PHYS12 CH:8 The Physics of Collisions

Why Crashes Change Everything

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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.

The Mystery of Collisions

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

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:

- **8.1:** Describe momentum, impulse, and the impulse-momentum theorem

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

The Universal Law: Momentum

$$\boxed{\vec{p} = m\vec{v}}$$

Momentum equals mass times velocity. The quantity of motion.

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- Directly proportional to mass and velocity

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Momentum equals mass times velocity. The quantity of motion.

Key insights:

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

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

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

Net force equals the rate of change of momentum.

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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).

The Universal Law: Impulse

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

Impulse equals force times time equals change in momentum.

8.1 The Force of Time

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Key insight: A small force over long time = Large force over short time

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Key insight: A small force over long time = Large force over short time

In the Real World

Airbags increase collision time → decrease force on your body.

8.1 Engineering Life-Savers

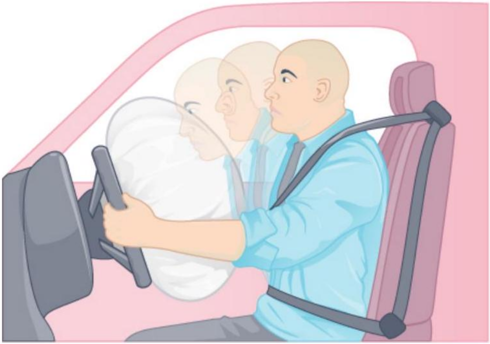

Figure: Airbags and seat belts installed in vehicles

8.1 Engineering Life-Savers

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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Substitute: $\vec{p} = (110\ \text{kg})(8\ \text{m/s})$

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Self-correct in a different color:

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

Substitute: $\vec{p} = (110 \text{ kg})(8 \text{ m/s})$

$$\boxed{\vec{p} = 880 \text{ kg} \cdot \text{m/s}}$$

Reveal: The Quantity of Motion

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Check: Large mass, moderate speed $\rightarrow$ 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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$$\boxed{\vec{F}_{\text{net}} = 660 \text{ N}}$$

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

The Universal Law: Conservation of Momentum

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

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.

8.2 Figure Skating and Angular Momentum

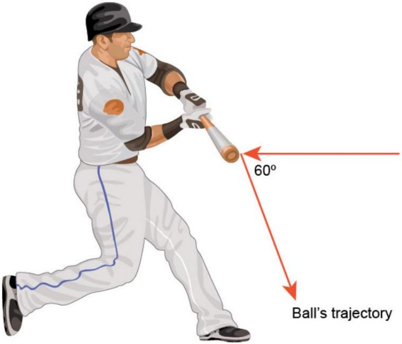

Figure: Ice skater spinning faster by pulling arms in

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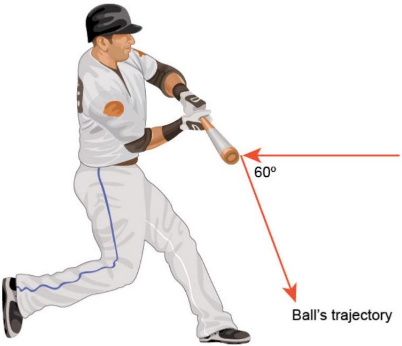

Figure: Ice skater spinning faster by pulling arms in

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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- **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).

Key Insight

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

8.3 Elastic Collision

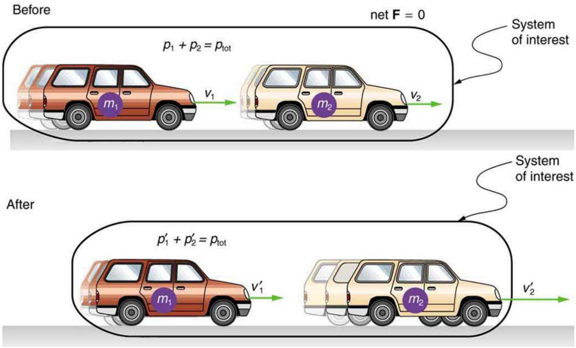


Figure: One-dimensional elastic collision

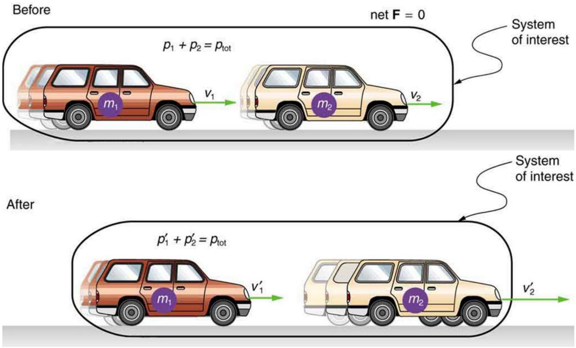
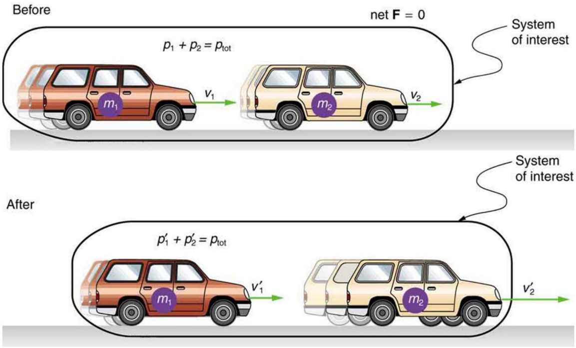


Figure: One-dimensional elastic collision

Conservation of momentum:

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



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Conservation of momentum:

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

Conservation of kinetic energy:

8.3 Inelastic Collision

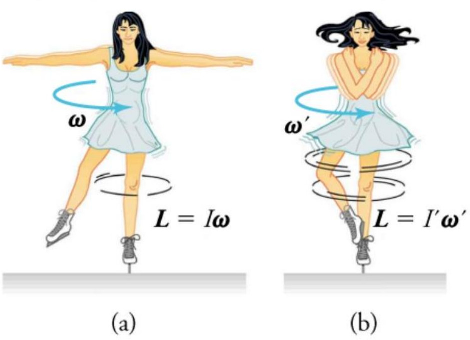
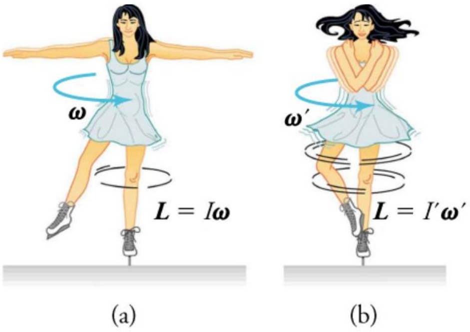


Figure: Perfectly inelastic collision - objects stick together



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

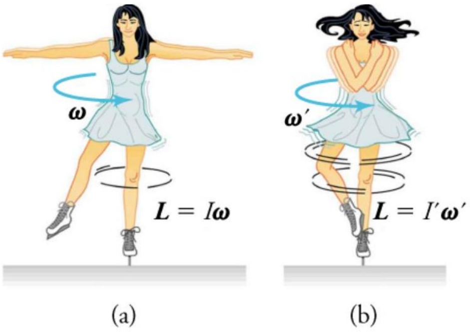

Figure: Perfectly inelastic collision - objects stick together

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.

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.

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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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Conservation of momentum (inelastic):

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Substitute ($v_2 = 0$):

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

Reveal: The Recoil

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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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Self-correct in a different color:
Conservation of momentum:

$$m_1 v_1 + m_2 v_2 = m_1 v_1' + m_2 v_2'$$

Reveal: The Ricochet

Self-correct in a different color:
Conservation of momentum:

$$m_1 v_1 + m_2 v_2 = m_1 v_1' + m_2 v_2'$$

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.

Figure: 2D collision with m_2 initially at rest

8.3 Two-Dimensional Collisions

Figure: 2D collision with m_2 initially at rest

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

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