Lecture: October 1, 2010

- How long would it take to walk to Alpha Centauri?

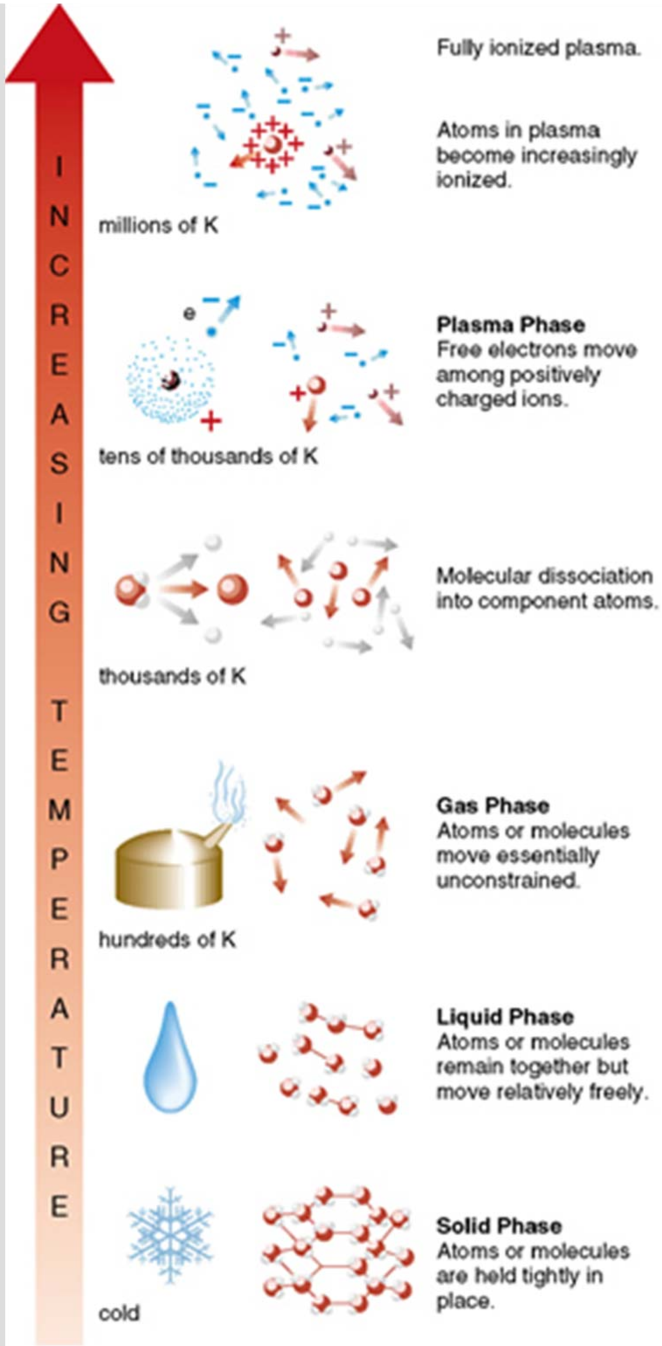
Announcements:

Next Observatory Opportunity: Wednesday October 6

Phases of Matter

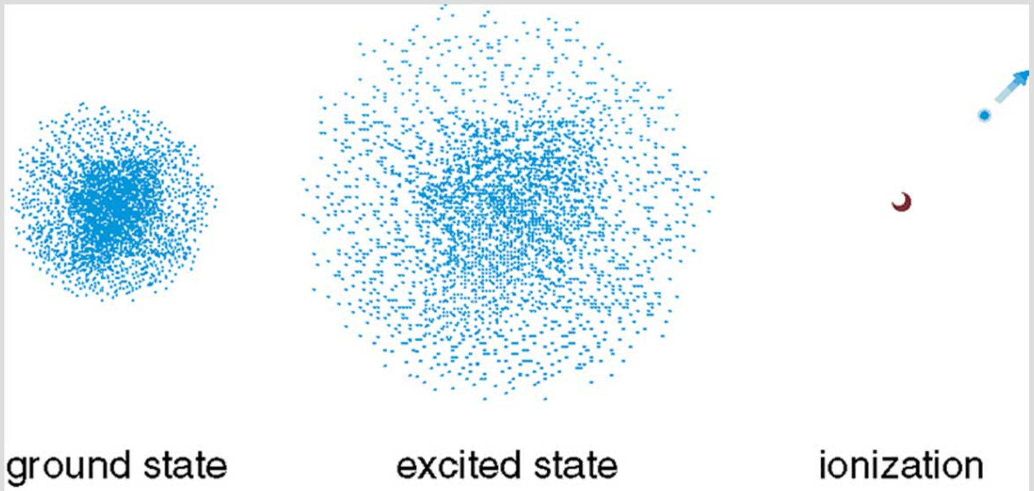
- the phases
  - solid
  - liquid
  - gas
  - plasma

  depend on how tightly bound the atoms and/or molecules are
- As temperature increases, these bonds are loosened:



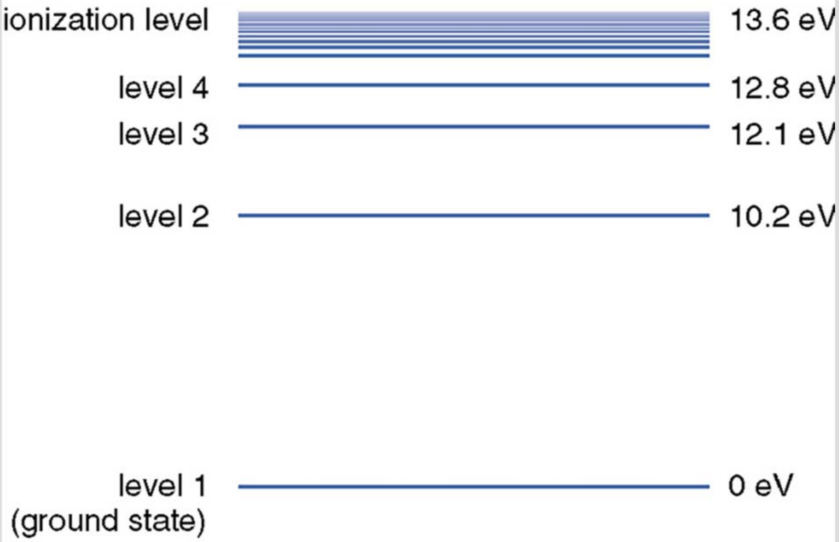
Electron Orbits

- Electrons can gain or lose energy while they orbit the nucleus.
- When electrons have the lowest energy possible, we say the atom is in the **ground state**.
- When electrons have more energy than this, we say the atom is in an **excited state**.
- When electrons gain enough energy to escape the nucleus, we say the atom is **ionized**.



Electron Energy Levels

- But, electrons can not have just <u>any</u> energy while orbiting the nucleus.
- Only certain energy values are allowed.
- Electrons may only gain or lose certain specific amounts of energy.



- Each element (atom and ion) has its own distinctive set or pattern of energy levels.
- This diagram depicts the energy levels of Hydrogen.

5. Universal Laws of Motion

"If I have seen farther than others, it is because I have stood on the shoulders of giants."

Sir Isaac Newton (1642 – 1727)
Physicist

Sir Isaac Newton (1642-1727)

- Perhaps the greatest genius of all time
- Invented the reflecting telescope
- Invented calculus
- Connected gravity and planetary forces

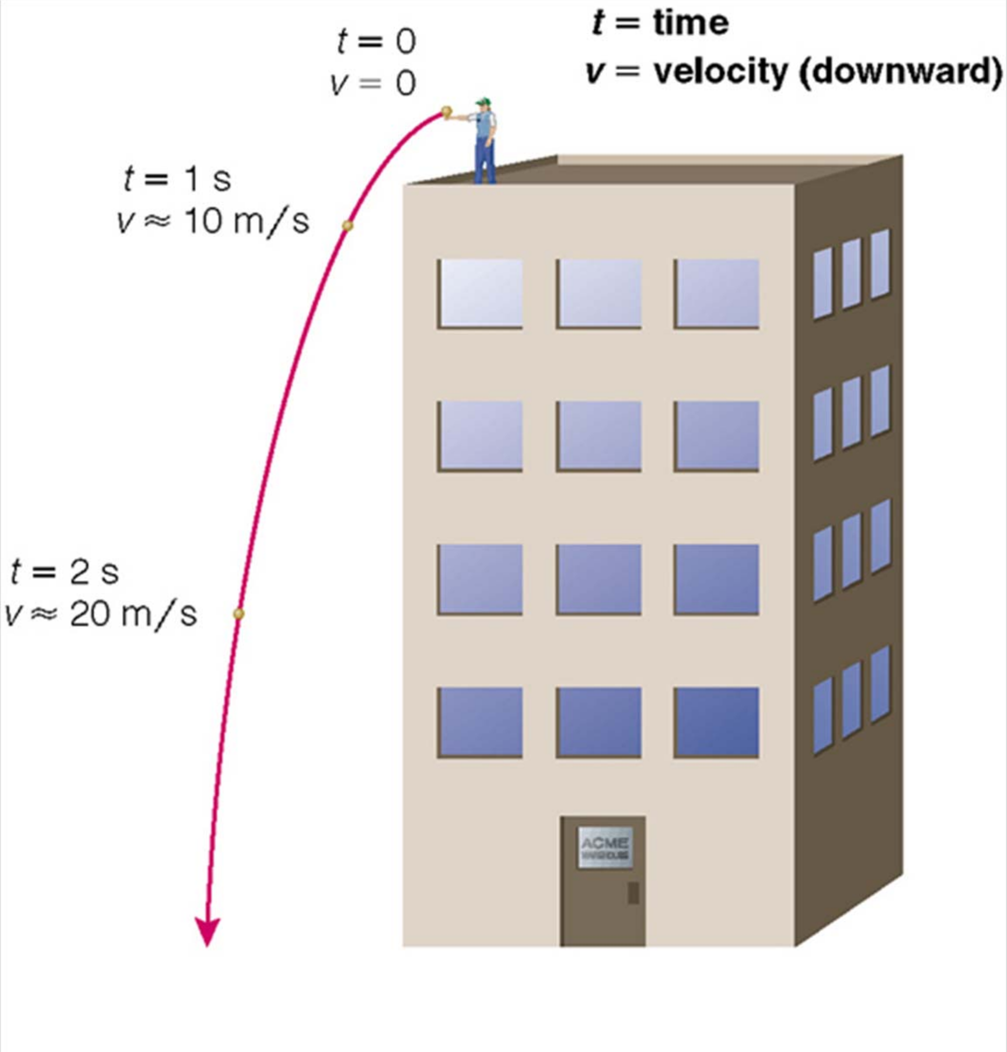
Philosophiae naturalis principia mathematica

Objects in Motion

- **Position** – coordinates at any given time [m]
- **speed** – rate at which an object moves, i.e. the distance traveled per unit time [m/s; mi/hr]
- **velocity** – an object's speed in a certain direction, e.g. "10 m/s moving east"
- **acceleration** – a change in an object's velocity, i.e. a change in either speed or direction is an acceleration [m/s^2]

The Acceleration of Gravity

- As objects fall, they accelerate.
- The acceleration due to Earth's gravity is 9.8 m/s each second, or $g = 9.8\ m/s^2$.
- The higher you drop the ball, the greater its velocity will be at impact.



The Acceleration of Gravity (*g*)

- Galileo demonstrated that *g* is the same for all objects, regardless of their mass!
- This was confirmed by the Apollo astronauts on the Moon, where there is no air resistance.

Forces

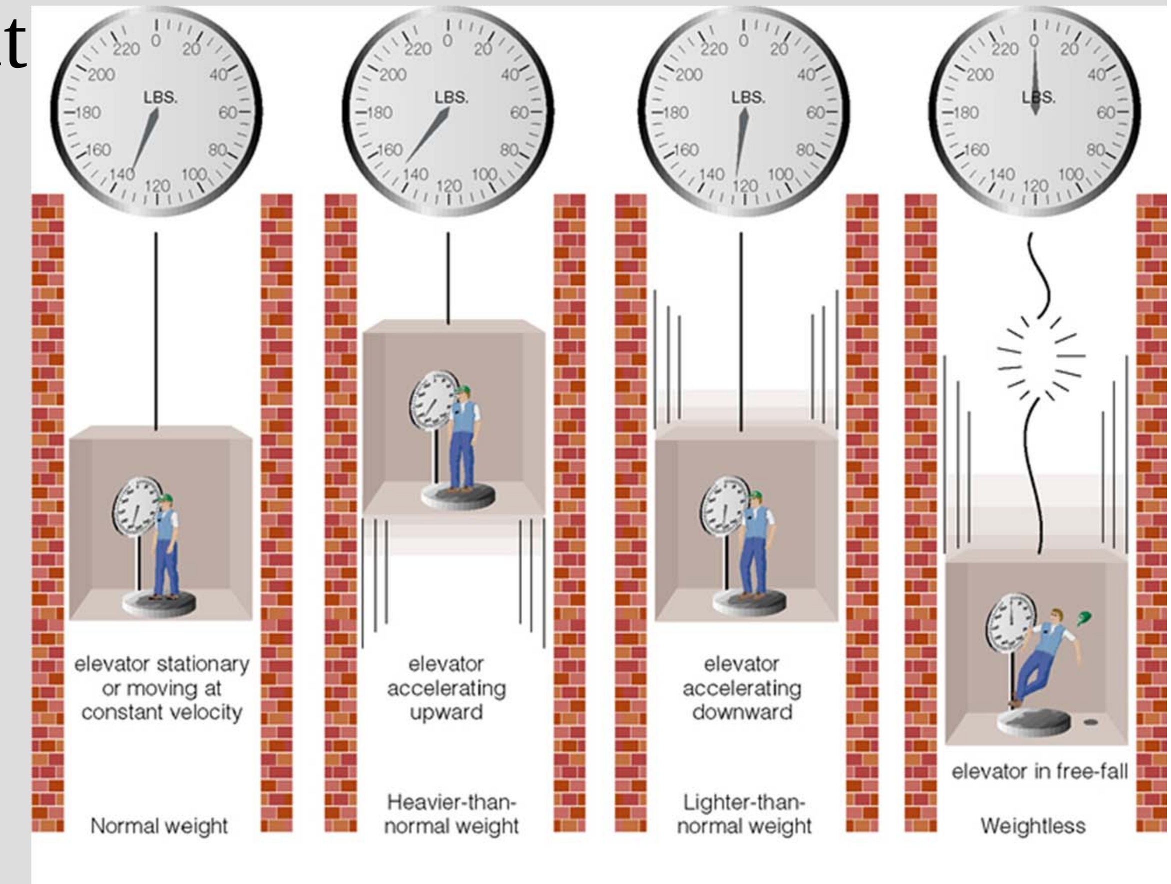
- Forces change the motion of objects.
- **momentum** – the (mass x velocity) of an object
- **force** – anything that can cause a change in an object’s momentum
- As long as the object’s mass does not change, the force causes a change in velocity, or an…

acceleration

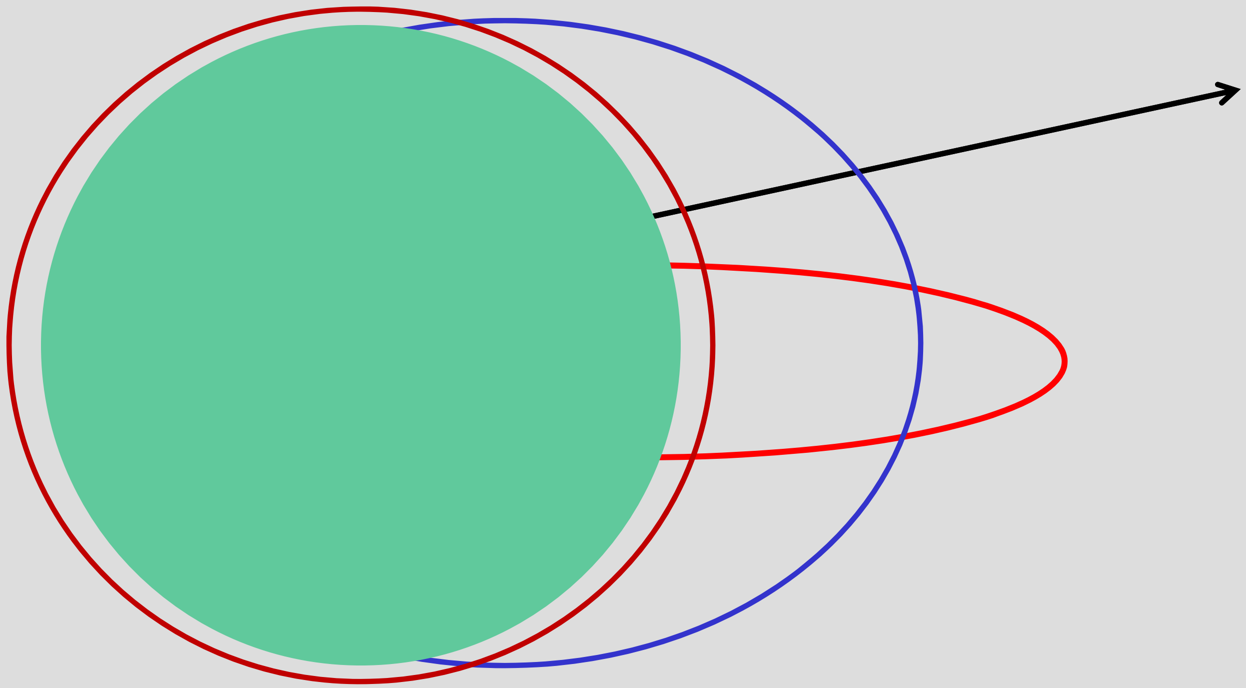
Is Mass the Same Thing as Weight?

- **mass** – the amount of matter in an object
- **weight** – a measurement of the *force* which acts upon an object

When in "free-fall," you are weightless!!



Depending on its initial velocity, the cannonball will either fall to Earth, continually free-fall (orbit), or escape the force of Earth's gravity.



Newton’s Laws of Motion

1 A body at rest or in motion at a constant speed along a straight line remains in that state of rest or motion unless acted upon by an outside force.

Newton’s Laws of Motion

2 The change in a body’s velocity due to an applied force is in the same direction as the force and proportional to it, but is inversely proportional to the body’s mass.

$$F = m\,a$$

Newton's Laws of Motion

3 For every applied force, a force of equal size but opposite direction arises.

Newton's Laws of Motion

A baseball accelerates as the pitcher applies a force by moving his arm. (Once released, this force and acceleration cease, so the ball's path changes only due to gravity and effects of air resistance.)

A spaceship needs no fuel to keep moving in space.

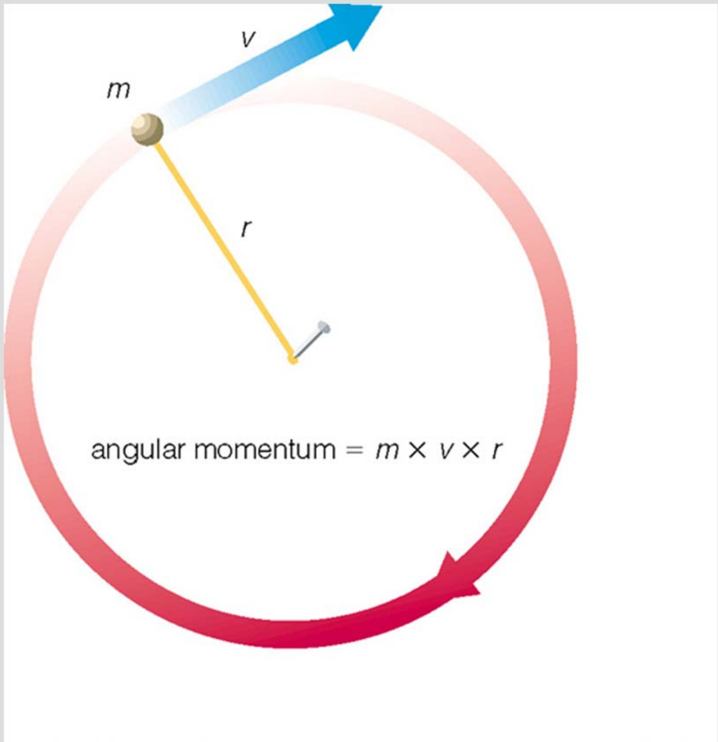
A rocket is propelled upward by a force equal and opposite to the force with which gas is expelled out its back.

Conservation of Momentum

- Like energy, the total amount of momentum in the Universe is conserved and does not change.

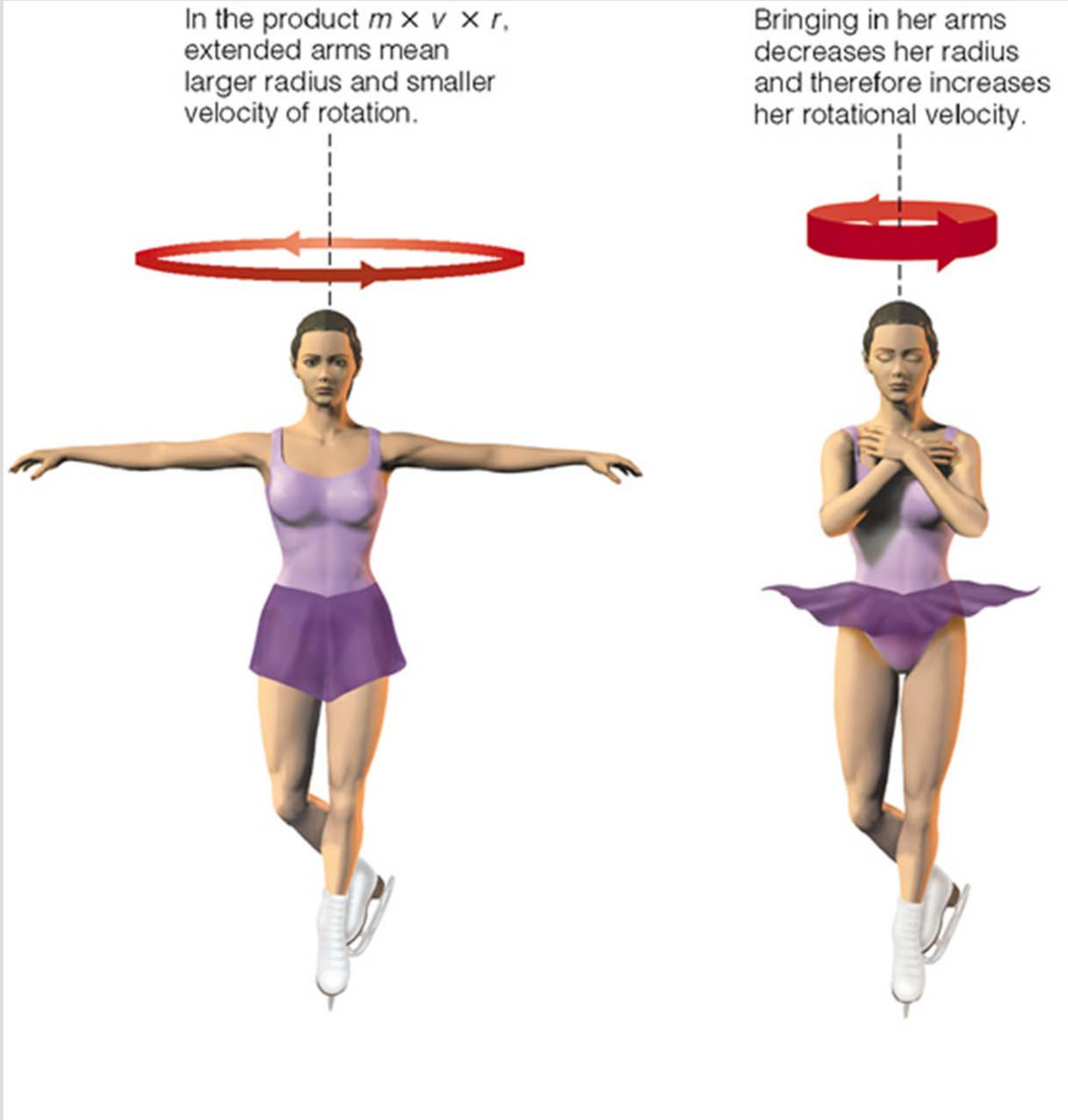
Angular Momentum

- **angular momentum** – the momentum involved in spinning /circling = mass x velocity x radius
- **torque** – anything that can cause a change in an object's angular momentum (*twisting force*)



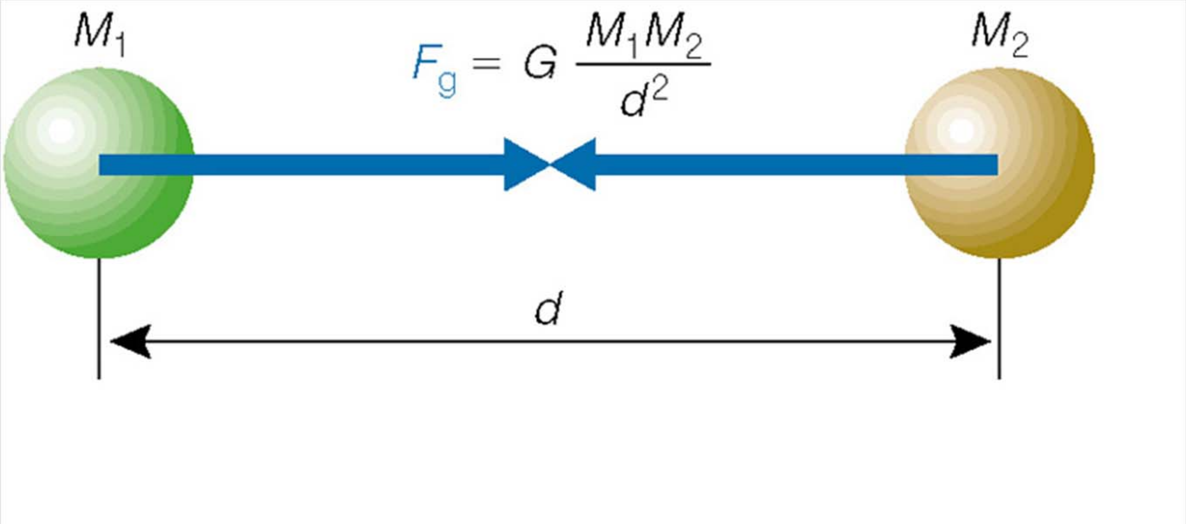
Conservation of Angular Momentum

- In the absence of a net torque, the total angular momentum of a system remains constant.



Universal Law of Gravitation

Between every two objects there is an attractive force, the magnitude of which is directly proportional to the mass of each object and inversely proportional to the square of the distance between the centers of the objects (inverse square law).



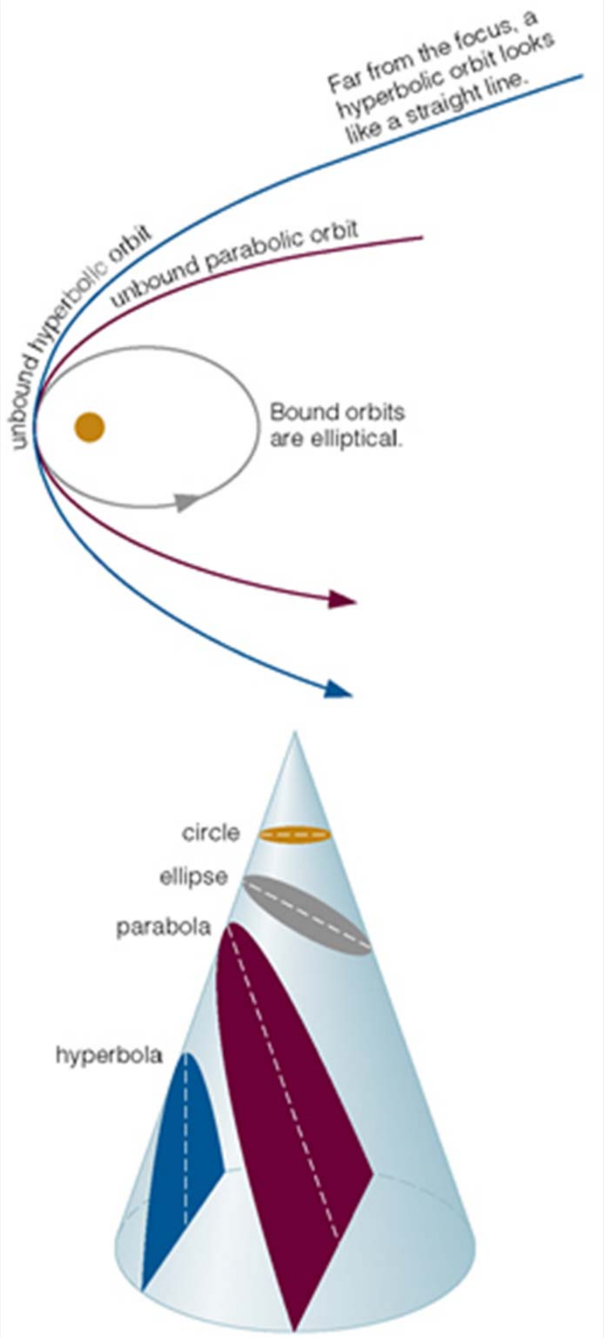
Gravity

$$F = \frac{GMm}{r^2} \qquad E_{pot} = \frac{GMm}{r}$$

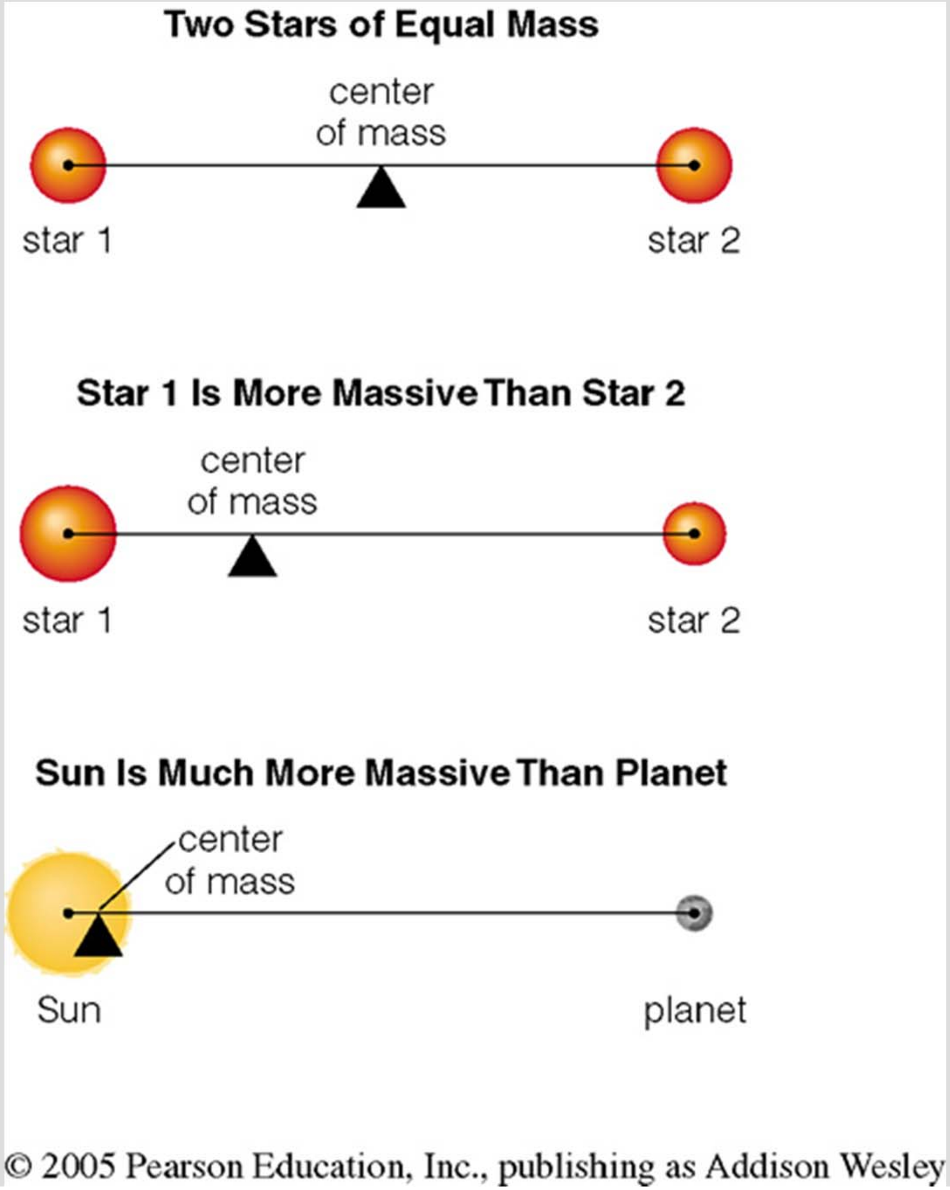
$G=6.7\times10^{-11}$ (in mks)

Orbital Paths

- Both objects in an orbital system follow ellipses with the center of mass (balance point) at one focus.
- Extending Kepler's Law #1, Newton found that ellipses were not the only orbital paths.
- possible orbital paths
  - ellipse (bound)
  - parabola (unbound)
  - hyperbola (unbound)



Centers of mass



Newton's Version of Kepler's Third Law

Using the calculus, Newton was able to derive Kepler's Third Law from his own Law of Gravity.

In its most general form:

$$P^2 = 4\pi^2 a^3 / G (m_1 + m_2)$$

If you can measure the orbital period of two objects (P) and the distance between them (a), then you can calculate the sum of the masses of both objects ($m_1 + m_2$).

Orbits

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

$$v = \sqrt{\frac{GM}{r}}$$

$$P = \frac{2\pi r}{v} = 2\pi\sqrt{\frac{r^3}{GM}}$$

Kepler's Third!

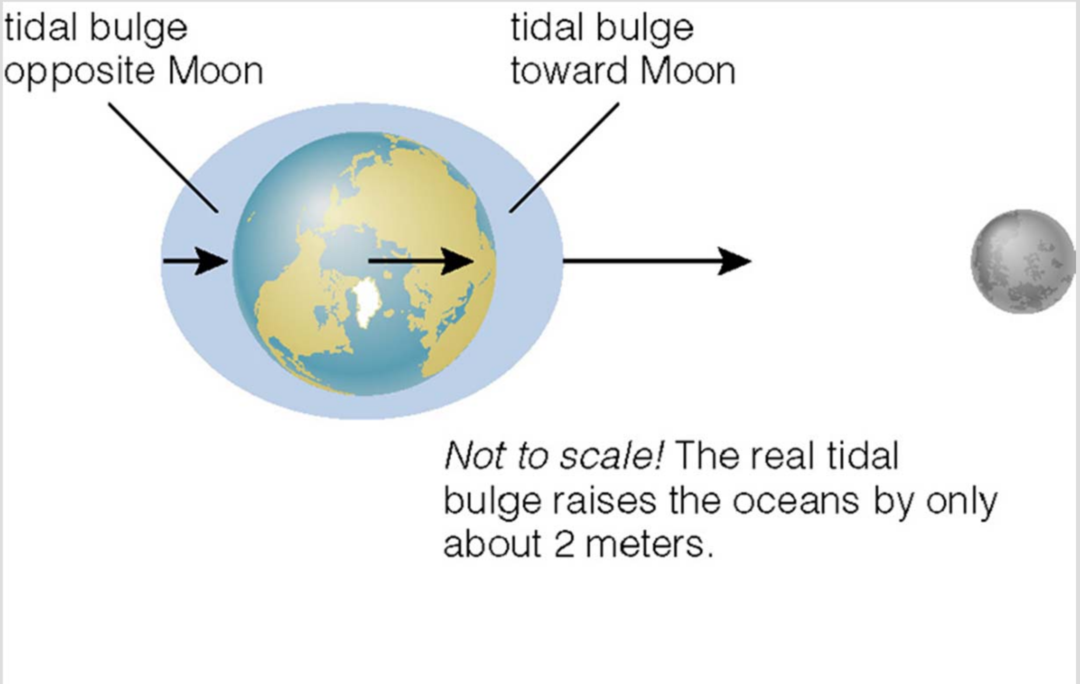
$$P^2 = \frac{4\pi^2}{GM} a^3$$

Escape Velocity

$$\frac{1}{2}mv^2 = \frac{GMm}{R}$$

$$v = \sqrt{\frac{2GM}{R}}$$

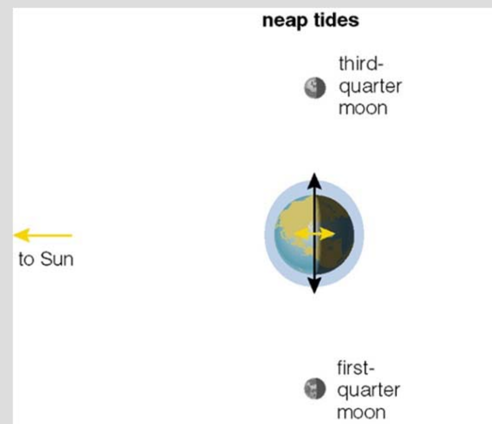
Tides

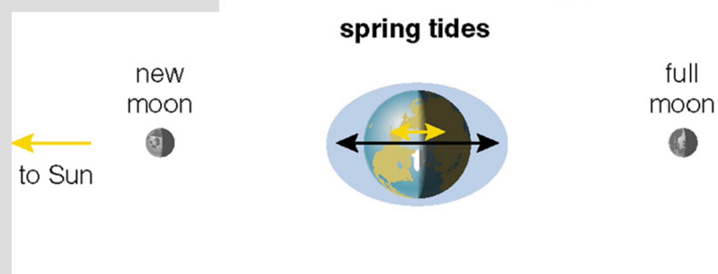


- Since gravitational force decreases with $(\text{distance})^2$, the Moon's pull on Earth is strongest on the side facing the Moon, and weakest on the opposite side.
- The Earth gets stretched along the Earth-Moon line.
- The oceans rise relative to land at these points.

Tides

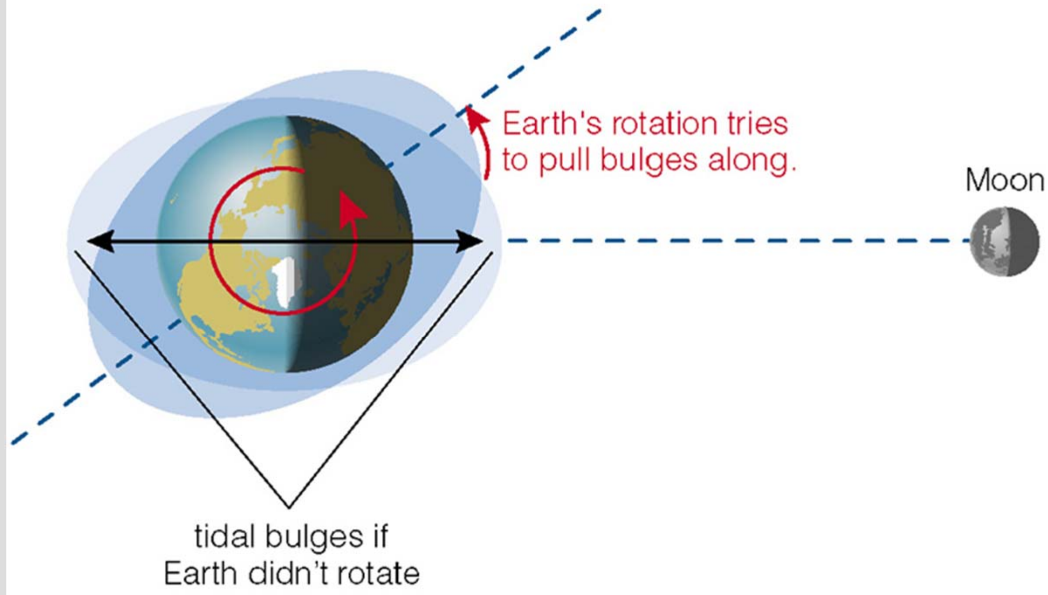
- Every place on Earth passes through these points, called **high tides**, twice per day as the Earth rotates.
- High tides occur every 12 hours 25minutes
  - remember, the Moon moves!
- The Sun's tidal effect on Earth is not as strong.
  - the ratio Earth's diameter : distance to Sun is much less than ratio Earth's diameter : distance to Moon
- When the Sun & Moon pull in the same direction (new & full phases)
  - high tide is higher than usual (**spring**)
- When the Sun & Moon pull at right angles (first & last quarter phases)
  - high tide is lower than usual (**neap**)





Tidal Friction

- This fight between Moon's pull & Earth's rotation causes friction.
- Earth's rotation slows down (1 sec every 50,000 yrs.)



- Conservation of angular momentum causes the Moon to move farther away from Earth.

Synchronous Rotation

- …is when the rotation period of a moon, planet, or star equals its orbital period about another object.
- Tidal friction on the Moon (caused by Earth) has slowed its rotation down to a period of one month.
- The Moon now rotates synchronously.
  – We always see the same side of the Moon.
- Tidal friction on the Moon has ceased since its tidal bulges are always aligned with Earth.

Changing Orbits

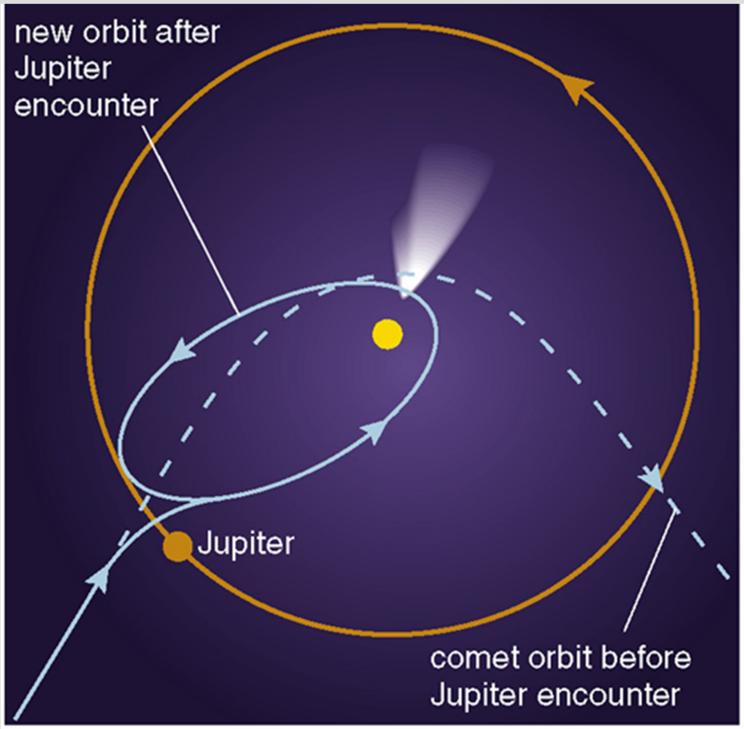
orbital energy = kinetic energy + gravitational potential energy

conservation of energy implies:

orbits can't change spontaneously

An object can't crash into a planet unless its orbit takes it there.

An orbit can only change if it gains/loses energy from another object, such as a gravitational encounter:



If an object gains enough energy so that its new orbit is unbound, we say that it has reached **escape velocity**.