Planetary Motion

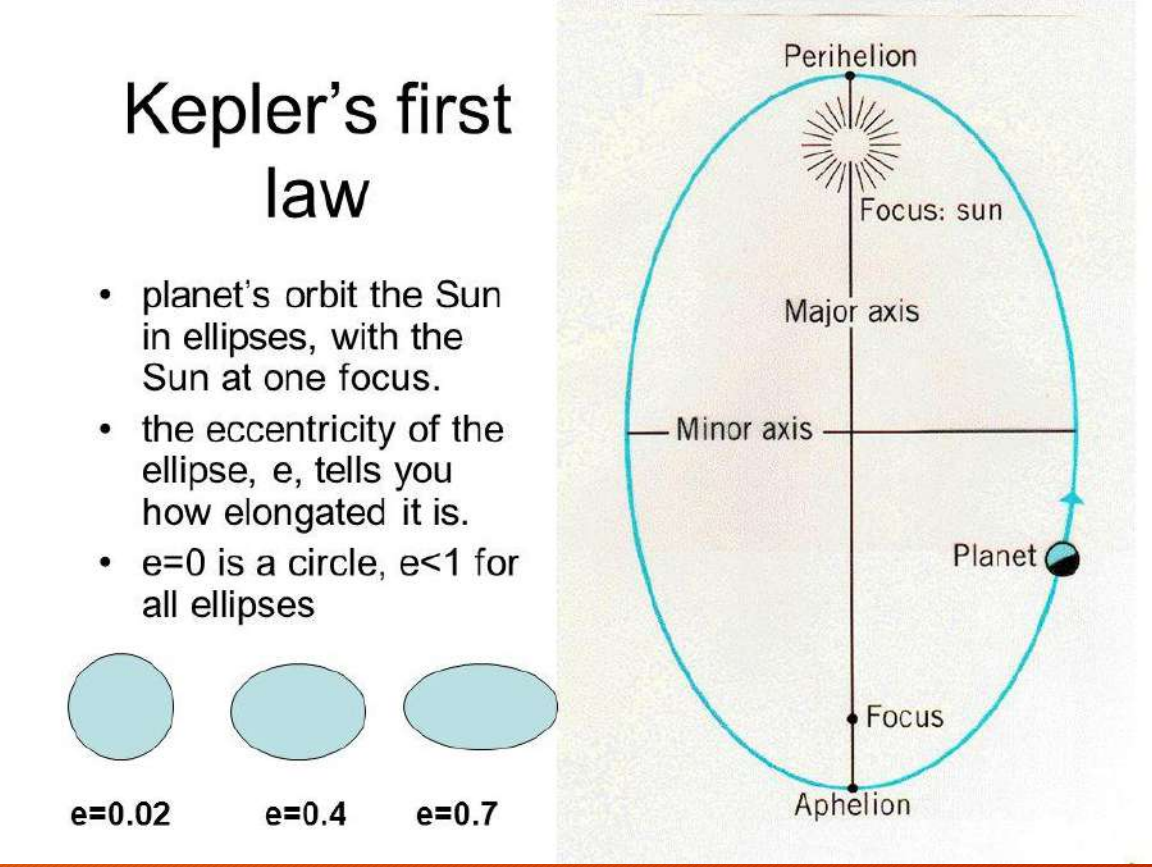
Laws of Planetary Motion

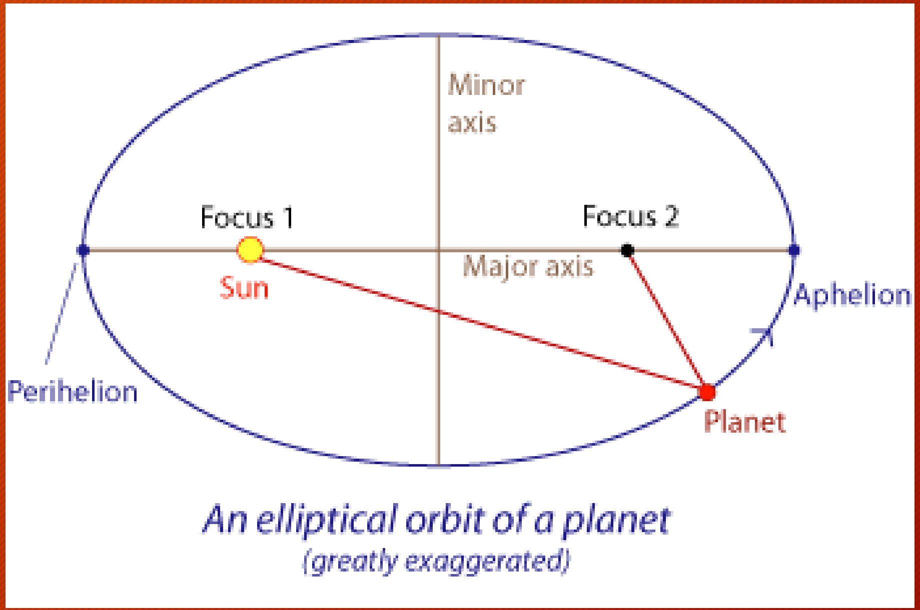
- In the early 1600s, Johannes Kepler proposed three laws of planetary motion.
- Three statements that described the motion of planets in a sun-centered solar system.
- Law of Ellipses
- Law of Equal Areas
- Law of Harmonies
- video clip Voyager

Keplar’s First Law

- Law of Ellipses
- The path of the planets about the sun is elliptical in shape.
- The center of the sun being located at one focus
- An ellipse is a special curve in which the sum of the distances from every point on the curve to two other points is a constant.
- The other two points are known as the **foci** (focus) of the ellipse.
- The closer together that these points are, the more closely that the ellipse resembles the shape of a circle.

Keplar's First Law





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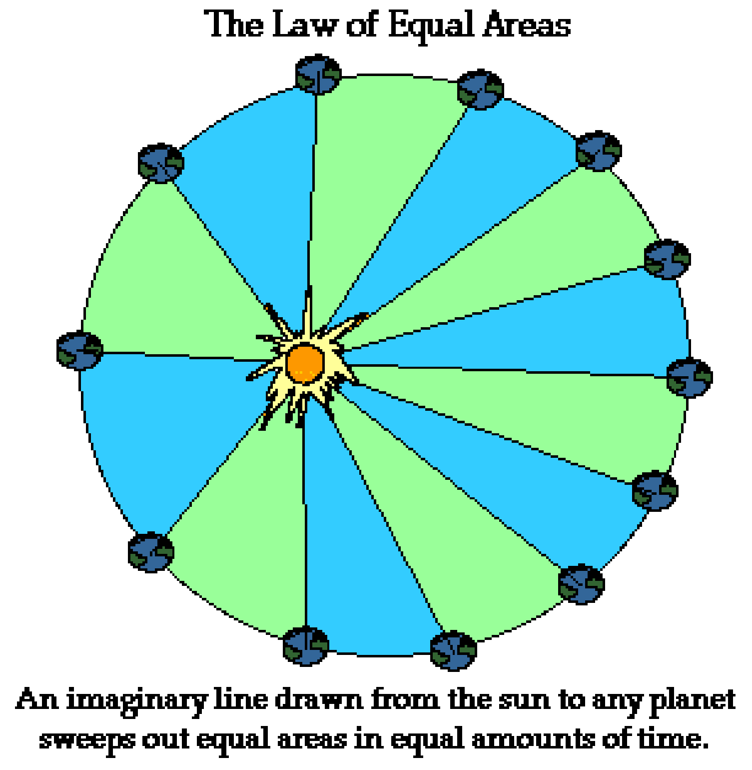
Keplar's Second Law

- Law of Equal Areas
- Describes the speed at which any given planet will move while orbiting the sun.
- The speed at which any planet moves through space is constantly changing.
- A planet moves fastest when it is closest to the sun and slowest when it is furthest from the sun.
- Yet, if an imaginary line were drawn from the center of the planet to the center of the sun, that line would sweep out the same area in equal periods of time.
- The **aphelion** is the point in the orbit of an object where it is farthest from the Sun.
- The point in orbit where an object is nearest to the sun is called the **perihelion**.

Keplar's Second Law

- The areas formed when the earth is closest to the sun can be approximated as a wide but short triangle; whereas the areas formed when the earth is farthest from the sun can be approximated as a narrow but long triangle. These areas are the same size.
- Since the *base* of these triangles are shortest when the earth is farthest from the sun, the earth would have to be moving more slowly in order for this imaginary area to be the same size as when the earth is closest to the sun.



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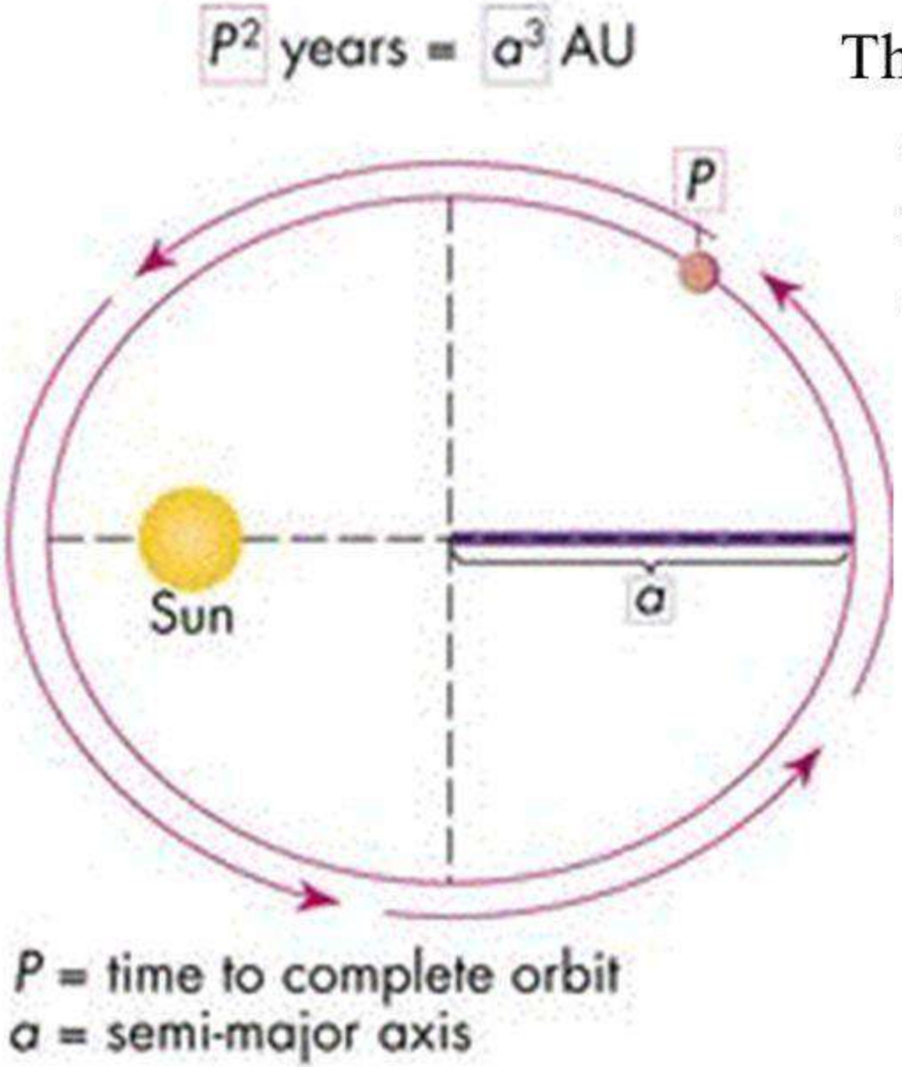
Keplar’s Third Law

- The Law of Harmonies
- Compares the orbital period and radius of orbit of a planet to those of other planets.
- A comparison between the motion characteristics of different planets.
- The comparison being made is that the ratio of the squares of the periods to the cubes of their average distances from the sun is the same for every one of the planets.
- Additionally, the same law that describes the T^2/R^3 ratio for the planets' orbits about the sun also accurately describes the T^2/R^3 ratio for any satellite (whether a moon or a man-made satellite) about any planet.
- clip. Third Law Clip

Kepler's Third Law of Planetary Motion

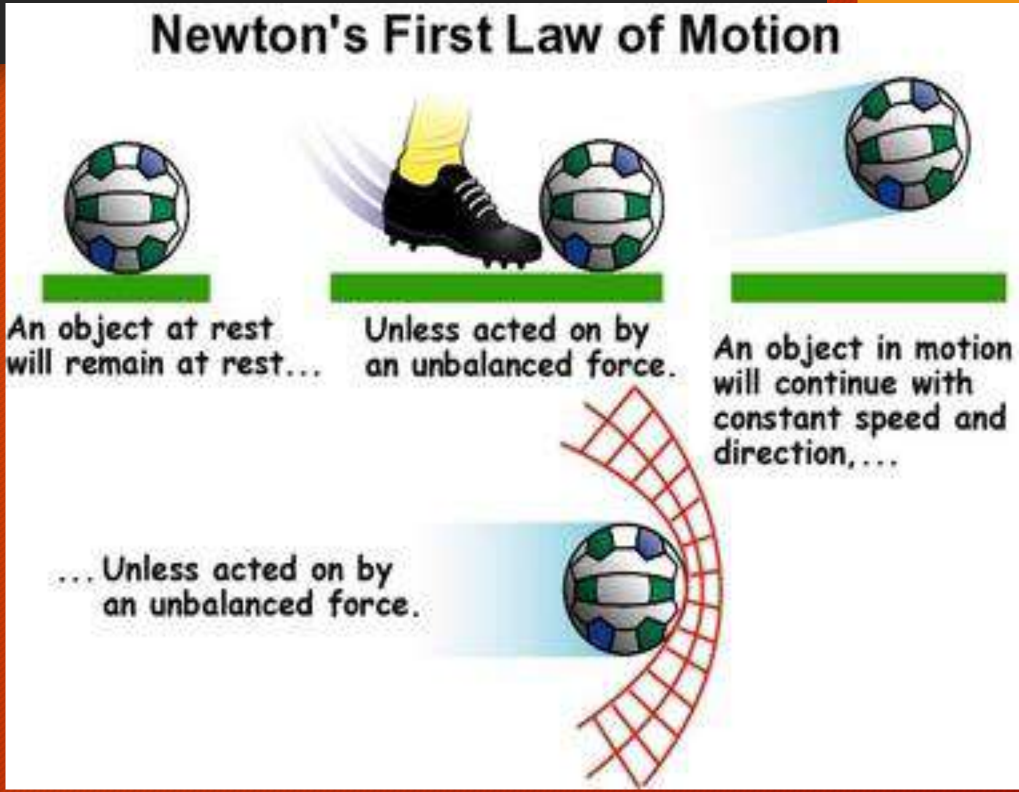


The amount of time it takes a planet to orbit the Sun is related to the size of its orbit by $P^2(\text{years}) = a^3(\text{AU})$

- 1 AU (astronomical unit) is the semimajor axis of the Earth's orbit. <u>Earth's average distance from the Sun.</u>
- It doesn't matter how elliptical the orbit as long as the average distance is the same

Newton’s First Law of Motion

- Law of Inertia
- An object at rest remains at rest and an object in motion maintains its velocity unless it experiences an unbalanced force.
- **Inertia**: the tendency of an object at rest to remain at rest or continue moving with a constant velocity.
- Voyager video.



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Newton’s Second Law of Motion

- The unbalanced force acting on an object equals the objects’s mass times its acceleration.
- Force = mass x acceleration **F= ma**
- Measured in Newtons
- **Force**: the cause of acceleration or change in an object’s velocity.
- **Net Force**: combination of all of the forces acting on an object. If net force is zero – no acceleration. Objects accelerate in the direction of the net force.

Newton's Second Law

- **Balanced forces:** cancel each other. The combined force = 0
- Net Force = 0
- **Unbalanced forces:** Combined forces acting on an object to produce a net force = 0
- The net force will cause the object to accelerate.
- **Acceleration:** any change in velocity.

Newton's Third Law

- Law of Action and Reaction
- For every action force, there is an equal and opposite reaction force.
- Forces are equal and opposite, but not balanced because two different objects are involved.
- Some forces result from *contact interactions* (normal, frictional, tensional, and applied forces are examples of contact forces) and other forces are the result of action-at-a-distance interactions (gravitational, electrical, and magnetic forces).
- **Friction**: the force between 2 objects in contact that opposes the motion of either object.
- Hidden Figures Video Clip

Newton’s Third Law

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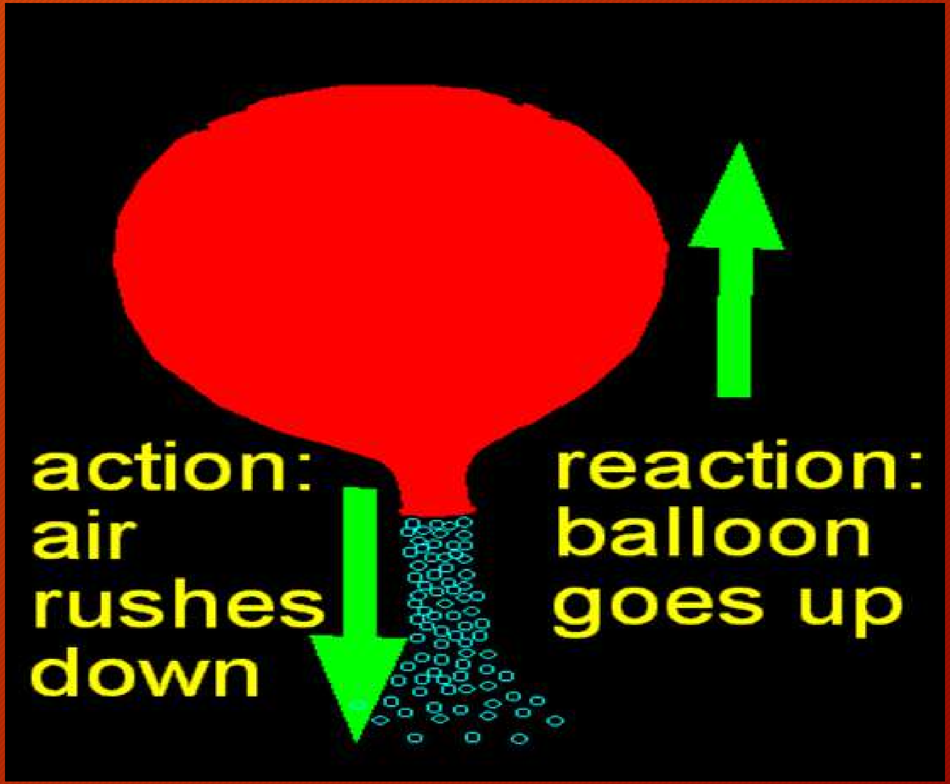

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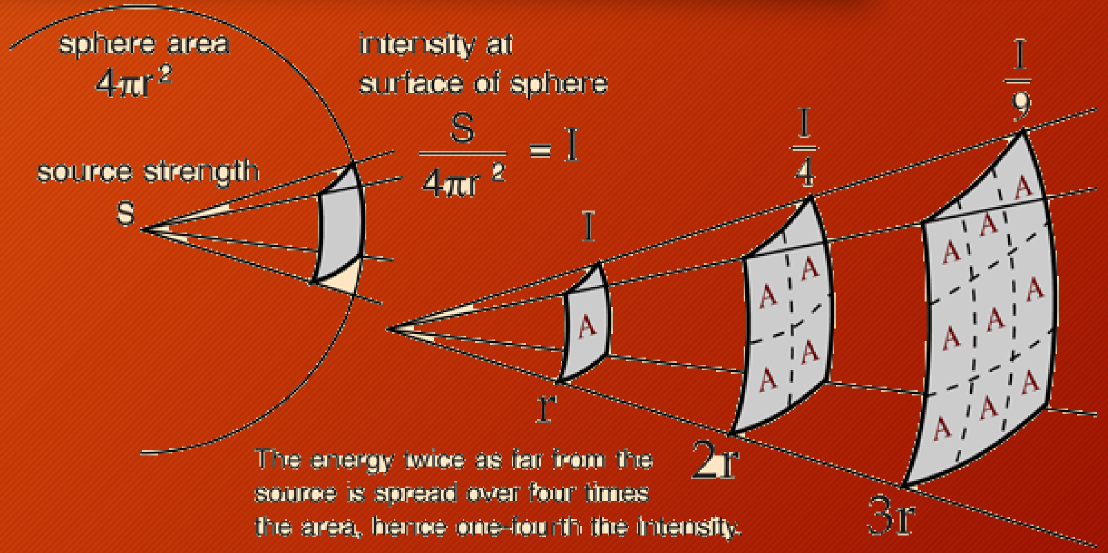
Inverse Square Law

- A principle that expresses the way radiant energy propagates through space.
- The rule states that the power intensity per unit area from a point source, if the rays strike the surface at a right angle, varies inversely according to the square of the distance from the source.
- For gravity and electromagnetic forces spreading out in a complete sphere, the area of the sphere increases with the square of the radius of the sphere.
- The intensity decreases as the inverse square of the radius.
- image



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Mass, Weight and Gravity

- **Mass**: the amount of matter in an object
- **Weight**: the gravitational force an object experiences due to its mass.
- **Gravity**: the attraction between two particles of matter due to their mass.
- Force of gravity depends on objects' mass and distance between the two objects.
- The gravitational force between 2 objects is proportional to the product of their masses.
- The greater the mass of an object, the larger the gravitational force exerts on other objects.
- Video Different masses
- NYU's interactive

Gravitational Force – Newton's Law of Universal Gravitation

- **ALL** objects attract each other with a force of gravitational attraction. Gravity is universal. This force of gravitational attraction is directly dependent upon the masses of both objects and inversely proportional to the square of the distance that separates their centers.
- Since the gravitational force is directly proportional to the mass of both interacting objects, more massive objects will attract each other with a greater gravitational force. So as the mass of either object increases, the force of gravitational attraction between them also increases.
- Since gravitational force is inversely proportional to the square of the separation distance between the two interacting objects, more separation distance will result in weaker gravitational forces. So as two objects are separated from each other, the force of gravitational attraction between them also decreases
- gravitational force and velocity vectors

Law of Universal Gravitation

- m_1 = mass of first object
- m_2 = mass of second object
- d^2 = distance representing objects centers
- Equation results in the units of force – newtons

$$F_{grav} = \frac{(6.673 \times 10^{-11}\ N\ m^2/kg^2)\cdot(5.98 \times 10^{24}\ kg)\cdot(70\ kg)}{(6.38 \times 10^{6}\ m)^2}$$

$$F_{grav} = 686\ N$$

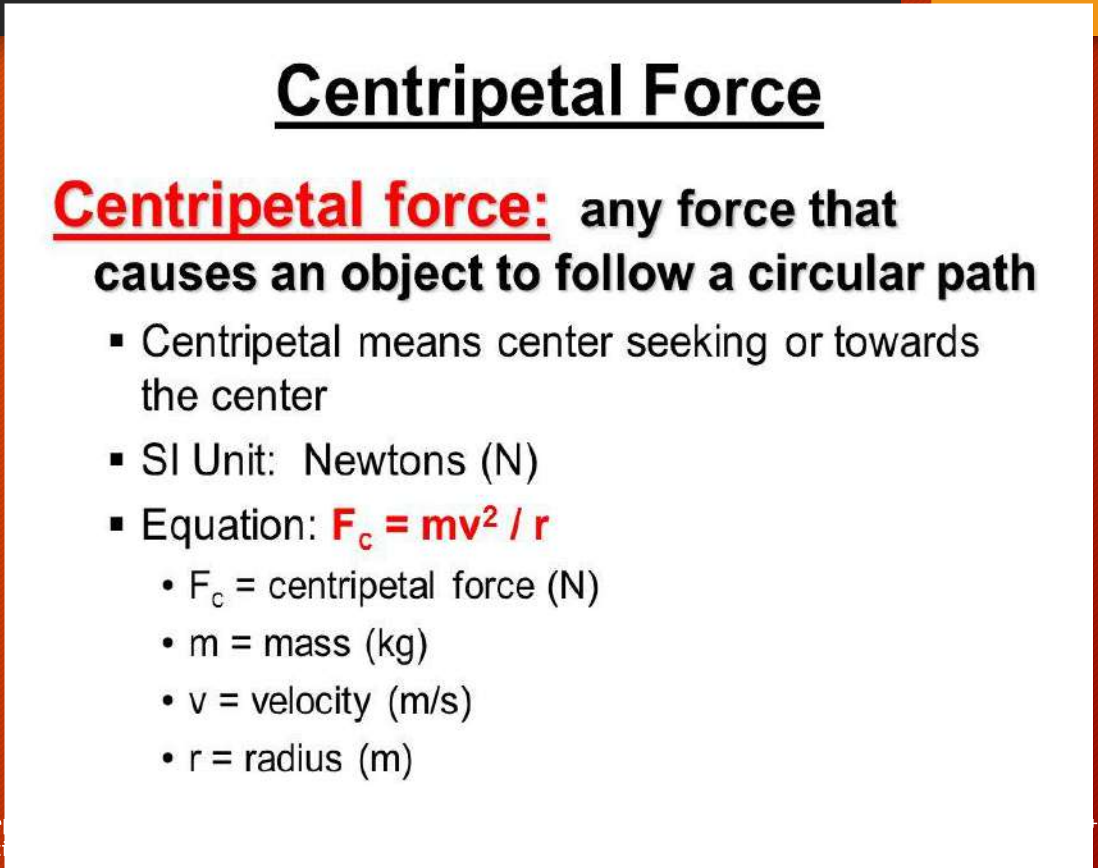
$$F_{grav} = \frac{G * m_1 * m_2}{d^2}$$

where G represents the universal gravitation constant

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

Centripetal Force

- Any force that pulls or pushes an object toward the center of the circle.
- For object's moving in circular motion, there is a net force acting towards the center which causes the object to *seek* the center.
- The presence of an unbalanced force is required for objects to move in circles.



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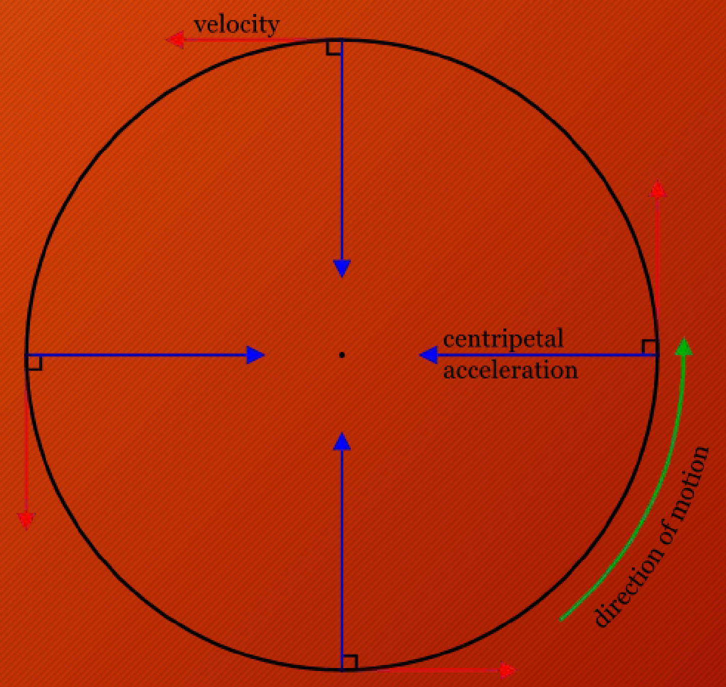
Uniform Circular Motion

- The motion of an object in a circle at a constant speed.
- As an object moves in a circle, it is constantly changing its direction.
- An object undergoing uniform circular motion is moving with a constant speed.
- Nonetheless, it is accelerating due to its change in direction. The direction of the acceleration is inwards.
- The net force acting upon such an object is directed towards the center of the circle. The net force is said to be an inward or ***centripetal* force**.



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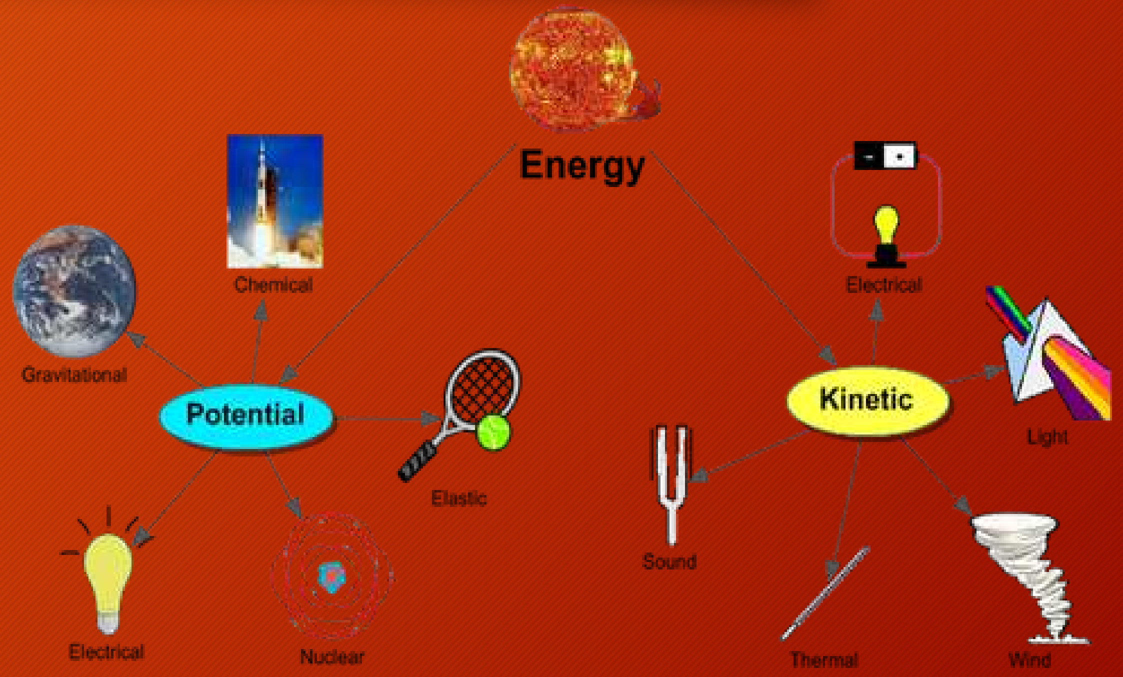
Potential Energy

- Stored energy or energy held in readiness.
- **Elastic:** energy stored in any type of stretched or compressed material.
- **Gravitational:** stored energy that depends on height and mass. Effected more by height.
- P.E. = Mass x 9.8m/s^2 x height
- SI Unit = Joule
- video Energy Examples



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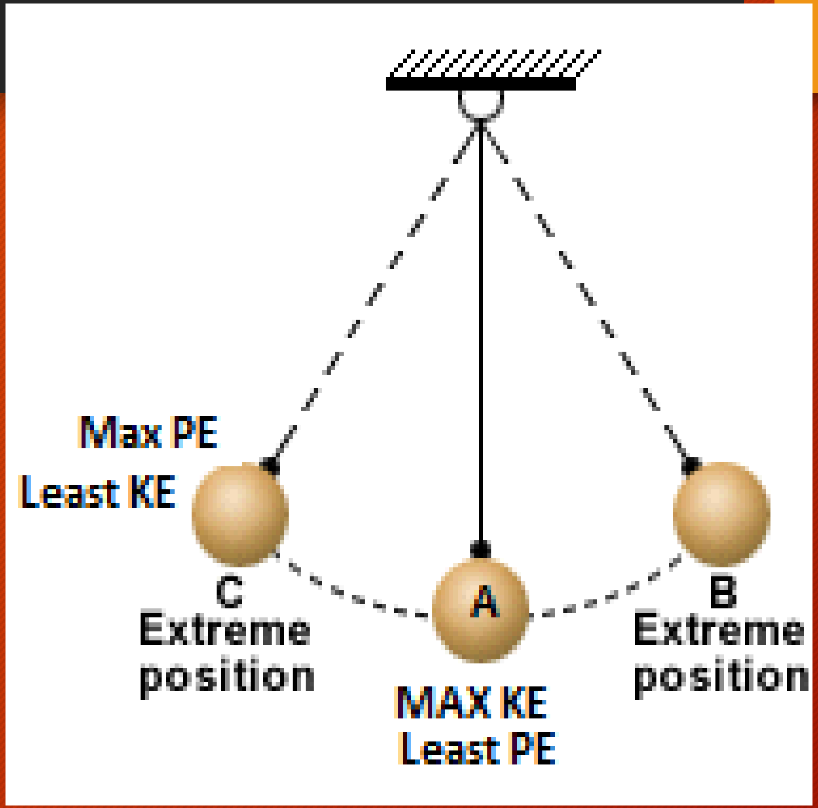
Kinetic Energy

- Energy that an object has because its in motion.
- Depends on mass and velocity.
- Kinetic Energy = Mass x Velocity^2/2
- SI Unit: 1 Joule
- Depends on velocity more than mass.
- Small increase in velocity = a large increase in energy.



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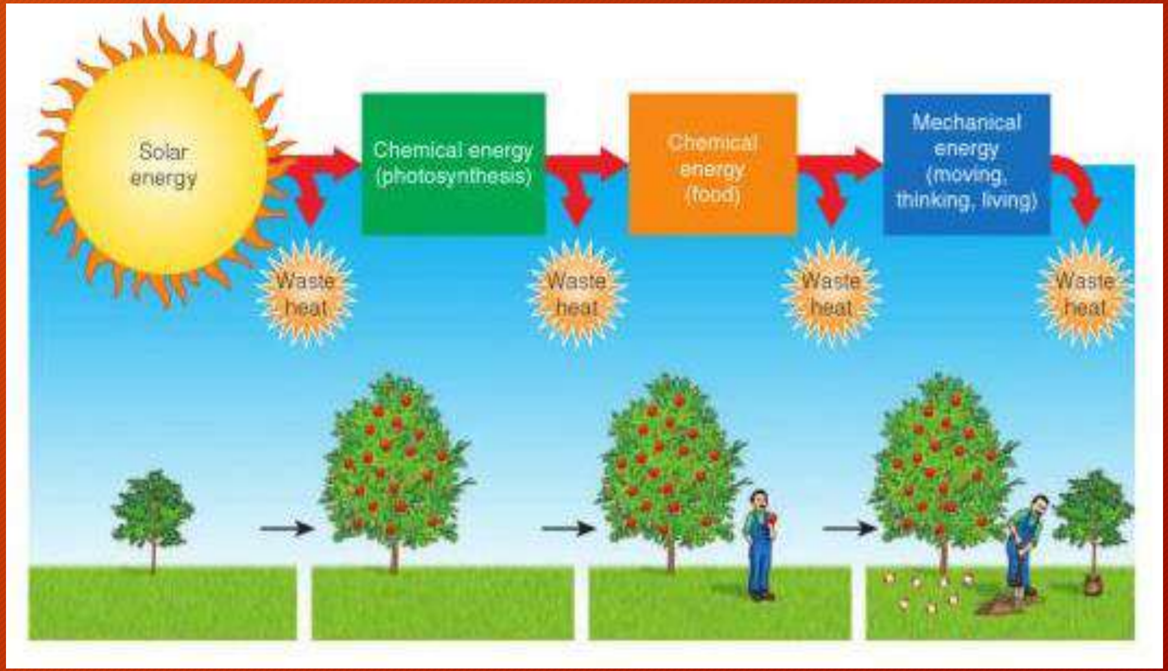
Law of Conservation of Energy

- Energy cannot be created or destroyed.
- Energy can be transferred.
- Energy Conversions: Energy transfers or changes form to another type of energy.
- Total energy in the system stays the same
- **Closed**: flow of energy in a system is small enough to be ignored
- **Open**: exchange energy with the outside. Example - Earth



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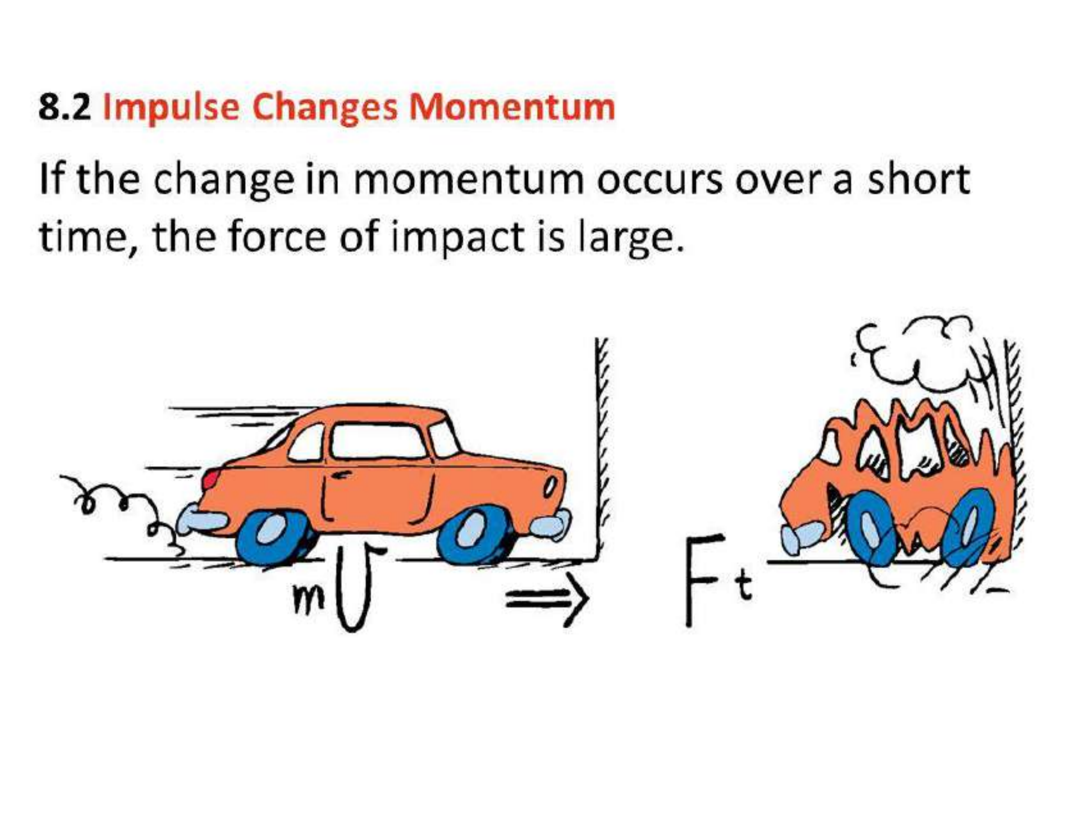
Momentum

- A quantity defined as the product of an object's mass and its velocity.
- An object's momentum is in the same direction as its velocity.
- Momentum = mass x velocity
- **P = mv**
- The SI unit is kg*m/s
- **Law of Conservation of Momentum**: the total amount of momentum in a system is conserved.



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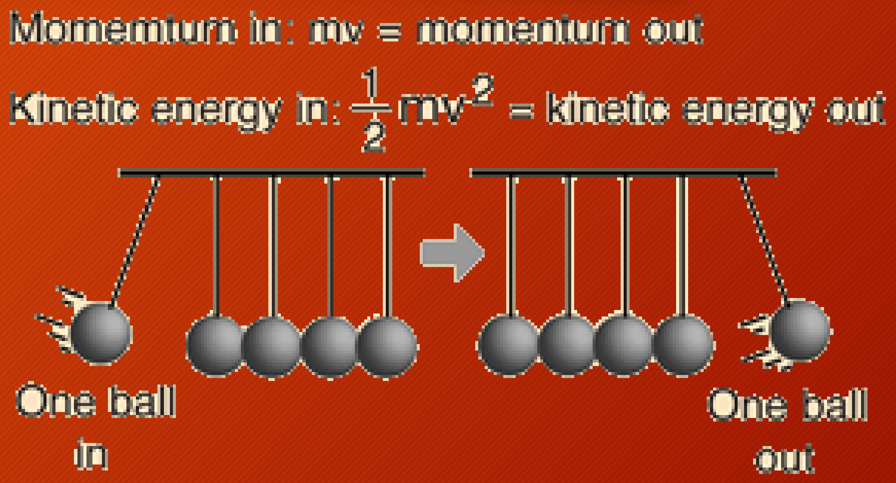
Magnitude of Collisions

- In a collision, a force acts upon an object for a given amount of time to change the object's velocity. The product of force and time is known as **impulse**. The product of mass and velocity change is known as **momentum change**. In a collision the impulse encountered by an object is equal to the momentum change it experiences.
- Momentum is conserved in all collisions. If the objects collide and momentum and kinetic energy of the objects are conserved than we call this collision "**elastic *collision***". On the other hand if the momentum of the object is conserved but kinetic energy is not conserved than we call this type of collision "**inelastic *collision***".
- series of car crashes

Elastic Collisions

- Elastic collisions are collisions in which both momentum and kinetic energy are conserved. The total system kinetic energy before the collision equals the total system kinetic energy after the collision.



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Inelastic Collisions

- If total kinetic energy is not conserved, then the collision is referred to as an inelastic collision.
- A large portion of the kinetic energy is converted to other forms of energy such as sound energy and thermal energy etc..

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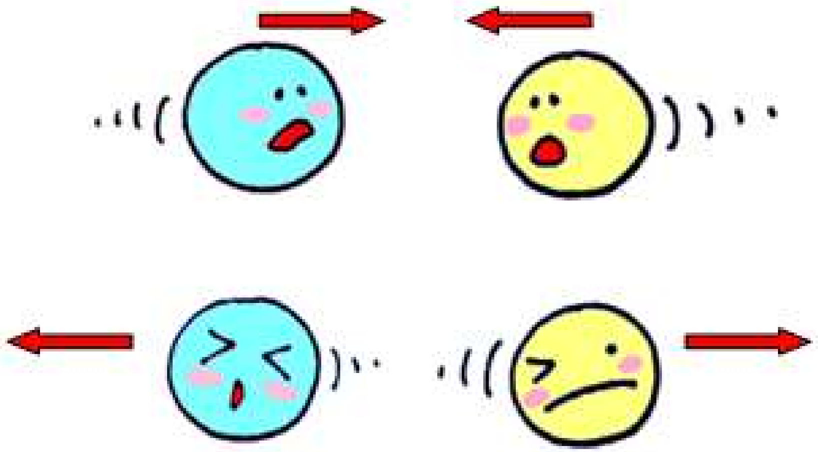
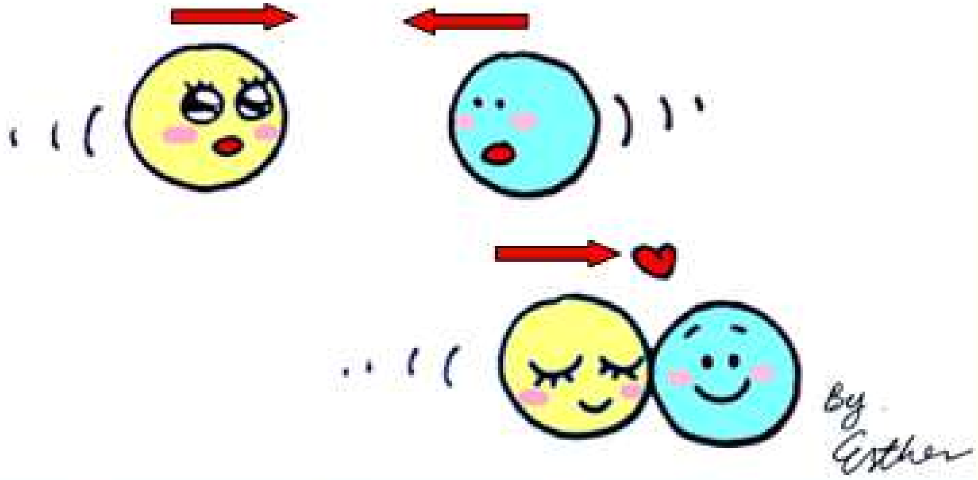
There are two kinds of collision:

Elastic collision	**Inelastic collision**
	
Objects that collide move **separately** after collision.	Objects that collide move **together** after collision.
Total momentum and **total energy** of the system are **conserved.**	
Kinetic energy is conserved.	**Kinetic energy** is NOT conserved.

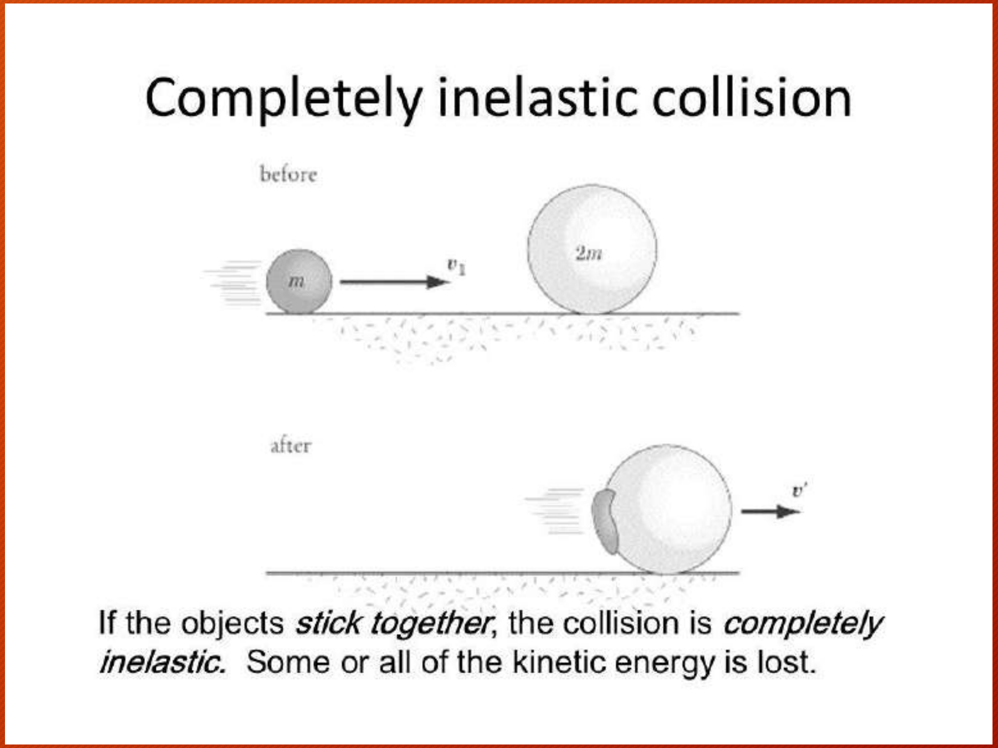
Test Your Understanding

Is the collision between the bird and the ball elastic or inelastic?

Perfectly Inelastic Collisions

- A **perfectly inelastic collision** is one in which the maximum amount of kinetic energy has been lost during a collision, making it the most extreme case of an inelastic collision.

- In most cases, you can tell a perfectly inelastic collision because of the objects in the collision "stick" together
- demonstration



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