Newton's Law of Universal Gravitation

Newton developed the idea that two bodies exert a force on each other over a distance.

He set about determining the gravitational force that the Earth exerts on the Moon. In doing so, he concluded that the force of gravity decreases with the square of the distance r between the centers of the two bodies.

$$F_g \propto \frac{1}{r^2}$$

Newton also realized that the force of gravity depended on the mass of the two bodies.

$$F_g \propto m_1 m_2$$

Newton went a step further, and proposed that there would exist a force of gravitational attraction between all objects. Thus he proposed his **law of universal gravitation**:

Every particle in the universe attracts every other particle with a force that is proportional to the product of their masses and inversely proportional to the square of the distance between them. This force acts along the line joining the two particles.

$$\boxed{F_g = \frac{Gm_1 m_2}{r^2}}$$

The value of the constant G was determined over 100 years later by Henry Cavendish.

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

Example 1

A $50\ kg$ person and a $75\ kg$ person are sitting $0.5\ m$ apart on a bench. Determine the magnitude of the gravitational force each exerts on the other.

Example 2 Force on the Moon.

Find the net force on the Moon $\left(m_M = 7.35\times10^{22}\ kg\right)$ due to the gravitational attraction of both the Earth $\left(m_E = 5.98\times10^{24}\ kg\right)$ and the Sun $\left(m_S = 1.99\times10^{30}\ kg\right)$, assuming they are at right angles to each other.

Note: Earth is $3.84\times10^{8}\ m$ from the Moon, and the Sun is $1.50\times10^{11}\ m$ from both the Earth and the Moon.

Gravitation Law Worksheet

1. What is the force of gravitational attraction between two $1.8\times10^{8}\ kg$ supertankers moored so that their centers are located $94\ m$ apart? ($2.4\times10^{2}\ N$)

2. A woman standing on the surface of the earth, $6.38\times10^{6}\ m$ from its center, has a mass of $50.0\ kg$. If the mass of the earth is $5.98\times10^{24}\ kg$, what is the force of gravity on the woman? ($4.9\times10^{2}\ N$)

3. The force of gravitational attraction between two masses is $36\ N$. What will be the force if one mass is doubled and the distance between them is tripled? ($8.0\ N$)

4. Mars has a radius 0.54 times that of Earth and a mass 0.11 times that of Earth. If the force of gravity on you is $600\ N$ on Earth, what will it be on Mars? ($230\ N$)

5. The planet Jupiter has a mass of $1.9\times10^{27}\ kg$ and a radius of $7.2\times10^{7}\ m$. Calculate the acceleration due to gravity on Jupiter. ($24\ m/s^{2}$)

6. An apparatus like the one Cavendish used to find G has a large lead ball that is $5.9\ kg$ in mass and a small one that is $0.047\ kg$. Their centers are separated by $0.055\ m$. Find the force of attraction between them. ($6.1\times10^{-9}\ N$)

7. Compute the gravitational force the sun exerts on Jupiter. ($4.2\times10^{23}\ N$)

8. Two spherical balls are placed so their centers are $2.6\ m$ apart. The force between the two balls is $2.75\times10^{-12}\ N$. What is the mass of each ball if one ball is twice the mass of the other ball? ($0.4\ kg$, $0.8\ kg$)

9. Four masses are located on a plane as illustrated below. What is the magnitude of the net gravitational force on mass 1 due to the other three masses? ($6.8\times10^{-10}\ N$)