

Momentum

AP Physics

Momentum

- Can be calculated with $p = mv$
- Units are $\frac{kg \cdot m}{s}$
- or $N \cdot s$
- ***Momentum is a vector***

$$p_x = mv_x \quad p_y = mv_y$$

ex

- What is the momentum possessed by a car with a mass of 2 350 kg if it is traveling at 125 km/h?
 - The velocity must be expressed in units of m/s, so we do the conversion

$$125 \frac{\cancel{\text{km}}}{\cancel{\text{h}}} \left(\frac{1 \cancel{\text{h}}}{3600 \text{ s}} \right) \left(\frac{1000 \text{ m}}{1 \cancel{\text{km}}} \right) = 34.72 \text{ m/s}$$

$$p = mv \quad p = 2350 \text{ kg} \left(34.72 \frac{\text{m}}{\text{s}} \right)$$

- $p = 81\,600 \text{ kg m/s}$

Newton's 2nd Law

- $F = ma$
- Can also be expressed as

$$F = \frac{\text{change in momentum}}{\text{time interval}} \qquad F = \frac{\Delta p}{\Delta t}$$

$$F = \frac{\Delta p}{\Delta t} = \frac{mv_f - mv_i}{\Delta t} = \frac{m(v_f - v_i)}{\Delta t}$$

Impulse

- Impulse-Momentum Theorem

$$F \Delta t = \text{Impulse}$$

$$F \Delta t = \Delta p$$

- Impulse changes Momentum
 - *(because force causes acceleration)*

Chicken feather/boulder problem

- You (mass = 55 kg) run into boulder at 8.0 m/s. You stop in 0.010 s. What force acts on you?

$$F \Delta t = m(v_f - v_i)$$

$$F = \frac{m(v_f - v_i)}{t}$$

$$F = 55 \text{ kg} \left(0 - 8.0 \frac{\text{m}}{\text{s}} \right) \frac{1}{0.010 \text{ s}}$$

$$F = 44\,000 \text{ N}$$

- Now you run into a haystack, it takes 3.5 s to stop. What force acts?

$$F = 55 \text{ kg} \left(0 - 8.0 \frac{\text{m}}{\text{s}} \right) \frac{1}{3.5 \text{ s}}$$

$$F = 130 \text{ N}$$

- Hw #1
- Don't forget from last section
- $KE = \frac{1}{2} mv^2$
- $PE_g = mgh$

Conservation of Momentum

Elastic & Inelastic Collisions

Collision types

- Elastic – Objects collide without being permanently deformed and without generating heat.
 - Objects bounce perfectly in elastic collisions
- Perfectly Inelastic – Colliding objects get tangled and coupled together.
- Inelastic – objects deform during collisions, but move separately after collision
- ***Elastic collision \equiv kinetic energy is conserved***
- ***Perfectly inelastic collision \equiv object stick together and have same velocity.***
- ***Inelastic collision \equiv kinetic energy is not conserved***

p in collisions

- Momentum is Conserved in all collisions in isolated system -- no external forces acting

$$m_1 v_{1i} + m_2 v_{2i} = m_1 v_{1f} + m_2 v_{2f}$$

- Or, Momentum before = momentum after

$$p_i = p_f$$

Ex

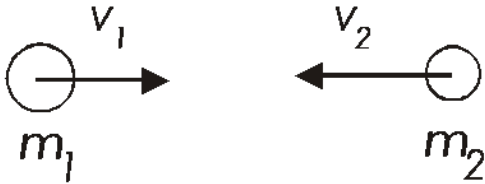
- 15 000 kg Railroad car moving at 2.5 m/s collides and couples with stationary 12 500 kg car. What is new velocity of the two cars?

$$v_f = 1.4 \frac{m}{s}$$

- 2 mud balls collide in a perfectly elastic collision. One has a mass of 4.0 kg, the second has a mass of 3.5 kg. The first one has a velocity of 3.4 m/s, the second has a velocity of -4.8 m/s. What is their velocity after the collision?

$$v_f = -0.43 \frac{m}{s}$$

Head on Collisions



- Momentum and KE are conserved

- Simplifying eqns gives us

$$v_{1i} - v_{2i} = -(v_{1f} - v_{2f})$$

$$m_1 (v_{1i} - v_{1f}) = m_2 (v_{2f} - v_{2i})$$

$$m_1 v_{1i} + m_2 v_{2i} = m_1 v_{1f} + m_2 v_{2f}$$

$$\frac{1}{2} m_1 v_{1i}^2 + \frac{1}{2} m_2 v_{2i}^2 = \frac{1}{2} m_1 v_{1f}^2 + \frac{1}{2} m_2 v_{2f}^2$$

Ex

$$v_1 = 4.75 \text{ m/s}$$



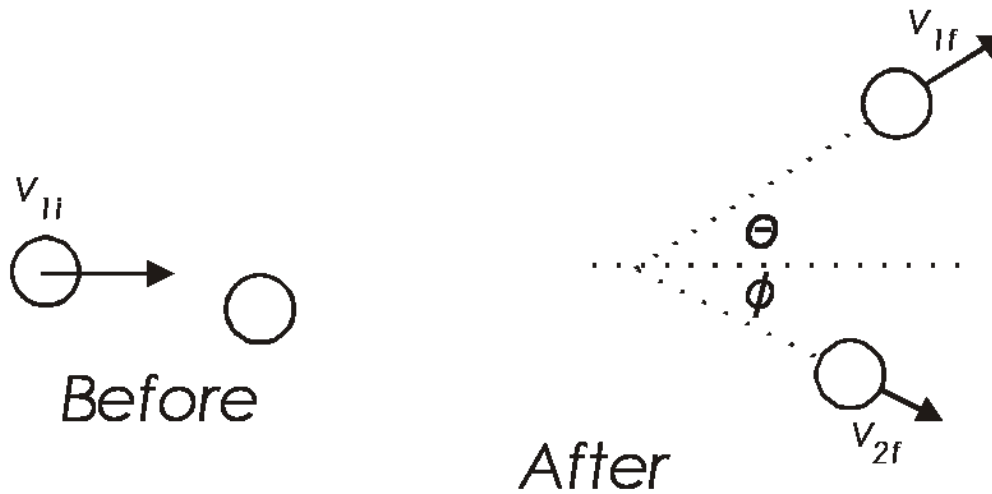
$$m_1 = 2.50 \text{ kg}$$

$$v_2 = 8.60 \text{ m/s}$$



$$m_2 = 2.85 \text{ kg}$$

Glancing collisions

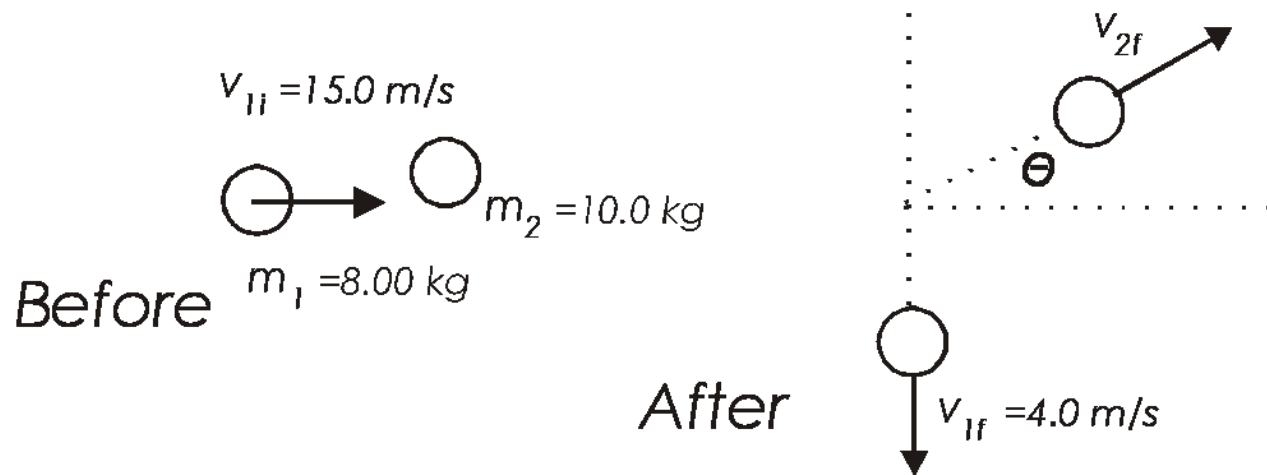


$$\sum p_{ix} = \sum p_{fx}$$

$$\sum p_{iy} = \sum p_{fy}$$

Ex

- An 8.00 kg mass moving east at 15.0 m/s strikes a 10.0 kg mass that is at rest. The 8.00 kg mass ends up going south at 4.00 m/s. What is the velocity of the second ball? What percent of the KE is lost in the collision?



V_{2f}

$$p_{ix} = p_{fx} \quad m_1 v_{1ix} + m_2 v_{2ix} = \cancel{m_1 v_{1fx}} + m_2 v_{2fx} \quad m_1 v_{1i} = m_2 v_{2x}$$

- $$v_{2x} = \frac{m_1 v_{1i}}{m_2} \quad v_{2x} = 8.00 \text{ kg} \left(15.0 \frac{\text{m}}{\text{s}} \right) \left(\frac{1}{10.0 \text{ kg}} \right) = 12 \text{ m/s}$$

$$p_{iy} = p_{fy} \quad \cancel{m_1 v_{1iy}} + \cancel{m_2 v_{2iy}} = m_1 v_{1fy} + m_2 v_{2fy} \quad m_2 v_{2fy} = -m_1 v_{1fy}$$

$$v_{2fy} = \frac{-m_1 v_{1fy}}{m_2} \quad v_{2fy} = 3.20 \frac{\text{m}}{\text{s}}$$

- $$\text{Pythagorean thrm} \rightarrow v_2 = 12.4 \frac{\text{m}}{\text{s}}$$

- Hw #4

AP Question

- Two identical objects A and B of mass M move on a one-dimensional, horizontal air track. Object B initially moves to the right with speed v_0 . Object A initially moves to the right with speed $3v_0$, so that it collides with object B. Friction is negligible. Express your answers to the following in terms of M and v_0 .
- a. Determine the total momentum of the system of the two objects.
- b. A student predicts that the collision will be totally inelastic (the objects stick together on collision). Assuming this is true, determine the following for the two objects immediately after the collision.
 - i. The speed
 - ii. The direction of motion (left or right)
- When the experiment is performed, the student is surprised to observe that the objects separate after the collision and that object B subsequently moves to the right with a speed $2.5v_0$.
- c. Determine the following for object A immediately after the collision.
 - i. The speed
 - ii. The direction of motion (left or right)
- d. Determine the kinetic energy dissipated in the actual experiment