ F = 9.79 \text{N} \]

Now we have a measurable force. One pound is 4.448 Newtons, so this force is 2.20 pounds. As stated above, one kilogram weighs about 2.20 pounds on Earth. An object’s weight is Earth’s gravitational attractive force on it.

We are all aware that Earth attracts objects by gravity, but it’s not obvious that everything attracts everything else because all the objects around us are so much smaller than Earth.

The first person to measure the gravitational attractive force between two ordinary objects was Henry Cavendish in 1798. In order to measure such a weak force, Cavendish
suspended one set of his gravitating masses from a wire. The red spheres in the diagram below represent two 1.61 pound lead balls. The larger spheres were stationary 348 pound balls.

The gravitational attractive force of the large spheres on the smaller ones twisted the wire slightly, and from the amount of twist, Cavendish was able to calculate the attractive force, which was less than two ten billionths of a Newton, about the weight of a grain of sand.