Momentum and Collisions

AP Physics
Unit 5

Learning Goals:
Momentum and Collisions

- Define the linear momentum of an object and explain how it differs from KE
- Explain the conditions under which the total momentum of a system is constant and why total momentum is constant in a collision
- Identify the differences and similarities between elastic, inelastic, and completely inelastic collisions
- Apply conservation of momentum and ME to problems involving elastic collisions

Formula's on AP Equation Sheet

- **p = mv** momentum w/ mass & velocity
  momentum is a Vector!!
- **Δp =FΔt** momentum w/ force & time

Exam Tip:

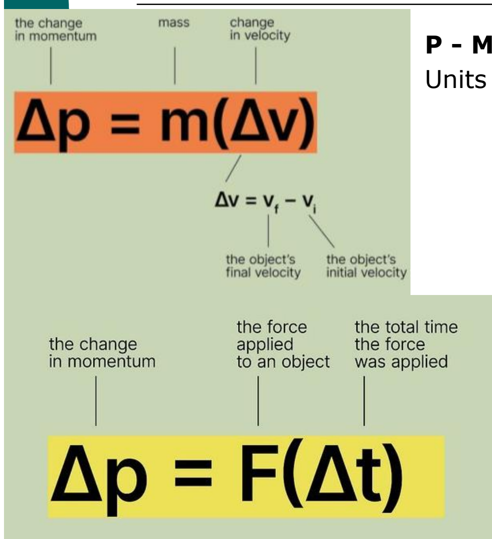
Momentum - lower case p

Power - capital P

Momentum

- **Momentum (p)** can be defined as "mass in motion." All objects have mass; so if an object is moving, then it has momentum
  - **Vector Quantity** that depends on objects:
    - Speed
    - Mass
    - Direction of motion
  - Momentum is constant if there are no unbalanced forces acting on your defined system
- **When to use:**
  - Collisions
  - Whenis a force being applied over some time interval
  - Discussing a systems center of mass

Momentum – AP formulas



P - Momentum
Units – Kg m/s

F is ΣF_{net}

- This means if the next force is zero, the change in momentum is zero
- Momentum Conserved!!

Momentum vs KE

- **Momentum** depends on Velocity
  - **Vector**
- **KE** depends on speed
  - **Scalar**

Can smaller objects ever have as much momentum as a large object?

Yes, but smaller mass object has to move with a higher velocity

Conservation of Momentum

When a collision occurs in an isolated system, the total momentum of the system is conserved - both in magnitude and direction.

"Isolated system" means there's no external net force acting on the system –

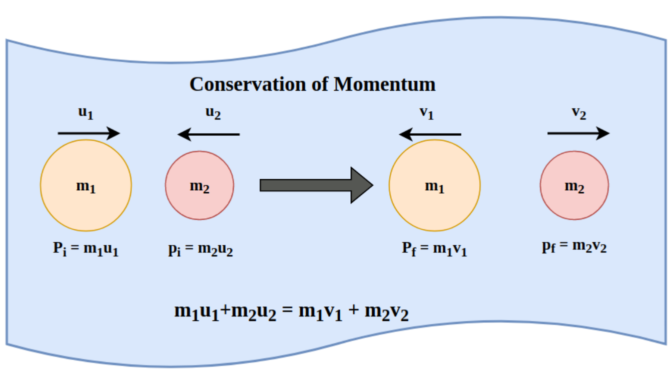
- *Example:* carts and tracks, momentum is conserved as long as friction is negligible.

Like with energy conservation, total momentum is conserved in a collision, but momentum can be transferred from one object to another within the system.

Conservation of Momentum

$$m_1\mathbf{v}_{1,i} + m_2\mathbf{v}_{2,i} = m_1\mathbf{v}_{1,f} + m_2\mathbf{v}_{2,f}$$

total initial momentum = total final momentum



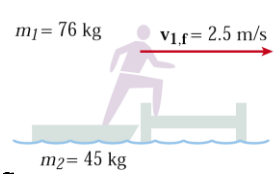
Conservation of Momentum

- IF the next external force exerted on a system is zero, the **total momentum of the system** is constant
- $\mathbf{p}_{total,f} = \mathbf{p}_{total,i}$
- Change in Momentum also equal to
- $\mathbf{\Delta p = mV_f - mV_i}$

Conservation of Momentum Problem

Example: *A 76 kg boater, initially at rest in a stationary 45 kg boat, steps out of the boat and onto the dock. If the boater moves out of the boat with a velocity of 2.5 m/s to the right, what is the final velocity of the boat?*

Diagram:



Given:

<u>Man</u>	<u>Boat</u>
m_{man} = 76 kg	m_{Boat} = 45 kg
$v_{man,i}$ = 0	$v_{Boat,i}$ = 0
$v_{man,f}$ = 2.5 m/s (right)	$v_{Boat,f}$ = ?

Conservation of Momentum Problem

Both man and Boat start from rest

Soln:

$$m_{man}\cancelto{0}{V_{man,i}} + m_{Boat}\cancelto{0}{V_{Boat,i}} = m_{man}V_{man,f} + m_{Boat}\mathbf{V}_{\mathbf{Boat,f}}$$

$$m_{Boat}\mathbf{V}_{\mathbf{Boat,f}} =- m_{man}V_{man,f}$$

$$\mathbf{V}_{\mathbf{Boat,f}} =- (m_{man}/ m_{Boat})\ V_{man,f}$$

$$\mathbf{V}_{\mathbf{Boat,f}} =- (76kg\ /\ 45kg\ )\ (2.5\ m/s)$$

$$\boxed{\mathbf{V}_{\mathbf{Boat,f}} =- 4.2\ m/s \quad \text{or } 4.2\ m/s \text{ to the left}}$$

Impulse

IMPULSE (J) is a measure of how much force is applied for how much time, and it's equal to the change in momentum.

or

- Is the change in momentum, and results from force acting over a period of time

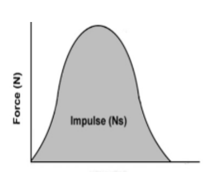
$$\mathbf{F\Delta t = m\Delta v}$$

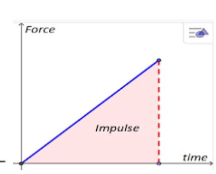
Impulse   **Momentum**

Impulse

- $J = F\ \Delta t$
- Units: N·s

Impulse = Area under F vs t graph





Impulse – Momentum Theorem

- The impulse due to all forces acting on an object (the net force) is equal to the change in momentum of the object:

$$\mathbf{F}\Delta t = \Delta\mathbf{p} = m\mathbf{v_f} - m\mathbf{v_i}$$

Impulse **Momentum**

- Explains follow through in sports:
  - longer contact → greater change in momentum
- Force is reduced when the time interval of an impact is increased

Impulse – Momentum Example

A 1.3 kg ball is coming straight at a 75 kg soccer player at 13 m/s who kicks it in the exact opposite direction at 22 m/s with an average force of 1200 N. How long are his foot and the ball in contact?

answer:

$F_{net}\, t = \Delta p.$

$\Delta p = m \Delta v = m (v_f - v_0)$ Since the ball changes direction

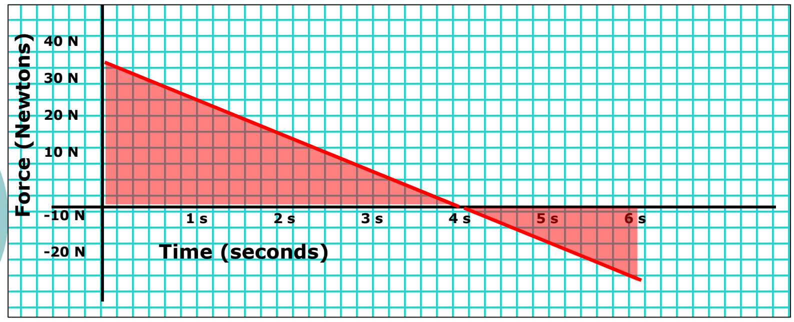
$\Delta p = 1.3\text{kg} [22\text{m/s} - (-13\text{m/s})]$

$\Delta p = 46 \text{ kg·m /s}$

$(1200\text{N})\ t = 46 \text{ kg·m /s.}$

$t = 0.038 \text{ s}$

During this contact time the ball compresses substantially and then decompresses. This happens too quickly for us to see, though. This compression occurs in many cases, such as hitting a baseball or golf ball.



If the object has a mass of 2.0 kg, what was the object's change in momentum? velocity?

$\vec{p} = m\Delta\vec{v} = \vec{F}\Delta t$

Δp =FΔt

$\Delta\vec{v} = \vec{F}\Delta t/\boldsymbol{m}$

Impulse = F·t

Impulse = Area under F·t

$$\Delta\vec{v} = \frac{\mathbf{60\ N \cdot \boldsymbol{s}}}{\mathbf{2.0}\ \boldsymbol{kg}}$$

= ½bh = .5 x 40 x 4 = 80 N·s

= ½bh = ½ x 20 x 2 = 20 N·s

$\Delta\mathbf{v} = \mathbf{30}\,\frac{\mathbf{m}}{\mathbf{s}}$

Δp = Impulse = 80 N·s – 20 N·s = **60 N·s or** $\frac{\boldsymbol{kg \cdot m}}{\boldsymbol{s}}$