

8

Law of Universal Gravitation

8-1 Gravitational Force

Vocabulary

Law of Universal Gravitation: Every particle attracts every other particle with a force that is proportional to the mass of the particles and inversely proportional to the square of the distance between them.

$$F \propto \frac{mM}{d^2}$$

The sign \propto means “proportional to.” To make an equation out of the above situation, insert a quantity called the **universal constant of gravitation, G** .

$$G = 6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2$$

Now the magnitude of this gravitational force can be represented as

$$\text{Force} = \frac{(\text{universal constant of gravitation})(\text{mass 1})(\text{mass 2})}{(\text{distance})^2}$$

$$\text{or } F = \frac{GmM}{d^2}$$

Like all other forces, the gravitational force of attraction between two objects is measured in newtons.

Solved Examples

Example 1: The gravitational force of attraction between Earth and the sun is 1.6×10^{23} N. What would this force have been if Earth were twice as massive?

Solution: The gravitational force of attraction between two bodies is proportional to the mass of each of the two bodies. As one mass increases, the gravitational force between the two bodies increases proportionally. Therefore, if Earth’s mass were doubled, the gravitational force between the sun and Earth would double as well.

$$\text{Therefore, } F = 2F_0 = 2(1.6 \times 10^{23} \text{ N}) = 3.2 \times 10^{23} \text{ N}$$

Example 2: The gravitational force of attraction between Earth and the sun is 1.6×10^{23} N. What would this gravitational force have been if Earth had formed twice as far away from the sun?

Solution: The gravitational force of attraction between two bodies is inversely proportional to the square of the distance between them. In this case, if the distance is twice as great, the force between Earth and the sun would be $1/4$ as much.

$$\text{Therefore, } F \propto \frac{1}{d^2} \quad \text{or} \quad F = \frac{F_o}{4} = \frac{(1.6 \times 10^{23} \text{ N})}{4} = 4.0 \times 10^{22} \text{ N}$$

Example 3: Oliver, whose mass is 65 kg, and Olivia, whose mass is 45 kg, sit 2.0 m apart in their physics classroom. a) What is the force of gravitational attraction between Oliver and Olivia? b) Why don't Oliver and Olivia drift toward each other?

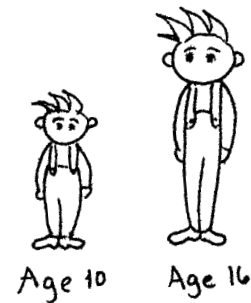
a. *Given:* $m_{\text{Oliver}} = 65 \text{ kg}$ *Unknown:* $F = ?$
 $M_{\text{Olivia}} = 45 \text{ kg}$ *Original equation:* $F = \frac{GmM}{d^2}$
 $d = 2.0 \text{ m}$
 $G = 6.67 \times 10^{-11} \text{ Nm}^2/\text{kg}^2$

Solve: $F = \frac{GmM}{d^2} = \frac{(6.67 \times 10^{-11} \text{ Nm}^2/\text{kg}^2)(65 \text{ kg})(45 \text{ kg})}{(2.0 \text{ m})^2} = 4.9 \times 10^{-8} \text{ N}$

b. Because the gravitational force of Earth is much greater than the force Oliver and Olivia exert on each other.

Practice Exercises

Exercise 1: When Royce was 10 years old, he had a mass of 30 kg. By the time he was 16 years old, his mass increased to 60 kg. How much larger is the gravitational force between Royce and Earth at age 16 compared to age 10?



Answer: _____

Exercise 2: On February 20, 1962, John Glenn became the first American to orbit Earth. If John Glenn weighed 640 N on Earth's surface, a) how much would he have weighed if his Mercury spacecraft had (hypothetically) remained at twice the distance from the center of Earth? b) Why is it said that an astronaut is never truly "weightless?" (Read more about John Glenn at <http://www.johnglennhome.org>)

Answer: **a.** _____

Answer: **b.** _____

Exercise 3: Mr. Gewanter, whose mass is 60.0 kg, is doing a physics demonstration in the front of the classroom. a) How much gravitational force does he exert on 55.0-kg Martha in the front row, 1.50 m away? b) How does this compare to what he exerts on 65.0-kg Lester, 4.00 m away in the back row?

Answer: **a.** _____

Answer: **b.** _____

Exercise 4: Astrologers claim that your personality traits are determined by the positions of the planets in relation to you at birth. Scientists argue that these gravitational effects are so small that they are totally insignificant. Compare the gravitational attraction between you and Mars to the gravitational attraction between you and your 70.0-kg doctor at the moment of your birth, if the doctor stands 0.500 m away. NOTE: $M_M = 6.42 \times 10^{23}$ kg, $d_{E-M} = 7.83 \times 10^{10}$ m. This is the average distance between Earth and Mars. This distance varies as the two planets orbit the sun.

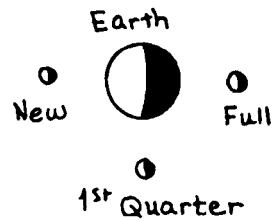
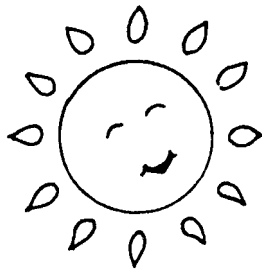
Answer: _____

Answer: _____

Exercise 5: Our galaxy, the Milky Way, contains approximately 4.0×10^{11} stars with an average mass of 2.0×10^{30} kg each. How far away is the Milky Way from our nearest neighbor, the Andromeda Galaxy, if Andromeda contains roughly the same number of stars and attracts the Milky Way with a gravitational force of 2.4×10^{30} N?

Answer: _____

Exercise 6: Tides are created by the gravitational attraction of the sun and moon on Earth. Calculate the net force pulling on Earth during a) a new moon, b) a full moon, c) a first quarter moon. The diagram is intended to help your understanding of the situation but is *not* drawn to scale. ($m_M = 7.35 \times 10^{22}$ kg, $m_E = 5.98 \times 10^{24}$ kg, $m_S = 1.99 \times 10^{30}$ kg, $d_{E-M} = 3.84 \times 10^8$ m, $d_{E-S} = 1.50 \times 10^{11}$ m)



Answer: **a.** _____

Answer: **b.** _____

Answer: **c.** _____