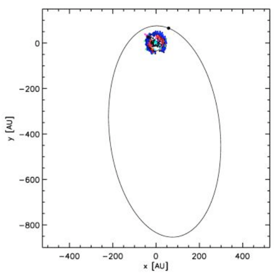
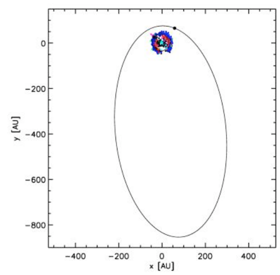
Kepler’s Laws



What they tell us, and where they come from

Kepler’s Laws



Question: why did I put this picture here? How is it related to Kepler’s Laws?

What they tell us, and where they come from

Kepler’s Laws of Planetary Motion

- The orbits of planets (and everything else) are ellipses, with the Sun at one focus.
- A line from the Sun to a planet sweeps out equal areas in equal intervals of time
- The semimajor axes and orbital periods are related by the Harmonic Law

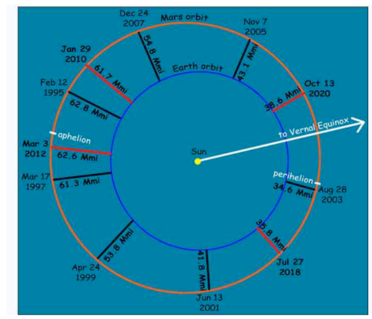
A question (?)

Is Kepler’s 3rd Law, $a^3=P^2$ only due to the fact that the planets further out have a longer orbit to complete in a period?

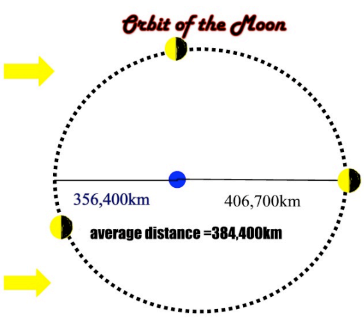
Kepler's Laws are even more general than orbits in the solar system…they govern orbits throughout the universe, like those of stars at the center of the Milky Way galaxy

http://www.eso.org/public/videos/eso0846h

Applications of Kepler's Laws: variations in the opposition of Mars

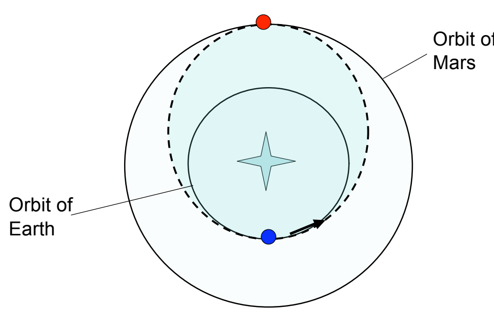


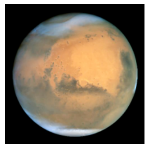
Another application of Kepler's 1st Law: the orbit of the Earth's Moon.



Explains difference between total and annular solar eclipses

How long does it take for a trip to Mars?





The length of a trip to Mars

For Earth: a=1.00 au
For Mars: a =1.52 au
For spaceship, major axis = 1.00 + 1.52 = 2.52 au
semimajor axis = 2.52/2 =1.26 au

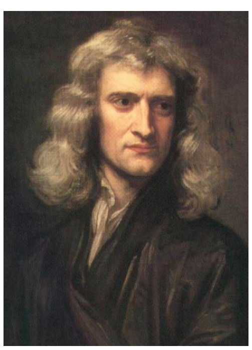
$$a^3 = P^2 \tag{1}$$
$$P^2 = a^3 = (1.26)^3 = 2.00 \tag{2}$$
$$P = \sqrt{a^3} = \sqrt{2.00} = 1.41 \text{ years} \tag{3}$$

We only want half of a period (Earth to Mars, not Mars to Earth) so time = 1.41/2 = 0.707 years = 258 days (8.5 months)

Next topic: where do Kepler's Laws come from

What is the deeper significance of them? Why is nature that way?

Isaac Newton…beginning of modern physics



Newton's laws of motions: the foundation of physics and the start for our understanding of orbits

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

$$\textit{acceleration} = a = \frac{\text{change in velocity}}{\text{change in time}} = \frac{V_2 - V_1}{t_2 - t_1} \tag{1}$$

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.

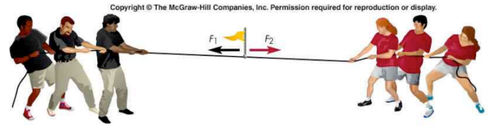
1. An object in motion remains in motion with the same velocity, unless acted on by an external force. An object at rest remains at rest unless acted on by an external force.

2. If an object with a mass m is acted upon by an external net force F, it accelerates according to the law

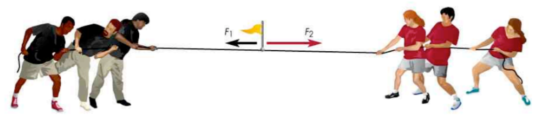
$$F = ma, \text{ or} \tag{2}$$
$$a = \frac{F}{m} \tag{3}$$

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



A F_1 equals F_2 so rope remains at rest.



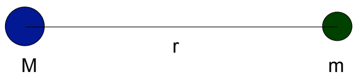
B F_2 is greater than F_1 so rope is accelerated to the right.

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?

The nature of Gravity: gravity holds the solar system together

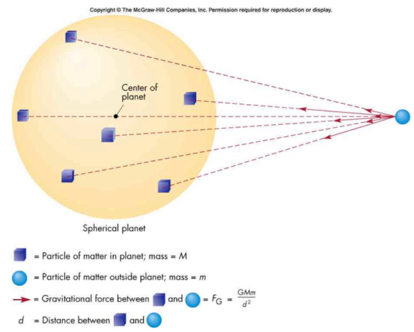


Gravity is an attractive force between two objects because they have mass

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

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

The gravitational force from spherical object



Centripetal acceleration and central force