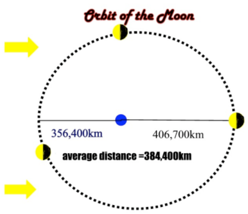
Newton's Laws of Motion and Planetary Orbits



Gravity makes the solar system go round

Getting ahead of things a bit…using Kepler's Laws to explore Saturn with the Cassini spacecraft

- http://saturn.jpl.nasa.gov/video/videodetails/?videoID=85
- http://saturn.jpl.nasa.gov/video/videodetails/?videoID=197

Newton's Laws of Motion…vocabulary

Newton's description of *dynamics*, or the laws governing the motion of the planets, relied on the development of *kinematics*, which is the mathematical language that describes motion of objects. Here are some terms which are important in kinematics.

- *speed* is the rate at which you are moving. It has units of meters/sec. The speed doesn't depend on the direction you are going.
- *velocity* is a mathematical quantity called a *vector*; it has both magnitude and direction. The magnitude of velocity is the speed. However, the velocity, being a vector, has a direction as well. The velocities corresponding to moving east at 50 mph is different from moving south at 50 mph.
- *acceleration* is also a vector. The acceleration is the amount the velocity changes, divided by the time interval over which this change occurs. In terms of equations, we have

$$acceleration = a = \frac{\text{change in velocity}}{\text{change in time}} = \frac{V_2 - V_1}{t_2 - t_1} \quad (1)$$

Newton's Laws of Motion

Acceleration occurs if the speed of an object changes while the direction of motion stays the same, if the speed stays constant while the direction of motion changes, or if both the speed and the direction changes.

Newton's Laws of Motion

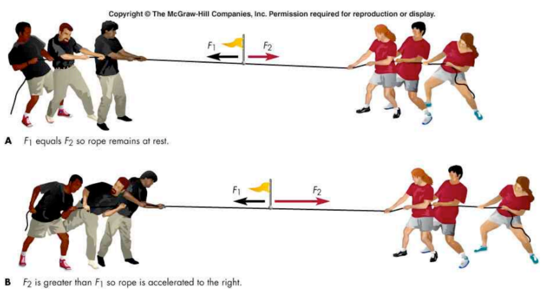
With the kinematic definitions above, we are ready to state Newton's Laws.

1. An object in motion remains in motion with the same velocity, unless acted on by an external force. An object at rest remains at rest unless acted on by an external force.
2. If an object with a mass m is acted upon by an external net force F, it accelerates according to the law

$$F = ma, \text{ or} \quad (2)$$
$$a = \frac{F}{m} \quad (3)$$

3. "To every action, there is an opposite and equal reaction". That definition sounds neat, but a more useful definition is: If an object A exerts a force on object B, object B also exerts a force on A, which is equal in magnitude, but opposite in direction to the first force.

The net force is what moves things

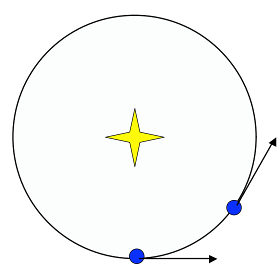


Demonstrations of Newton's Laws of Motion

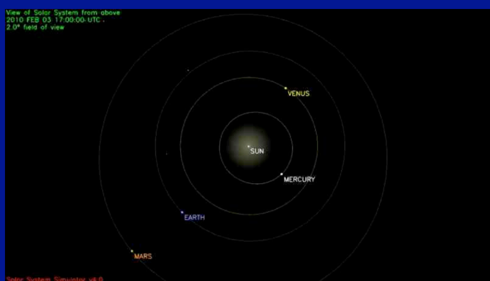
Demonstrations of Newton's Laws of Motion

What does this have to do with solar system objects? Or astronomy?

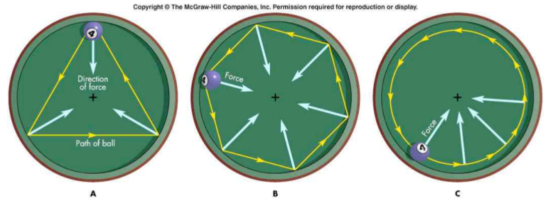
A planet in an orbit around the Sun has its **velocity** change from one second to another, so it is accelerating. A **force** must therefore be acting on it, but what kind of force?



The orbits of the planets means they are acted on by a force



Centripetal acceleration and central force…let's figure out the nature of the force



For an object moving on a circular path the acceleration is always towards the center of the circle. So the force must be pointing in that direction, too.

What kind of force could produce that motion?

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What kind of force could produce that motion?

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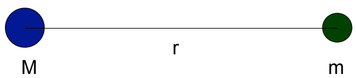
The nature of Gravity: gravity holds the solar system together

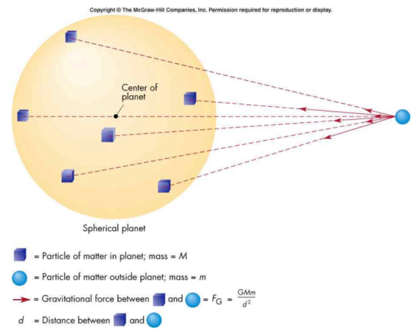


Gravity is an attractive force between two objects because they have mass

$$F = \frac{GMm}{r^2}$$

So what does this have to do with the motion of the planets?

The gravitational force from spherical object



The application of Newtonian physics to orbital motion

- The solution to F=ma for a planet is an ellipse with the Sun at one focus (Kepler's 1st Law)
- The semimajor axis and orbital period are related by:

$$P^2 = \frac{4\pi^2 a^3}{G(M+m)}$$

Kepler's 3rd Law (or is it?) ??????

The application of Newtonian physics to orbital motion (continued)

Since the force is always in the direction of the center of the ellipse, the **torque** is always zero, and **angular momentum** is constant

Kepler's 2nd Law is a consequence

demonstration

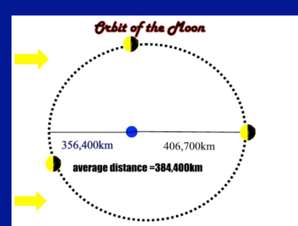
Summary---Newton’s laws of motion, and Newton’s equation for the gravitational force (Newtonian mechanics) allow us to understand, and calculate with tremendous precision, the orbits of planets and other objects in the solar system.

Next Topic: The Moon

The nearest astronomical object, Rosetta Stone of the solar system

Relative size of the Earth and Moon

The orbit of the Moon



The Moon and similar objects