MOMENTUM DAY 3: CONSERVATION & SYSTEM BOUNDARIES

⏱ Warm-Up: Newton's Third Law Review (2 min)

Cart A pushes on Cart B during a collision.

1. How does the force on A from B compare to the force on B from A? ____________________

2. How does the *time* A pushes on B compare to the time B pushes on A? ____________________

3. If $J = F \cdot \Delta t$, how do the impulses compare? ____________________

THE KEY INSIGHT: INTERNAL FORCES CANCEL

NEWTON'S THIRD LAW + IMPULSE

When two objects interact:

- $\vec{F}_{A \text{ on } B} = -\vec{F}_{B \text{ on } A}$ (Third Law)
- They interact for the same time Δt
- Therefore: $\vec{J}_{\text{on } A} = -\vec{J}_{\text{on } B}$

Result: The impulses are equal and opposite. The total momentum of the pair doesn't change!

Conservation of Momentum: In an isolated system (no external forces), total momentum is constant.

$$\vec{p}_{\text{total, before}} = \vec{p}_{\text{total, after}}$$

WHAT IS A "SYSTEM"?

SYSTEM BOUNDARIES

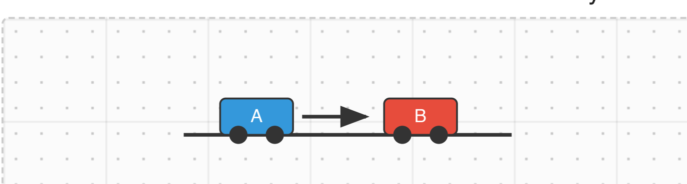
A **system** is a group of objects you choose to analyze together. Draw an imaginary boundary around them.

Internal forces:
Forces between objects *inside* the system.
✓ These cancel (N3L)!

External forces:
Forces from objects *outside* the system.
✗ These change momentum!

WE DO **Drawing System Boundaries**

Two carts collide on a frictionless track. Draw the system boundary and classify forces.



Draw a dashed line around BOTH carts (the system).

Classify these forces:

Force	Internal or External?
A pushes B	
B pushes A	
Normal from track	
Gravity on carts	

Is the system isolated? ______ **Why?** ______________________________

SOLVING CONSERVATION PROBLEMS: THE SETUP

PROBLEM-SOLVING FRAMEWORK

1. **Define the system** (what's inside the boundary?)
2. **Check for isolation** (are external forces zero or balanced?)
3. **Write:** $p_{\text{before}} = p_{\text{after}}$
4. **Expand:** $m_1 v_{1i} + m_2 v_{2i} = m_1 v_{1f} + m_2 v_{2f}$
5. **Substitute and solve**

WE DO **Collision: Finding Final Velocity**

A 3.0 kg cart moving at +4.0 m/s collides with a 2.0 kg cart at rest. They stick together. Find the final velocity.

Before:

After (stuck together):

$p_{\text{before}} = m_1 v_{1i} + m_2 v_{2i}$

$p_{\text{after}} = (m_1 + m_2) v_f$

Set equal and solve:

YOU DO **Collision: Objects Moving Toward Each Other**

A 4.0 kg cart moving at +6.0 m/s collides head-on with a 2.0 kg cart moving at –3.0 m/s. They stick together.

a. What is the total momentum before? ________ kg·m/s

b. What is the final velocity? ________ m/s

c. Which direction do they move after? ________

Common Error: Forgetting signs! If objects move in opposite directions, their momenta have opposite signs. Add them algebraically.

WHEN IS MOMENTUM NOT CONSERVED?

THINK **External Forces**

For each scenario, identify if momentum is conserved for the given system. If not, identify the external force.

Scenario	System	Conserved?	If not, what external force?
Two ice skaters push off each other	Both skaters		
Car brakes to a stop	Car only		
Bullet embeds in a block on a smooth table	Bullet + block		
Ball falls and hits the ground	Ball only		
Ball falls and hits the ground	Ball + Earth		

MOMENTUM VS. KINETIC ENERGY

TWO DIFFERENT QUANTITIES

	Momentum $\vec{p}$	Kinetic Energy KE
Formula	$\vec{p} = m\vec{v}$	$KE = \frac{1}{2}mv^2$
Type	Vector (has direction)	Scalar (no direction)
When Conserved?	**Only in** isolated system	Only in *elastic* collisions

WE DO **Inelastic Collision: Lost Energy**

A 4.0 kg cart moving at 3.0 m/s collides with a stationary 2.0 kg cart. They stick together.

Step 1: Find v_f using Momentum

$p_{\text{before}} = p_{\text{after}}$

$v_f =$ ______________ m/s

Step 2: Find Energy Loss (ΔK)

$K_{\text{initial}} = \frac{1}{2}m_1 v_{1i}^2 =$ ______________

$K_{\text{final}} = \frac{1}{2}(m_{tot})v_f^2 =$ ______________

$\Delta K = K_f - K_i =$ ______________ J

WE DO **Explosion (Energy Gained)**

A 1.5 kg cart holds a 0.50 kg firecracker. Everything is at rest. The firecracker explodes, sending a 0.20 kg piece forward at +15 m/s and a 0.30 kg piece backward.

a) Find the backward velocity of the 0.30 kg piece. (Assume the 1.5kg cart doesn't move).

YOU DO **Explosion (Energy Gained) — Part b**

b) Calculate ΔK. Where did this energy come from?

HOMEWORK

1 Conceptual: System Choice

A cannon on wheels fires a cannonball. Explain why momentum is conserved for the cannon+ball system but NOT for just the cannonball.

2 Calculation: Energy Loss in Collision

A 5.0 kg cart moving at +3.0 m/s collides with a 3.0 kg cart moving at +1.0 m/s (same direction). They stick together.

a. Use conservation of momentum to find the final velocity.
b. Calculate the total kinetic energy BEFORE the collision.
c. Calculate the total kinetic energy AFTER the collision.
d. How much energy was "lost" (converted to other forms)?

3 Head-On Collision

A 1200 kg car traveling east at 15 m/s collides head-on with an 800 kg car traveling west at 20 m/s. They lock bumpers and move together.

a. What is the velocity of the wreckage? (Magnitude and direction)
b. Which direction does it move?

4 Recoil

A 60 kg astronaut floating in space throws a 5.0 kg tool away at 8.0 m/s. What is the astronaut's recoil velocity?

5 AP-Style: System Boundaries

A ball is dropped and bounces off the floor. A student claims momentum is not conserved because the ball's momentum changes direction. Critique this claim by discussing appropriate system boundaries.

Lab Preview: Tomorrow we'll test conservation of momentum with real collisions. Think about: How would you verify that $p_{\text{before}} = p_{\text{after}}$?