PHYS12 CH:8 The Physics of Collisions

Why Crashes Change Everything

Mr. Gullo

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Outline

What if you could predict
exactly what happens when objects collide?

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Football tackles. Car crashes. Rocket launches.

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Football tackles. Car crashes. Rocket launches.

The same law governs them all.

The Great Exchange

Figure: NFC defensive backs gang tackle AFC running back during 2006 Pro Bowl

Learning Objectives

By the end of this section, you will be able to:

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- **8.1:** Describe momentum, impulse, and the impulse-momentum theorem
- **8.1:** Express Newton's second law in terms of momentum
- **8.1:** Solve problems using the impulse-momentum theorem

8.1 Mass in Motion

The Universal Law: Momentum

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Key insights:

- Directly proportional to mass and velocity
- Vector - same direction as velocity
- SI unit: $\mathrm{kg} \cdot \mathrm{m/s}$

8.1 The Civilian's Mistake

Civilian View vs. Reality

Civilian: "Speed is all that matters in a collision."
Physicist: "Mass matters just as much as velocity."

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The Mental Model

A slow-moving truck can have more momentum than a fast-moving bicycle.
Why? Mass wins.

8.1 Newton's Hidden Truth

The Original Second Law

$$\boxed{\vec{F}_{\text{net}} = \frac{\Delta \vec{p}}{\Delta t}}$$

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Net force equals the rate of change of momentum.

This is actually MORE fundamental than $F = ma$.

Why? This version works even when mass changes (like rockets burning fuel).

8.1 The Force of Time

The Universal Law: Impulse

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In the Real World

Airbags increase collision time → decrease force on your body.

8.1 Engineering Life-Savers

Figure: Airbags and seat belts installed in vehicles

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Figure: Airbags and seat belts installed in vehicles

Physics: $\vec{F}_{\text{net}} = \frac{\Delta \vec{p}}{\Delta t}$

Increase $\Delta t \rightarrow$ Decrease $\vec{F}_{\text{net}}$

8.1 Why Bend Your Knees?

The Challenge

Your friend dares you to jump off a bench without bending your knees. Why is this foolish?

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The Mental Model

Stiff legs: short collision time $\rightarrow$ HUGE force on bones.
Bent knees: long collision time $\rightarrow$ smaller force, no injury.

Attempt: The Football Player

The Challenge (3 min, silent)

A 110 kg football player runs at 8 m/s.

Given:

- $m = 110$ kg
- $v = 8$ m/s

Find: Momentum $\vec{p}$

Can you calculate the quantity of motion? Work silently.

Compare: Momentum Strategy

Turn and talk (2 min):

1. What equation did you use?
2. Did you include units?
3. Is momentum a scalar or vector?

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Name wheel: One pair share your approach (not your answer).

Reveal: The Quantity of Motion

Self-correct in a different color:

Equation: $\vec{p} = m\vec{v}$

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Check: Large mass, moderate speed → large momentum. Reasonable!

Attempt: Venus Williams' Serve

The Challenge (4 min, silent)

Venus Williams hits a 0.057 kg tennis ball. It accelerates from rest to 58 m/s in 5 ms.

Given:

- $m = 0.057$ kg
- $v_i = 0$ m/s, $v_f = 58$ m/s
- $\Delta t = 5 \times 10^{-3}$ s

Find: Average force on ball

Can you decode the power of this serve?

Compare: Impulse Strategy

Turn and talk (2 min):

1. Did you find Δp first or jump straight to force?
2. What's the relationship between impulse and momentum?
3. How did you handle the milliseconds?

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Reveal: The Power Serve

Self-correct in a different color:
Step 1 - Change in momentum:

$$\Delta \vec{p} = m(\vec{v}_f - \vec{v}_i) = (0.057)(58 - 0) = 3.3 \text{ kg} \cdot \text{m/s}$$

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Step 1 - Change in momentum:

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Step 2 - Force from impulse:

$$\vec{F}_{\text{net}} = \frac{\Delta\vec{p}}{\Delta t} = \frac{3.3}{5\times10^{-3}}$$

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$$\boxed{\vec{F}_{\text{net}} = 660 \text{ N}}$$

Check: About 150 pounds of force - that's a powerful serve!

Learning Objectives

By the end of this section, you will be able to:

- **8.2:** Describe the law of conservation of momentum

The Universal Law: Conservation of Momentum

For an isolated system:

$$\boxed{\vec{p}_{\text{tot}} = \text{constant}}$$

or

$$\boxed{\vec{p}_{\text{before}} = \vec{p}_{\text{after}}}$$

Total momentum is conserved.

8.2 The Universe's Accounting System

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or

$$\boxed{\vec{p}_{\text{before}} = \vec{p}_{\text{after}}}$$

Total momentum is conserved.

Isolated system: Net external force is zero.

8.2 Two Cars Colliding

Figure: Car m_1 bumps into car m_2. Total momentum conserved.

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Before: $\vec{p}_1 + \vec{p}_2 = m_1\vec{v}_1 + m_2\vec{v}_2$
After: $\vec{p}_1' + \vec{p}_2' = m_1\vec{v}_1' + m_2\vec{v}_2'$
Conservation: $m_1\vec{v}_1 + m_2\vec{v}_2 = m_1\vec{v}_1' + m_2\vec{v}_2'$

8.2 Why Momentum Seems to Vanish

The Illusion

A football player runs into the goalpost and bounces backward.
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His momentum changed! Is momentum conserved?

Answer: Expand the system to include Earth.

The Mental Model

Earth recoils backward (imperceptibly) when you push the goalpost.
Player's momentum transfers to the entire planet.

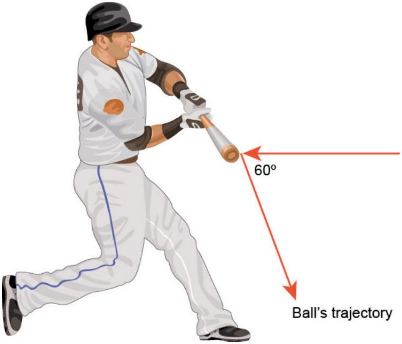

Figure: Ice skater spinning faster by pulling arms in

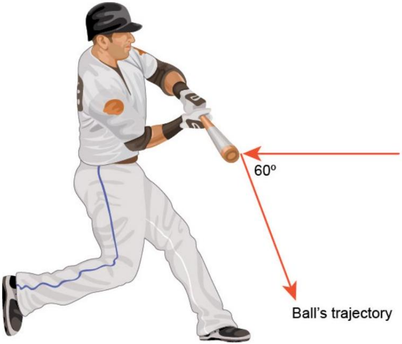

Figure: Ice skater spinning faster by pulling arms in

Angular momentum: $\vec{L} = I\vec{\omega}$
Conservation: $I_1\omega_1 = I_2\omega_2$
Decrease I (pull arms in) $\rightarrow$ Increase ω (spin faster)

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By the end of this section, you will be able to:

- **8.3:** Distinguish between elastic and inelastic collisions

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By the end of this section, you will be able to:

- **8.3:** Distinguish between elastic and inelastic collisions
- **8.3:** Solve collision problems using conservation of momentum

8.3 Two Types of Crashes

Elastic Collision

Objects bounce off each other. Kinetic energy is conserved.

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Objects stick together. Kinetic energy is NOT conserved (converted to heat).

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Objects stick together. Kinetic energy is NOT conserved (converted to heat).

Key Insight

Momentum is ALWAYS conserved (if isolated).
Kinetic energy is conserved ONLY in elastic collisions.

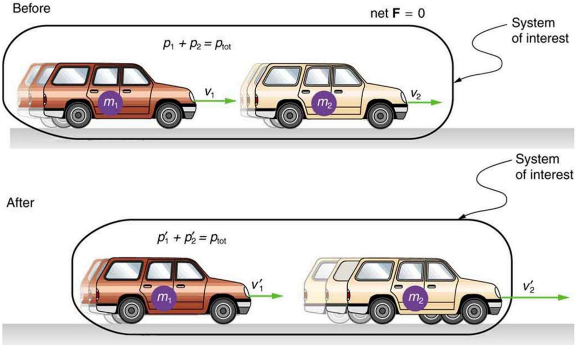

Figure: One-dimensional elastic collision

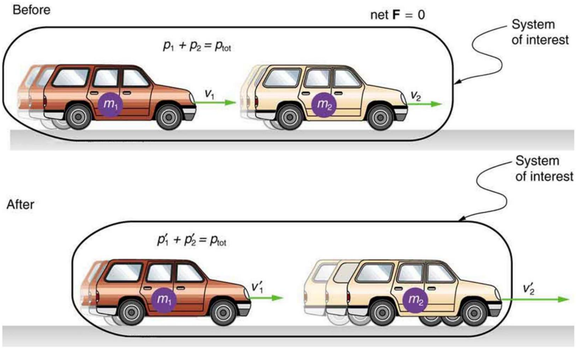

Figure: One-dimensional elastic collision

Conservation of momentum:

$$m_1\vec{v}_1 + m_2\vec{v}_2 = m_1\vec{v}_1' + m_2\vec{v}_2'$$

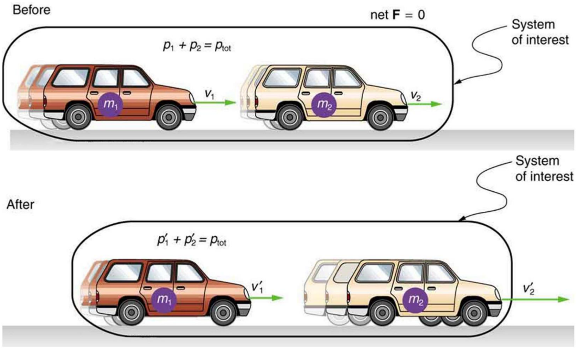

Figure: One-dimensional elastic collision

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Conservation of kinetic energy:

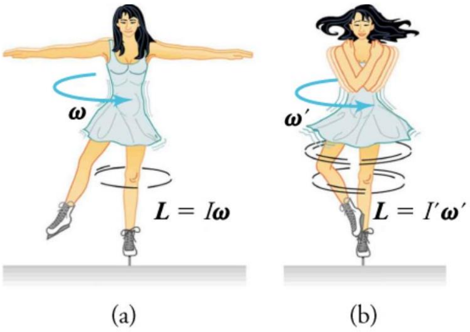

Figure: Perfectly inelastic collision - objects stick together

8.3 Inelastic Collision

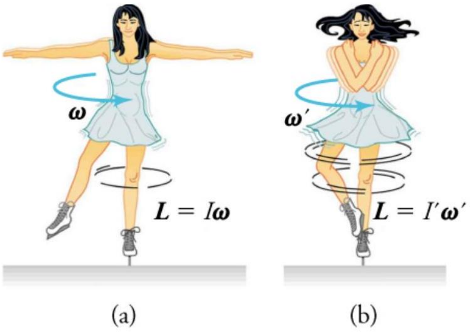

Figure: Perfectly inelastic collision - objects stick together

Conservation of momentum:

$$m_1\vec{v}_1 + m_2\vec{v}_2 = (m_1 + m_2)\vec{v}'$$

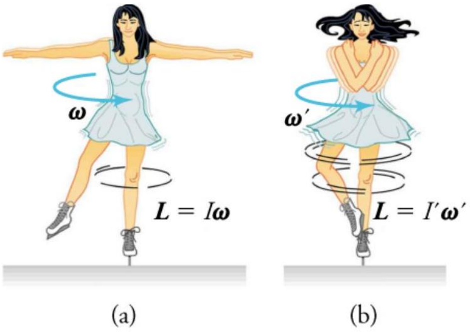

Figure: Perfectly inelastic collision - objects stick together

Conservation of momentum:

$$m_1\vec{v}_1 + m_2\vec{v}_2 = (m_1 + m_2)\vec{v}'$$

Key: Final velocity $\vec{v}'$ is the same for both objects.

Remember This

Elastic materials are bouncy.

$\rightarrow$ Elastic collisions: objects bounce off each other.

Inelastic materials are sticky.

$\rightarrow$ Inelastic collisions: objects stick together.

8.3 Memory Trick

Remember This

Elastic materials are bouncy.
$\rightarrow$ Elastic collisions: objects bounce off each other.

Inelastic materials are sticky.
$\rightarrow$ Inelastic collisions: objects stick together.

Common Mistake

Don't assume kinetic energy is conserved! Only in elastic collisions.

Attempt: Hockey Goalie Catch

The Challenge (4 min, silent)

A 70 kg goalie catches a 0.150 kg puck traveling at 35 m/s. The goalie is initially at rest.

Given:

- $m_1 = 0.150$ kg, $v_1 = 35$ m/s
- $m_2 = 70$ kg, $v_2 = 0$ m/s

Find: Final velocity v' of goalie-plus-puck

Can you predict the recoil?

Compare: Collision Type

Turn and talk (2 min):

1. Is this elastic or inelastic? How do you know?
2. Which conservation equation did you use?
3. What simplification happens because they stick together?

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Name wheel: One pair share your reasoning.

Reveal: The Recoil

Self-correct in a different color:
Conservation of momentum (inelastic):

$$m_1 v_1 + m_2 v_2 = (m_1 + m_2) v'$$

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Substitute ($v_2 = 0$):

$$v' = \frac{m_1 v_1}{m_1 + m_2} = \frac{(0.150)(35)}{0.150 + 70}$$

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$$\boxed{v' = 0.075 \text{ m/s}}$$

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$$\boxed{v' = 0.075 \text{ m/s}}$$

Check: Tiny recoil - goalie is much more massive than puck!

Attempt: Elastic Cart Collision

The Challenge (5 min, silent)

Cart 1 (0.350 kg) moving at 2 m/s collides with cart 2 (0.500 kg) moving at -0.5 m/s. After collision, cart 1 recoils at -4 m/s.

Given:

- $m_1 = 0.350$ kg, $v_1 = 2$ m/s, $v_1' = -4$ m/s
- $m_2 = 0.500$ kg, $v_2 = -0.5$ m/s

Find: Final velocity v_2' of cart 2

Compare: Momentum Algebra

Turn and talk (2 min):

1. How did you handle the negative velocities?
2. Which momentum equation did you use?
3. What did you solve for?

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Solve for v_2':

$$v_2' = \frac{m_1 v_1 + m_2 v_2 - m_1 v_1'}{m_2}$$

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Substitute:

$$v_2' = \frac{(0.350)(2) + (0.500)(-0.5) - (0.350)(-4)}{0.500} = 3.7 \text{ m/s}$$

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Check: Positive velocity means cart 2 moves to the right after collision.

8.3 Two-Dimensional Collisions

Figure: 2D collision with m_2 initially at rest

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Strategy: Break into components.
x-**direction:** $m_1 v_1 = m_1 v_1' \cos\theta_1 + m_2 v_2' \cos\theta_2$
y-**direction:** $0 = m_1 v_1' \sin\theta_1 + m_2 v_2' \sin\theta_2$

What You Now Know

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4. Conservation: $\vec{p}_{\text{tot}} =$ constant in isolated systems
5. Elastic collisions: objects bounce, KE conserved
6. Inelastic collisions: objects stick, KE lost
7. Momentum ALWAYS conserved (if isolated)

Key Equations

$$\vec{p} = m\vec{v} \tag{1}$$

$$\vec{F}_{\text{net}} = \frac{\Delta \vec{p}}{\Delta t} \tag{2}$$

$$J = \vec{F}_{\text{net}} \Delta t = \Delta \vec{p} \tag{3}$$

$$\vec{p}_{\text{tot}} = \text{constant (isolated system)} \tag{4}$$

$$m_1 v_1 + m_2 v_2 = m_1 v_1' + m_2 v_2' \text{ (elastic)} \tag{5}$$

$$m_1 v_1 + m_2 v_2 = (m_1 + m_2) v' \text{ (inelastic)} \tag{6}$$

Complete the assigned problems

posted on the LMS