

PHYS12 CH:8 The Physics of Collisions

Why Crashes Change Everything

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Outline

The Mystery of Collisions

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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Momentum equals mass times velocity. The quantity of motion.

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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

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Net force equals the rate of change of momentum.

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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}_{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:

- $m = 110 \text{ kg}$
- $v = 8 \text{ m/s}$

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

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

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

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

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:

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

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?
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Name wheel: One pair share your approach.

Reveal: The Power Serve

Self-correct in a different color:

Step 1 - Change in momentum:

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

Reveal: The Power Serve

Self-correct in a different color:

Step 1 - Change in momentum:

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

Step 2 - Force from impulse:

$$\vec{F}_{\text{net}} = \frac{\Delta \vec{p}}{\Delta t} = \frac{3.3}{5 \times 10^{-3}}$$

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$$\vec{F}_{\text{net}} = \frac{\Delta \vec{p}}{\Delta t} = \frac{3.3}{5 \times 10^{-3}}$$

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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

8.2 The Universe's Accounting System

The Universal Law: Conservation of Momentum

For an isolated system:

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

or

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

Total momentum is conserved.

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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. His momentum changed! Is momentum conserved?

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Answer: Expand the system to include Earth.

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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

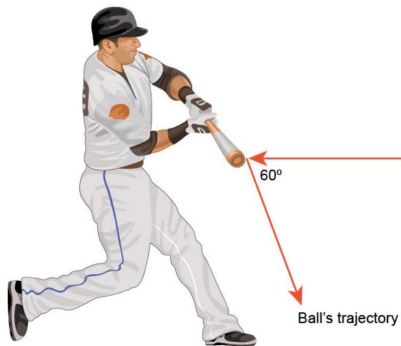


Figure: Ice skater spinning faster by pulling arms in

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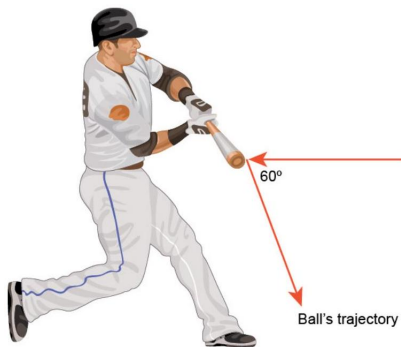


Figure: Ice skater spinning faster by pulling arms in

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).

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Elastic Collision

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Inelastic Collision

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

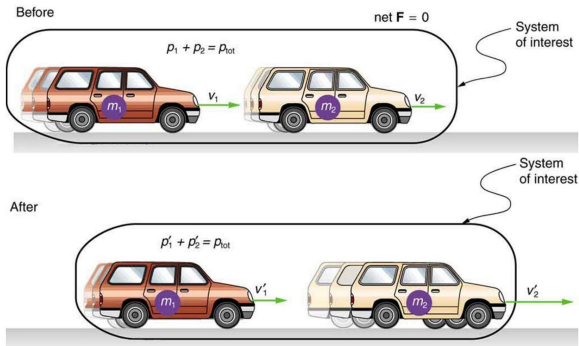


Figure: One-dimensional elastic collision

8.3 Elastic Collision

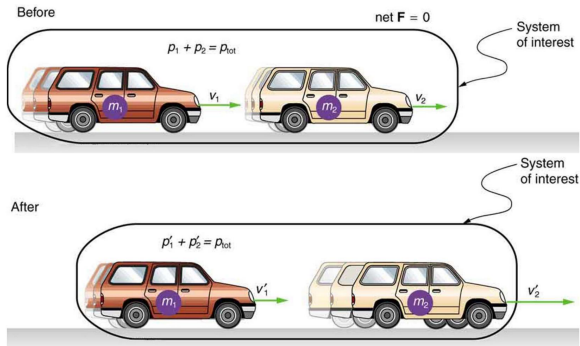


Figure: One-dimensional elastic collision

Conservation of momentum:

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

8.3 Elastic Collision

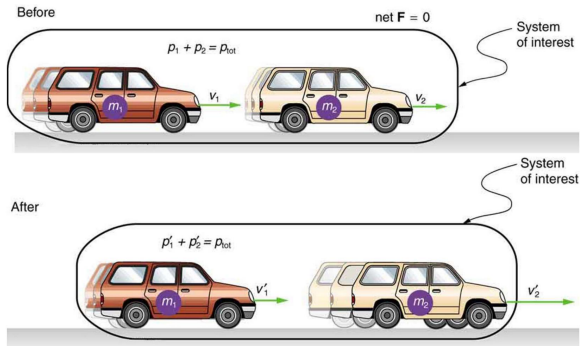


Figure: One-dimensional elastic collision

Conservation of momentum:

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

Conservation of kinetic energy:

8.3 Inelastic Collision

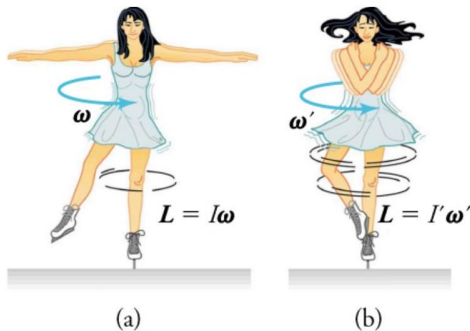


Figure: Perfectly inelastic collision - objects stick together

8.3 Inelastic Collision

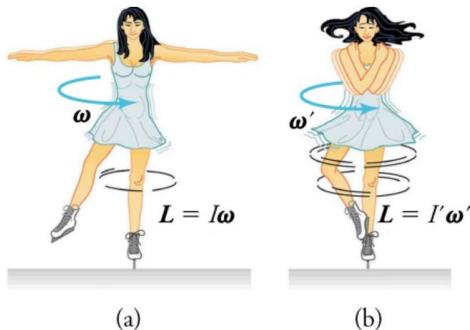


Figure: Perfectly inelastic collision - objects stick together

Conservation of momentum:

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

8.3 Inelastic Collision

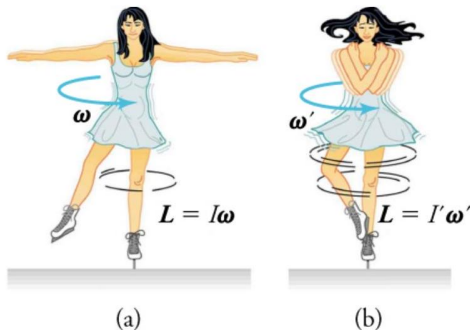


Figure: Perfectly inelastic collision - objects stick together

Conservation of momentum:

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

8.3 Memory Trick

Remember This

Elastic materials are bouncy.

→ Elastic collisions: objects bounce off each other.

Inelastic materials are sticky.

→ Inelastic collisions: objects stick together.

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Remember This

Elastic materials are bouncy.

→ Elastic collisions: objects bounce off each other.

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→ 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:

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

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):

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

Reveal: The Recoil

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Conservation of momentum (inelastic):

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

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

Substitute ($v_2 = 0$):

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

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

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Substitute ($v_2 = 0$):

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

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

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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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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Solve for v'_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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Figure: 2D collision with m_2 initially at rest

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: $0 = m_1 v'_1 \sin \theta_1 + m_2 v'_2 \sin \theta_2$

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- 4 Conservation: $\vec{p}_{\text{tot}} = \text{constant}$ in isolated systems

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- 5 Elastic collisions: objects bounce, KE conserved
- 6 Inelastic collisions: objects stick, KE lost
- 7 Momentum ALWAYS conserved (if isolated)

Key Equations

$$\vec{p} = m\vec{v} \quad (1)$$

$$\vec{F}_{\text{net}} = \frac{\Delta\vec{p}}{\Delta t} \quad (2)$$

$$J = \vec{F}_{\text{net}}\Delta t = \Delta\vec{p} \quad (3)$$

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

$$m_1v_1 + m_2v_2 = m_1v'_1 + m_2v'_2 \text{ (elastic)} \quad (5)$$

$$m_1v_1 + m_2v_2 = (m_1 + m_2)v' \text{ (inelastic)} \quad (6)$$

Complete the assigned problems
posted on the LMS

Temporary page!

\LaTeX was unable to guess the total number of pages correctly. There was some unprocessed data that should have been added to the document, so this extra page has been added to receive it.

If you rerun the document (without altering it) this surplus page will disappear, because \LaTeX now knows how many pages to expect for the document.