6.3: Newton's Universal Law of Gravity

Cavendish's apparatus to measure gravity Figure 5.3.1

In 1798, Henry Cavendish designed and created an apparatus and experiment to determine the density of the planet and the value of the gravitational constant, G. His apparatus involved a light, rigid rod about 2-feet long with two small lead spheres attached to the ends. The rod was suspended by a thin wire. When the rod rotated, the twisting of the wire pushed *backwards* to restore the rod to the original position.

Force of Gravity

In the mid-1600's, Newton wrote that the sight of a falling apple made him think of the problem of the motion of the planets. He recognized that the apple fell straight down because the earth attracted it and thought this same force of attraction might apply to the moon. It further occurred to him that motion of the planets might be controlled by the **gravity** of the sun. He eventually proposed the universal law of gravitational attraction as

$F = Gm_1m_2/d^2$

where *m1* and *m2* are the masses being attracted, d is the distance between the centers of the masses, G is the universal gravitational constant, and F is the force of attraction. The formula for gravitational attraction applies equally to two rocks resting near each other on the earth and to the planets and the sun. The value for the universal gravitational constant, G, was determined by Henry Cavendish (using the apparatus described in the introduction) to be $6.67 \times 10^{-11}\ N{\cdot}m^2/kg^2$.

Use the Newton's Apple simulation below to learn more about the Universal Law of Gravity and observe how this law unites the motion of objects on the Earth with the motion of all objects throughout our universe:

The moon is being pulled toward the earth and the earth toward the moon with the same force but in the opposite direction. The force of attraction between the two bodies produces a greater acceleration of the moon than the earth because the moon has smaller mass. Even though the moon is constantly falling toward the earth, it never gets any closer. This is because the velocity of the moon is perpendicular to the radius of the earth (as shown in the image above) and therefore the moon is moving away from the earth. The distance the moon moves away from the orbit line is exactly the same distance that the moon falls in the time period. This is true of all satellites and is the reason objects remain in orbit.

In the case of orbiting bodies, the centripetal force is the gravitational force and they undergo imperfect circular motion. Use the simulation below to learn more about gravity and orbital motion:

Examples

Example 5.3.1

Since we know the force of gravity on a 1.00 kg ball resting on the surface of the earth is 9.80 N, and we know the radius of the earth is 6380 km, we can use the equation for gravitational force to calculate the mass of the earth.

Solution

$m_e = Fd^2/Gm_1 = (9.80\ N)(6.38{\times}106\ m)^2/(6.67{\times}10^{-11}\ N{\cdot}m^2/kg^2)(1.00\ kg) = 5.98{\times}10^{24}\ kg$

Example 5.3.2

John and Jane step onto the dance floor about 20. m apart at the Junior Prom and they feel an attraction to each other. If John's mass is 70. kg and Jane's mass is 50. kg, assume the attraction is gravity and calculate its magnitude.

Solution

$F_g = Gm_1m_2/d^2 = (6.67{\times}10{-}11\ N{\cdot}m^2/kg^2)(70.\ kg)(50.\ kg)/(20.\ m)^2 = 5.8{\times}10^{-10}\ N$

This is an extremely weak force; it is probably not the force of attraction they truly felt.

Summary

- Newton proposed the universal law of gravitational attraction as $F=Gm_1m_2/d^2$.
- The universal gravitational constant, G, was determined by Cavendish to be $6.67 \times 10^{-11}\ N{\cdot}m^2/kg^2$.

Review

1. The earth is attracted to the sun by the force of gravity. Why doesn't the earth fall into the sun?
2. If the mass of the earth remained the same but the radius of the earth shrank to one-half its present distance, what would happen to the force of gravity on an object that was resting on the surface of the earth?
3. Lifting an object on the moon requires one-sixth the force that would be required to lift the same object on the earth because gravity on the moon is one-sixth that on earth. What about horizontal acceleration? If you threw a rock with enough force to accelerate it at 1.0 m/s^2 horizontally on the moon, how would the required force compare to the force necessary to accelerate the rock in the same way on the earth?
4. The mass of the earth is 5.98×10^{24} kg and the mass of the moon is 7.35×10^{22} kg. If the distance between the earth and the moon is 384,000 km, what is the gravitational force on the moon?

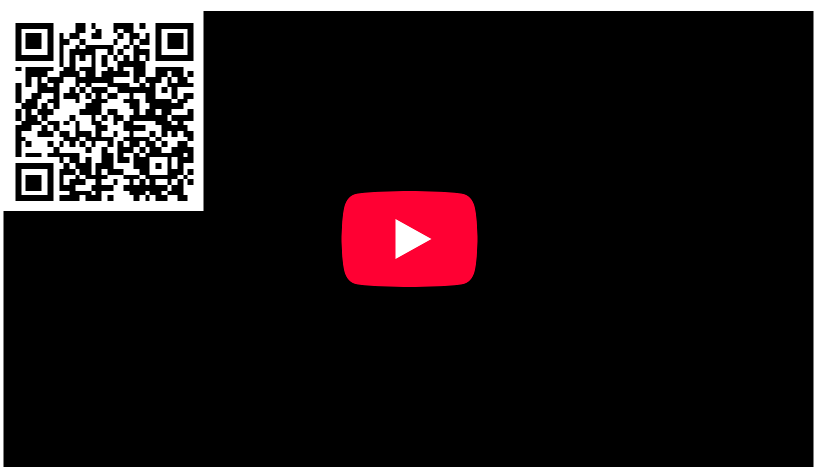
Explore More

Use this resource to answer the questions that follow.

1. What is gravity?
2. What caused the sun to form?
3. What is the relationship between the strength of a gravitational force and distance?
4. What is the relationship between the strength of a gravitational force and mass?

Resources

Does gravity effect everything at the same rate? The experiment in this MIT video helps to answer that question.



Additional Resources

Study Guide: Gravitation Study Guide

Real World Application: Earth's Orbit

PLIX: Play, Learn, Interact, eXplore: Size and Mass

Videos: