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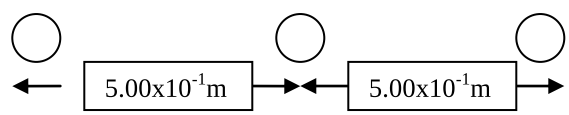
Universal Gravitation Worksheet

1. Two students are sitting 1.50m apart. One student has a mass of 70.0kg and the other has a mass of 52.0kg. What is the gravitational force between them? **($1.08x10^{-7}$N)**
2. What gravitational force does the moon produce on the earth if the centers of the moon and earth are $3.88x10^{8}$m apart and the moon has a mass of $7.34x10^{22}$kg? **($1.94x10^{20}$N)**
3. If the gravitational force between two objects of equal mass is $2.30x10^{-8}$N when the objects are 10.0m apart, what is the mass of each object? **($1.86x10^{2}$kg)**
4. Calculate the gravitational force on a $6.50x10^{2}$kg spacecraft that is $4.15x10^{6}$m above the surface of the earth. **($2.34x10^{3}$N)**
5. The gravitational force between two objects that are $2.1x10^{-1}$m apart is $3.2x10^{-6}$N. If the mass of one object is $5.5x10^{1}$kg, what is the mass of the other object. **(38kg)**
6. If two objects each with a mass of $2.0x10^{2}$kg, produce a gravitational force between them of $3.7x10^{-6}$N, what is the distance between them? **($8.5x10^{-1}$m)**
7. What is the gravitational force on a 70.0kg object sitting on the earth's surface? **($6.88x10^{2}$N)**
8. What is the gravitational force on a 35.0kg object standing on the earth's surface? **($3.44x10^{2}$N)**
9. What is the gravitational force on a 70.0kg object that is $6.37x10^{6}$m above the surface of the earth? **($1.72x10^{2}$N)**
10. What is the gravitational force on a 70.0kg object that is $3.18x10^{6}$mabove the earth's surface? **($3.06x10^{2}$N)**
11. Three objects A (m=10.0kg), B (m=10.0kg) and C (m= 15.0kg) are placed $5.00x10^{-1}$m apart in a straight line as shown below. What is the net gravitational force on object B due to A and C? **($1.33x10^{-8}$N)**
12. The gravitational force between two small masses A and B when placed a short distance apart is $3.24x10^{-7}$N. What is the gravitational force between these objects if the masses of both A and B are doubled and the distance is tripled? **($1.44x10^{-7}$N)**



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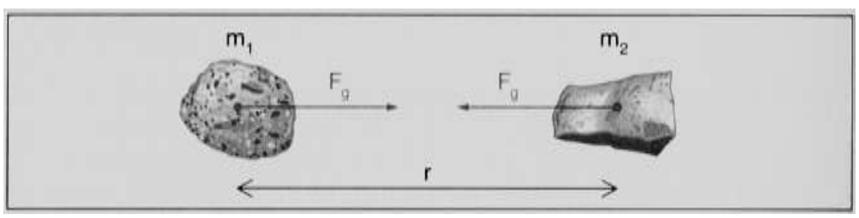
Newton's Law of Universal Gravitation

For an object to have weight, it must interact with another object. In other words, weight is dependent upon the surroundings. Any two masses will exert a mutual, attractive force, upon each other, called the gravitational attractive force. When Newton studied these attractive forces, he discovered, he discovered that larger masses had greater attractive forces. As well, he observed that the force decreased as the distance between the masses increased. From these observations, Newton formulated his law of universal gravitation.

$$F_g = Gm_1m_2 / r^2$$

In the formula, m_1 and m_2 are the magnitudes of the masses and r is the distance between their centers as shown below.



G is a number called the "Gravitational Constant", which relates the gravitational force in newtons to the masses in kilograms and the distance in meters. Its value is 6.67×10^{-11} Nm^2/kg^2. This value is extremely small, so the gravitational attractive force between two objects, like your body and a baseball, is so small that it goes unnoticed. The only object you encounter regularly that is massive enough to exert a noticeable force on you is the earth. This force is your weight.

Example: A melon is taken to the moon as a food item by astronauts. Its mass is 0.65kg. The mass of the moon is 7.36 $\times 10^{22}$kg and the radius of the moon is 1.74 $\times 10^{6}$m. What is the weight of the melon on the moon?

Solution: Weight = F_g

$$F_g = Gm_1m_2 / r^2 = 6.67 \times 10^{-11} N\cancel{m^2} \times 0.65\cancel{kg} \times 7.36 \times 10^{22}\cancel{kg} / \cancel{kg^2}\ (1.74 \times 10^{6}\ \cancel{m})^{\cancel{2}}$$

F_g = 1.1N

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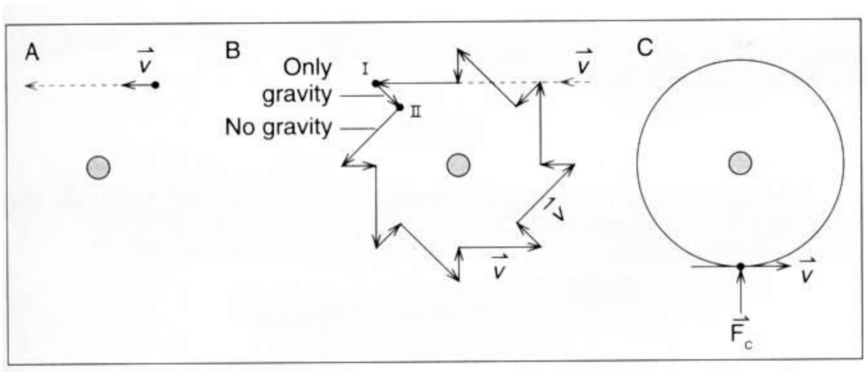
Gravitational Force as a Centripetal Force

Newton's first law says that any body (planet, star, meteor etc.) will remain in motion unless acted upon by another unbalanced force. All planets and other celestial bodies exert gravitational forces on each other (this is how many of the planets were discovered). Because the sun is by far the most massive body in the solar system it exerts the most force and keeps the planets in their orbits. Here's how:



If there were no gravity an object would travel past the sun without changing its course as in A. Consider however if the object encountered the gravitational force, as in B. It would travel unaltered to point I, there the gravitational force exerts a force towards the center of the sun the object then "falls" toward the sun along the line from I to II. At point II the velocity of the object re-enters the picture and the object moves perpendicular to the sun along the line labeled "no gravity". B shows a complete orbit executed in this manner. It is very choppy. In actuality both motions occur at the same time creating the circular (or elliptical) orbits we are familiar with.

Circular motion under gravitational force consititutes the basis for all satellite motion. Combining the equations for centripetal force and gravitational force we can calculate the velocities needed to keep satellites (in this case the moon) in orbit. Here's how:

$$F_g = F_c$$

$$G m_{Earth} m_{moon} / r^2 = m_{moon} v^2_{moon} / r$$

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$$Gm_{Earth} / r = v^2$$
$$v = \sqrt{(Gm_{earth} / r)}$$

Example:

If the moon is 3.84×10^5km from the Earth, what must its speed be?

Reasoning: Convert r to meters

3.84×10^8m

Solution:

$$v = \sqrt{(Gm_{earth} / r)}$$
$$v = \sqrt{[(6.67 \times 10^{-11} Nm^2/kg^2) \times (5.98 \times 10^{24} kg) / 3.84 \times 10^8 m]}$$
$$v = 1.02 \times 10^3 m/s$$

Problems:

1. If you weigh 490N on earth how much do you weigh on the moon?
2. What is the gravitational force between two masses of 15kg each, when their centers are 0.25m? Could you detect this force with even sensitive equipment?
3. What would be the weight of the moon if it were resting on the surface of the earth? Remember that r is the distance between the centers of the objects. $r_{earth} = 6.37 \times 10^6$m $m_{earth} = 5.98 \times 10^{24}$kg.
4. What is the mass of an object that weighs 55N on earth?
5. If a satellite were designed to orbit at 50.0km from the surface of the earth, what would be its velocity? How long would it take to complete 1 orbit?
6. What must the orbital speed of a satellite in an orbit that is 300km above the surface of the earth? How long would it take to complete 1 orbit?
7. The planet Neptune is 4.50×10^{12}km from the sun. The mass of the sun is 1.99×10^{30}kg. What is Neptune's orbital speed? How long does it take for Neptune to complete 1 orbit?