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Objectives

- **Compare** the momentum of different moving objects.
- **Compare** the momentum of the same object moving with different velocities.
- **Identify** examples of change in the momentum of an object.
- **Describe** changes in momentum in terms of force and time.

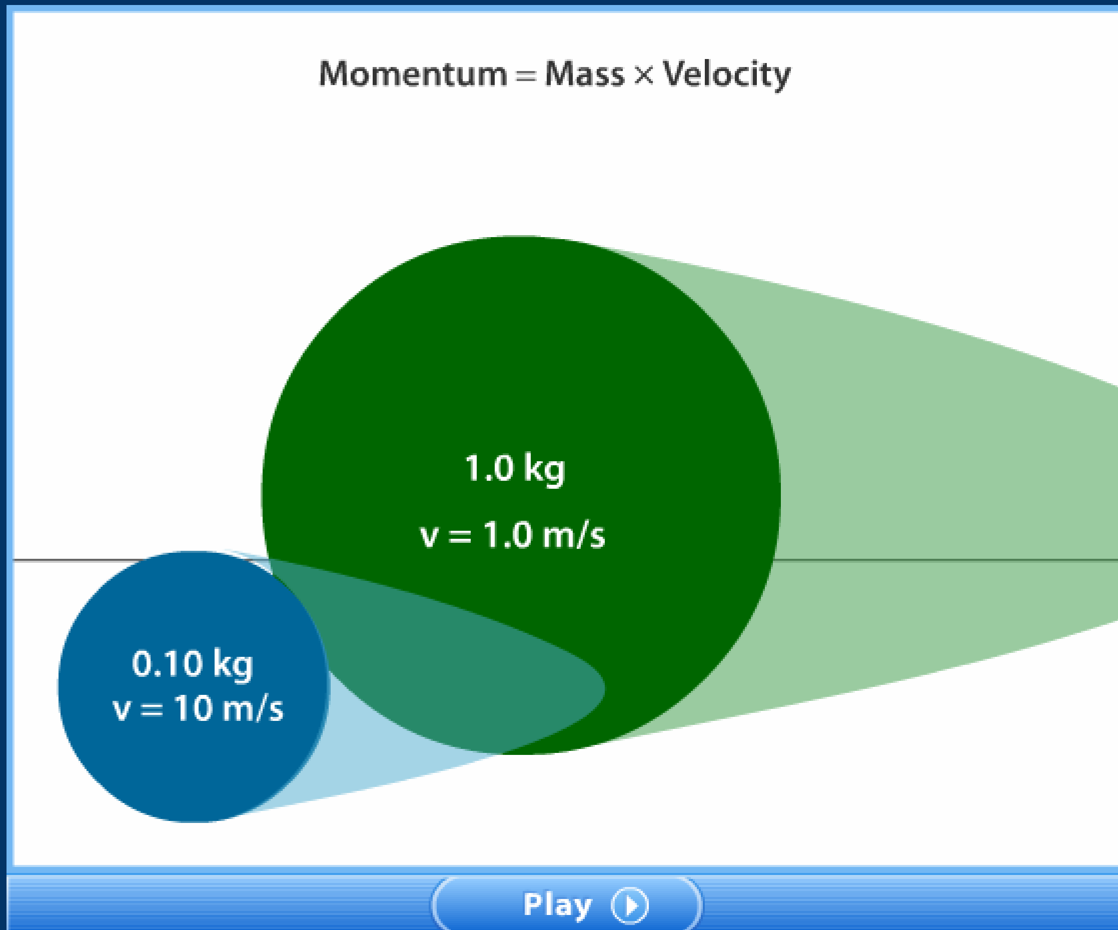
Linear Momentum

- **Momentum** is defined as mass times velocity.
- **Momentum** is represented by the symbol **p**, and is a *vector* quantity.

$$\mathbf{p} = m\mathbf{v}$$

$$\text{momentum} = \text{mass} \times \text{velocity}$$

Momentum



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Linear Momentum, *continued*

- **Impulse**
  - The product of the force and the time over which the force acts on an object is called **impulse.**
  - The **impulse-momentum theorem** states that when a net force is applied to an object over a certain time interval, the force will cause a change in the object's momentum.

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

force × time interval = change in momentum

Impulse

Impulse Momentum Theorem:

$$F\Delta t = \Delta p$$

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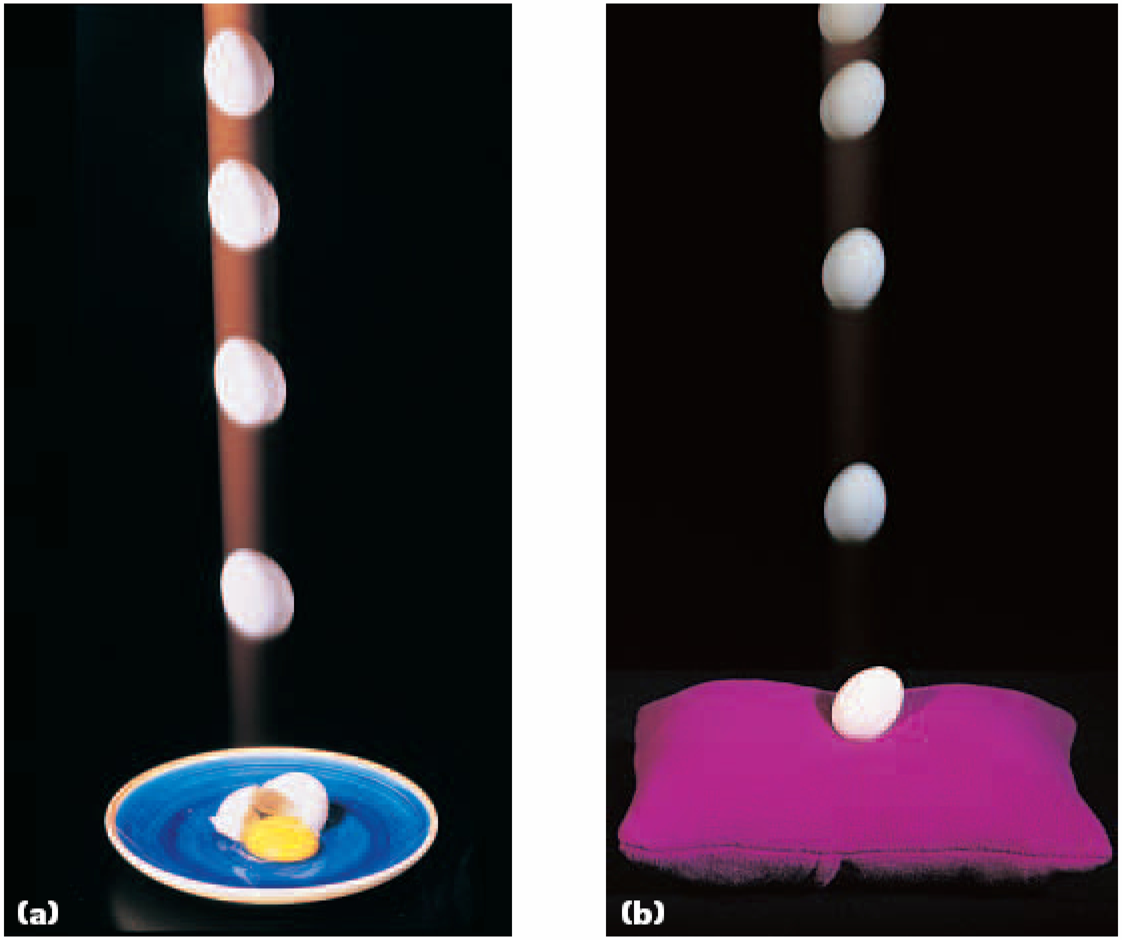
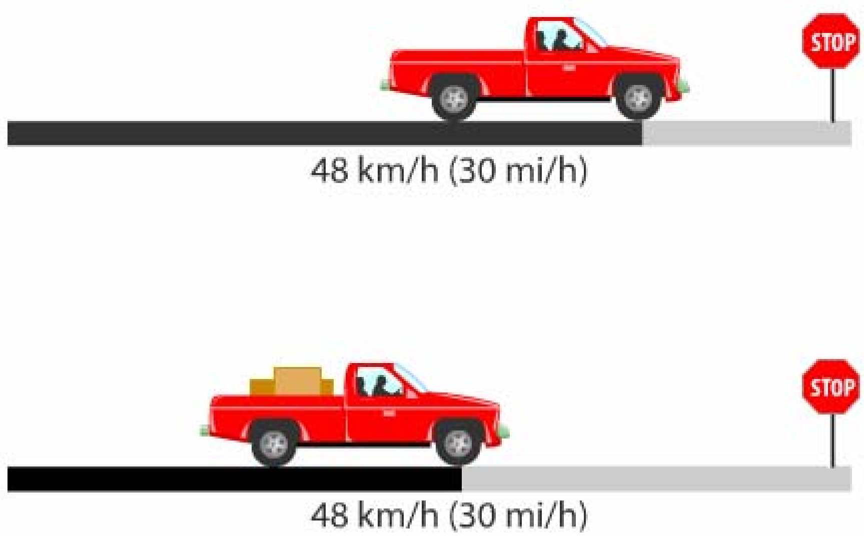
Linear Momentum, *continued*

- Stopping times and distances depend on the impulse-momentum theorem.
- Force is reduced when the time interval of an impact is increased.

Impulse-Momentum Theorem



Impulse-Momentum Theorem



Impulse-momentum theorem

$F\Delta t = \Delta p$ or $F\Delta t = \Delta p = mv_f - mv_i$

force × time interval = change in momentum

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Objectives

- **Describe** the interaction between two objects in terms of the change in momentum of each object.
- **Compare** the total momentum of two objects before and after they interact.
- **State** the law of conservation of momentum.
- **Predict** the final velocities of objects after collisions, given the initial velocities, force, and time.

Momentum is Conserved

The Law of Conservation of Momentum:

The total momentum of all objects interacting with one another remains constant regardless of the nature of the forces between the objects.

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

total initial momentum = total final momentum

Conservation of Momentum

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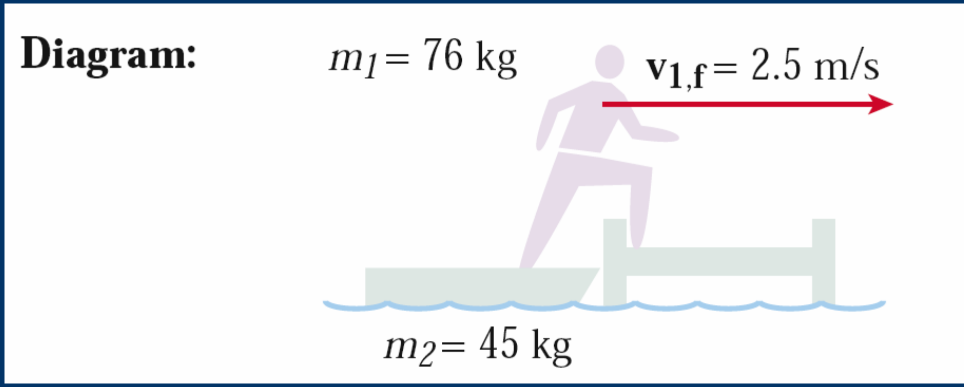
Sample Problem

Conservation of Momentum

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?



Sample Problem, *continued*

Conservation of Momentum

1. Define

Given:

$m_1 = 76$ kg $m_2 = 45$ kg

$\mathbf{v}_{1,i} = 0$ $\mathbf{v}_{2,i} = 0$

$\mathbf{v}_{1,f} = 2.5$ m/s to the right

Unknown:

$\mathbf{v}_{2,f} = ?$

Sample Problem, *continued*

Conservation of Momentum

2. Plan

Choose an equation or situation: Because the total momentum of an isolated system remains constant, the total initial momentum of the boater and the boat will be equal to the total final momentum of the boater and the boat.

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

Sample Problem, *continued*

Conservation of Momentum

2. Plan, *continued*

Because the boater and the boat are initially at rest, the total initial momentum of the system is equal to zero. Therefore, the final momentum of the system must also be equal to zero.

$$m_1\mathbf{v}_{1,f} + m_2\mathbf{v}_{2,f} = 0$$

Rearrange the equation to solve for the final velocity of the boat.

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

$$\mathbf{v}_{2,f} = -\left(\frac{m_1}{m_2}\right)\mathbf{v}_{1,f}$$

Sample Problem, *continued*

Conservation of Momentum

3. Calculate

Substitute the values into the equation and solve:

$$\mathbf{v}_{2,f} = -\left(\frac{76\ \text{kg}}{45\ \text{kg}}\right)(2.5\ \text{m/s to the right})$$

$$\mathbf{v}_{2,f} = -4.2\ \text{m/s to the right}$$

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Sample Problem, *continued*

Conservation of Momentum

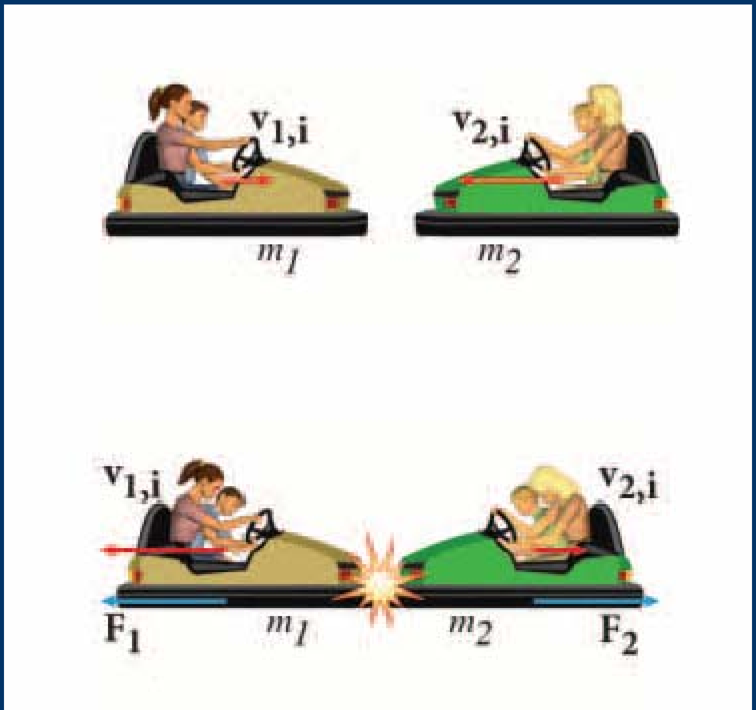
4. Evaluate

The negative sign for $\mathbf{v}_{2,f}$ indicates that the boat is moving to the left, in the direction opposite the motion of the boater. Therefore,

$$v_{2,f} = 4.2 \text{ m/s to the left}$$

Momentum is Conserved, *continued*

- Newton's third law leads to conservation of momentum
- During the collision, the force exerted on each bumper car causes a change in momentum for each car.
- The total momentum is the same before and after the collision.



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Objectives

- **Identify** different types of collisions.
- **Determine** the changes in kinetic energy during perfectly inelastic collisions.
- **Compare** conservation of momentum and conservation of kinetic energy in perfectly inelastic and elastic collisions.
- **Find** the final velocity of an object in perfectly inelastic and elastic collisions.

Collisions

- **Perfectly inelastic collision**

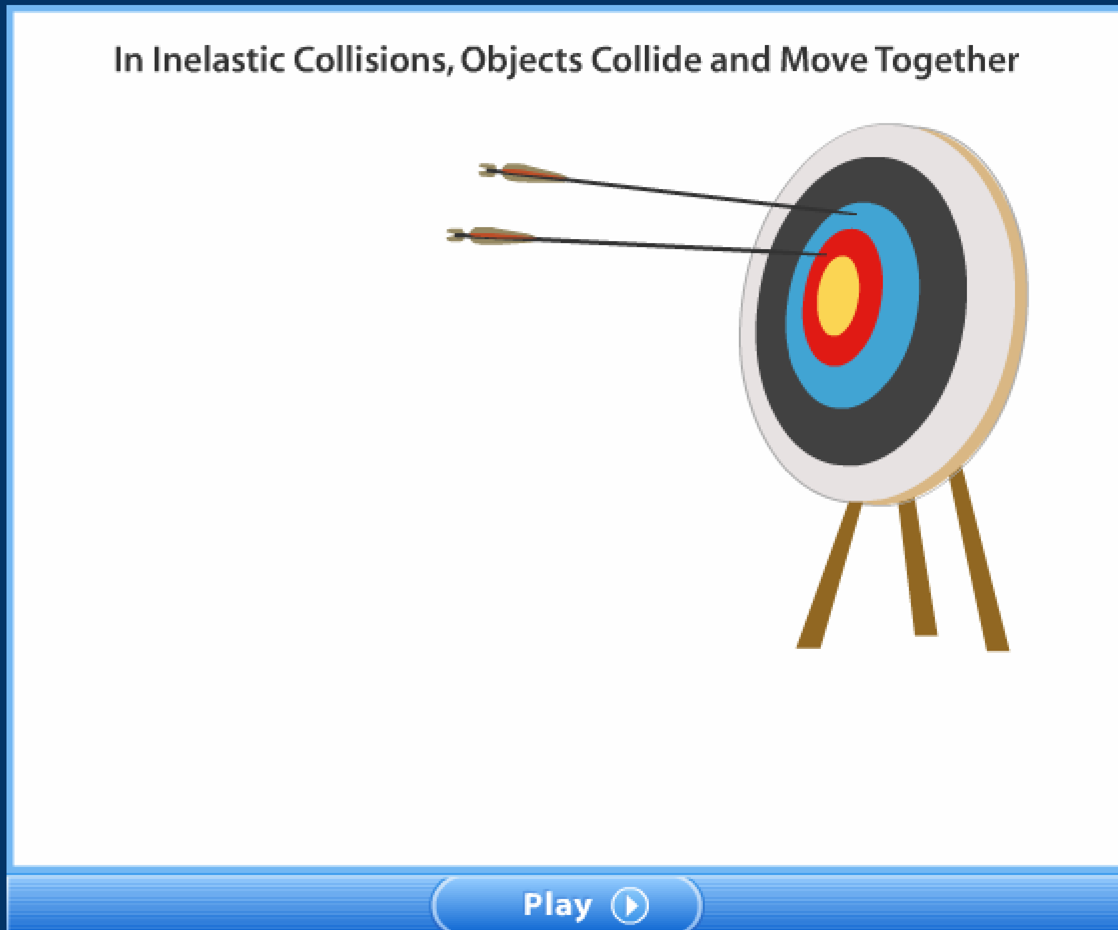
  A collision in which two objects stick together after colliding and move together as one mass is called a **perfectly inelastic collision.**

- Conservation of momentum for a perfectly inelastic collision:

$$m_1\mathbf{v}_{1,i} + m_2\mathbf{v}_{2,i} = (m_1 + m_2)\mathbf{v}_f$$

total initial momentum = total final momentum

Perfectly Inelastic Collisions



Sample Problem

Kinetic Energy in Perfectly Inelastic Collisions

Two clay balls collide head-on in a perfectly inelastic collision. The first ball has a mass of 0.500 kg and an initial velocity of 4.00 m/s to the right. The second ball has a mass of 0.250 kg and an initial velocity of 3.00 m/s to the left.What is the decrease in kinetic energy during the collision?

Sample Problem, *continued*

Kinetic Energy in Perfectly Inelastic Collisions

1. Define

Given: $m_1 = 0.500$ kg $m_2 = 0.250$ kg

$\mathbf{v}_{1,i} = 4.00$ m/s to the right, $v_{1,i} = +4.00$ m/s

$\mathbf{v}_{2,i} = 3.00$ m/s to the left, $v_{2,i} = -3.00$ m/s

Unknown: $\Delta KE = ?$

Sample Problem, *continued*

Kinetic Energy in Perfectly Inelastic Collisions

2. Plan

Choose an equation or situation: The change in kinetic energy is simply the initial kinetic energy subtracted from the final kinetic energy.

$$\Delta KE = KE_i - KE_f$$

Determine both the initial and final kinetic energy.

Initial: $KE_i = KE_{1,i} + KE_{2,i} = \frac{1}{2}m_1v_{1,i}^2 + \frac{1}{2}m_2v_{2,i}^2$

Final: $KE_f = KE_{1,f} + KE_{2,f} = \frac{1}{2}(m_1 + m_2)v_f^2$

Sample Problem, *continued*

Kinetic Energy in Perfectly Inelastic Collisions

2. Plan, *continued*

Use the equation for a perfectly inelastic collision to calculate the final velocity.

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

Sample Problem, *continued*

Kinetic Energy in Perfectly Inelastic Collisions

3. Calculate

Substitute the values into the equation and solve: First, calculate the final velocity, which will be used in the final kinetic energy equation.

$$v_f = \frac{(0.500\ \text{kg})(4.00\ \text{m/s}) + (0.250\ \text{kg})(-3.00\ \text{m/s})}{0.500\ \text{kg} + 0.250\ \text{kg}}$$

$$\mathbf{v_f} = 1.67\ \text{m/s to the right}$$

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Sample Problem, *continued*

Kinetic Energy in Perfectly Inelastic Collisions

3. Calculate, *continued*

Next calculate the initial and final kinetic energy.

$$KE_i = \frac{1}{2}(0.500\text{ kg})(4.00\text{ m/s})^2 + \frac{1}{2}(0.250\text{ kg})(-3.00\text{ m/s})^2 = 5.12\text{ J}$$

$$KE_f = \frac{1}{2}(0.500\text{ kg} + 0.250\text{ kg})(1.67\text{ m/s})^2 = 1.05\text{ J}$$

Sample Problem, *continued*

Kinetic Energy in Perfectly Inelastic Collisions

3. Calculate, *continued*

Finally, calculate the change in kinetic energy.

$$\Delta KE = KE_f - KE_i = 1.05\text{ J} - 5.12\text{ J}$$

$$\boxed{\Delta KE = -4.07\text{ J}}$$

4. Evaluate The negative sign indicates that kinetic energy is lost.

Elastic Collisions

- **Elastic Collision**

  A collision in which the total momentum and the total kinetic energy are conserved is called an **elastic collision.**

- **Momentum and Kinetic Energy Are Conserved in an Elastic Collision**

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

$$\frac{1}{2}m_1v_{1,i}^2 + \frac{1}{2}m_2v_{2,i}^2 = \frac{1}{2}m_1v_{1,f}^2 + \frac{1}{2}m_2v_{2,f}^2$$

Sample Problem, *continued*

Elastic Collisions

A 0.015 kg marble moving to the right at 0.225 m/s makes an elastic head-on collision with a 0.030 kg shooter marble moving to the left at 0.180 m/s. After the collision, the smaller marble moves to the left at 0.315 m/s. Assume that neither marble rotates before or after the collision and that both marbles are moving on a frictionless surface.What is the velocity of the 0.030 kg marble after the collision?

Sample Problem, *continued*

Elastic Collisions

1. Define

Given: m_1 = 0.015 kg m_2 = 0.030 kg

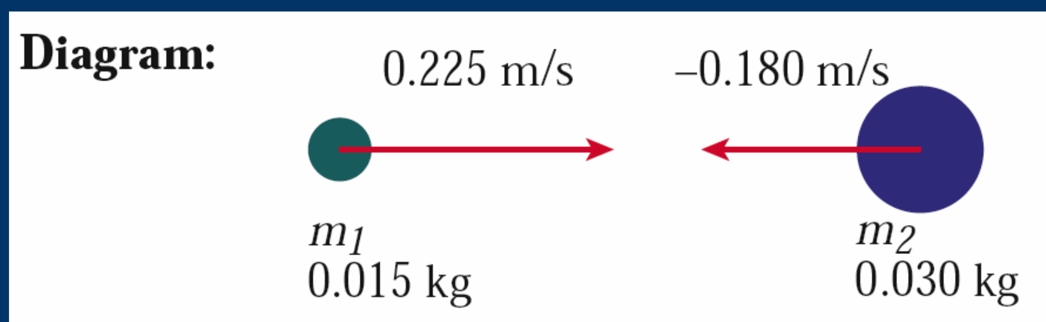
$\mathbf{v}_{1,i}$ = 0.225 m/s to the right, $v_{1,i}$ = +0.225 m/s

$\mathbf{v}_{2,i}$ = 0.180 m/s to the left, $v_{2,i}$ = –0.180 m/s

$\mathbf{v}_{1,f}$ = 0.315 m/s to the left, $v_{1,i}$ = –0.315 m/s

Unknown:

$\mathbf{v}_{2,f}$ = ?



Sample Problem, *continued*

Elastic Collisions

2. Plan

Choose an equation or situation: Use the equation for the conservation of momentum to find the final velocity of m_2, the 0.030 kg marble.

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

Rearrange the equation to isolate the final velocity of m_2.

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

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

End Of Slide

Sample Problem, *continued*

Elastic Collisions

3. Calculate

Substitute the values into the equation and solve: The rearranged conservation-of-momentum equation will allow you to isolate and solve for the final velocity.

$$v_{2,f} = \frac{(0.015\ \text{kg})(0.225\ \text{m/s}) + (0.030\ \text{kg})(-0.180\ \text{m/s}) - (0.015\ \text{kg})(-0.315\ \text{m/s})}{0.030\ \text{kg}}$$

$$v_{2,f} = \frac{(3.4\times10^{-3}\ \text{kg}\cdot\text{m/s}) + (-5.4\times10^{-3}\ \text{kg}\cdot\text{m/s}) - (-4.7\times10^{-3}\ \text{kg}\cdot\text{m/s})}{0.030\ \text{kg}}$$

$$v_{2,f} = \frac{2.7\times10^{-3}\ \text{kg}\cdot\text{m/s}}{3.0\times10^{-2}\ \text{kg}}$$

$$\boxed{\mathbf{v}_{2,f} = 9.0\times10^{-2}\ \text{m/s to the right}}$$

Sample Problem, *continued*

Elastic Collisions

4. Evaluate Confirm your answer by making sure kinetic energy is also conserved using these values.

$$\frac{1}{2}m_1v_{1,i}^2 + \frac{1}{2}m_2v_{2,i}^2 = \frac{1}{2}m_1v_{1,f}^2 + \frac{1}{2}m_2v_{2,f}^2$$

$$KE_i = \frac{1}{2}(0.015\text{ kg})(0.225\text{ m/s})^2 + \frac{1}{2}(0.030\text{ kg})(-0.180\text{ m/s})^2$$

$$= 8.7 \times 10^{-4}\text{ kg}\cdot\text{m}^2/\text{s}^2 = \boxed{8.7 \times 10^{-4}\text{ J}}$$

$$KE_f = \frac{1}{2}(0.015\text{ kg})(0.315\text{ m/s})^2 + \frac{1}{2}(0.030\text{ kg})(0.090\text{ m/s})^2$$

$$= 8.7 \times 10^{-4}\text{ kg}\cdot\text{m}^2/\text{s}^2 = \boxed{8.7 \times 10^{-4}\text{ J}}$$

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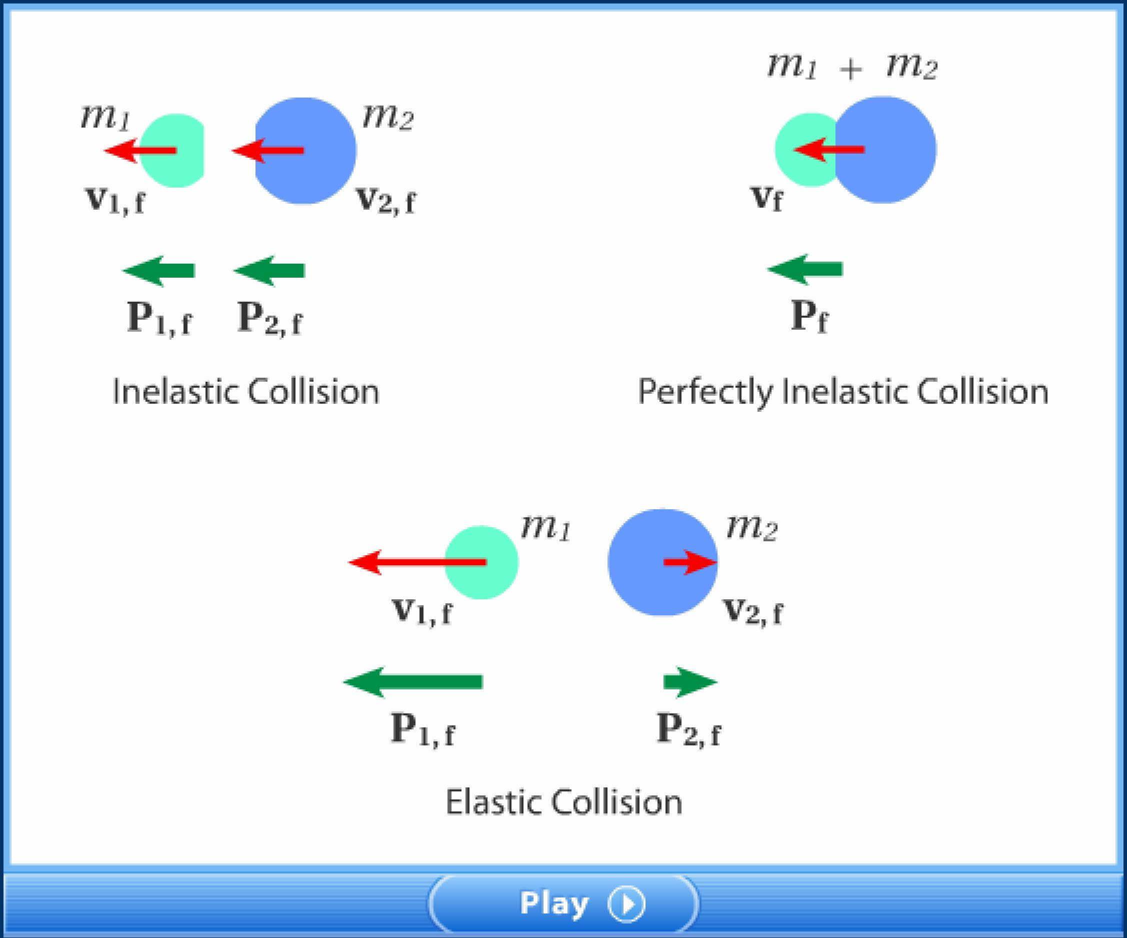
Types of Collisions



Multiple Choice

1. If a particle's kinetic energy is zero, what is its momentum?

   A. zero

   B. 1 kg • m/s

   C. 15 kg • m/s

   D. negative

Multiple Choice, *continued*

1. If a particle's kinetic energy is zero, what is its momentum?

A. zero

B. 1 kg • m/s

C. 15 kg • m/s

D. negative

Multiple Choice, *continued*

2. The vector below represents the momentum of a car traveling along a road.

The car strikes another car, which is at rest, and the result is an inelastic collision.Which of the following vectors represents the momentum of the first car after the collision?

F. 

G. 

H. 

J. 

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Multiple Choice, *continued*

2. The vector below represents the momentum of a car traveling along a road.

The car strikes another car, which is at rest, and the result is an inelastic collision.Which of the following vectors represents the momentum of the first car after the collision?

F. 

G. 

H. 

J. 

Multiple Choice, *continued*

3. What is the momentum of a 0.148 kg baseball thrown with a velocity of 35 m/s toward home plate?

A. 5.1 kg • m/s toward home plate

B. 5.1 kg • m/s away from home plate

C. 5.2 kg • m/s toward home plate

D. 5.2 kg • m/s away from home plate

Multiple Choice, *continued*

3. What is the momentum of a 0.148 kg baseball thrown with a velocity of 35 m/s toward home plate?

A. 5.1 kg • m/s toward home plate

B. 5.1 kg • m/s away from home plate

C. 5.2 kg • m/s toward home plate

D. 5.2 kg • m/s away from home plate

Multiple Choice, *continued*

Use the passage below to answer questions 4–5.

After being struck by a bowling ball, a 1.5 kg bowling pin slides to the right at 3.0 m/s and collides head-on with another 1.5 kg bowling pin initially at rest.

4. What is the final velocity of the second pin if the first pin moves to the right at 0.5 m/s after the collision?

F. 2.5 m/s to the left

G. 2.5 m/s to the right

H. 3.0 m/s to the left

J. 3.0 m/s to the right

Multiple Choice, *continued*

Use the passage below to answer questions 4–5.

After being struck by a bowling ball, a 1.5 kg bowling pin slides to the right at 3.0 m/s and collides head-on with another 1.5 kg bowling pin initially at rest.

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Multiple Choice, *continued*

Use the passage below to answer questions 4–5.

After being struck by a bowling ball, a 1.5 kg bowling pin slides to the right at 3.0 m/s and collides head-on with another 1.5 kg bowling pin initially at rest.

5. What is the final velocity of the second pin if the first pin stops moving when it hits the second pin?

A. 2.5 m/s to the left

B. 2.5 m/s to the right

C. 3.0 m/s to the left

D. 3.0 m/s to the right

Multiple Choice, *continued*

Use the passage below to answer questions 4–5.

After being struck by a bowling ball, a 1.5 kg bowling pin slides to the right at 3.0 m/s and collides head-on with another 1.5 kg bowling pin initially at rest.

5. What is the final velocity of the second pin if the first pin stops moving when it hits the second pin?

A. 2.5 m/s to the left

B. 2.5 m/s to the right

C. 3.0 m/s to the left

D. 3.0 m/s to the right

Multiple Choice, *continued*

6. For a given change in momentum, if the net force that is applied to an object increases, what happens to the time interval over which the force is applied?

F. The time interval increases.

G. The time interval decreases.

H. The time interval stays the same.

J. It is impossible to determine the answer from the given information.

Multiple Choice, *continued*

6. For a given change in momentum, if the net force that is applied to an object increases, what happens to the time interval over which the force is applied?

   F. The time interval increases.

   G. The time interval decreases.

   H. The time interval stays the same.

   J. It is impossible to determine the answer from the given information.

Multiple Choice, *continued*

7. Which equation expresses the law of conservation of momentum?

A. $\mathbf{p} = m\mathbf{v}$

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

C. $(1/2)m_1\mathbf{v}_{1,i}^2 + m_2\mathbf{v}_{2,i}^2 = (1/2)(m_1 + m_2)\mathbf{v}_f^2$

D. $KE = \mathbf{p}$

Multiple Choice, *continued*

7. Which equation expresses the law of conservation of momentum?

A. $\mathbf{p} = m\mathbf{v}$

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

C. $(1/2)m_1\mathbf{v}_{1,i}^2 + m_2\mathbf{v}_{2,i}^2 = (1/2)(m_1 + m_2)\mathbf{v}_f^2$

D. $KE = \mathbf{p}$

Multiple Choice, *continued*

8. Two shuffleboard disks of equal mass, one of which is orange and one of which is yellow, are involved in an elastic collision. The yellow disk is initially at rest and is struck by the orange disk, which is moving initially to the right at 5.00 m/s. After the collision, the orange disk is at rest.What is the velocity of the yellow disk after the collision?

F. zero

G. 5.00 m/s to the left

H. 2.50 m/s to the right

J. 5.00 m/s to the right

Multiple Choice, *continued*

8. Two shuffleboard disks of equal mass, one of which is orange and one of which is yellow, are involved in an elastic collision. The yellow disk is initially at rest and is struck by the orange disk, which is moving initially to the right at 5.00 m/s. After the collision, the orange disk is at rest.What is the velocity of the yellow disk after the collision?

F. zero

G. 5.00 m/s to the left

H. 2.50 m/s to the right

J. 5.00 m/s to the right

Multiple Choice, *continued*

Use the information below to answer questions 9–10.

A 0.400 kg bead slides on a straight frictionless wire and moves with a velocity of 3.50 cm/s to the right, as shown below. The bead collides elastically with a larger 0.600 kg bead that is initially at rest. After the collision, the smaller bead moves to the left with a velocity of 0.70 cm/s.

9. What is the large bead's velocity after the collision?

A. 1.68 cm/s to the right

B. 1.87 cm/s to the right

C. 2.80 cm/s to the right

D. 3.97 cm/s to the right

Multiple Choice, *continued*

Use the information below to answer questions 9–10.

A 0.400 kg bead slides on a straight frictionless wire and moves with a velocity of 3.50 cm/s to the right, as shown below. The bead collides elastically with a larger 0.600 kg bead that is initially at rest. After the collision, the smaller bead moves to the left with a velocity of 0.70 cm/s.

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D. 3.97 cm/s to the right

Multiple Choice, *continued*

Use the information below to answer questions 9–10.

A 0.400 kg bead slides on a straight frictionless wire and moves with a velocity of 3.50 cm/s to the right, as shown below. The bead collides elastically with a larger 0.600 kg bead that is initially at rest. After the collision, the smaller bead moves to the left with a velocity of 0.70 cm/s.

10. What is the total kinetic energy of the system after the collision?

F. 1.40×10^{-4} J

G. 2.45×10^{-4} J

H. 4.70×10^{-4} J

J. 4.90×10^{-4} J

Multiple Choice, *continued*

Use the information below to answer questions 9–10.

A 0.400 kg bead slides on a straight frictionless wire and moves with a velocity of 3.50 cm/s to the right, as shown below. The bead collides elastically with a larger 0.600 kg bead that is initially at rest. After the collision, the smaller bead moves to the left with a velocity of 0.70 cm/s.

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Short Response

11. Is momentum conserved when two objects with zero initial momentum push away from each other?

Short Response, *continued*

11. Is momentum conserved when two objects with zero initial momentum push away from each other?

Answer: yes

Short Response, *continued*

12. In which type of collision is kinetic energy conserved?

What is an example of this type of collision?

Short Response, *continued*

12. In which type of collision is kinetic energy conserved?

Answer: elastic collision

What is an example of this type of collision?

Answer: Two billiard balls collide and then move separately after the collision.

Short Response, *continued*

Base your answers to questions 13–14 on the information below.

An 8.0 g bullet is fired into a 2.5 kg pendulum bob, which is initially at rest and becomes embedded in the bob. The pendulum then rises a vertical distance of 6.0 cm.

13. What was the initial speed of the bullet? Show your work.

Short Response, *continued*

Base your answers to questions 13–14 on the information below.

An 8.0 g bullet is fired into a 2.5 kg pendulum bob, which is initially at rest and becomes embedded in the bob. The pendulum then rises a vertical distance of 6.0 cm.

13. What was the initial speed of the bullet? Show your work.

Answer: 340 m/s

Short Response, *continued*

Base your answers to questions 13–14 on the information below.

An 8.0 g bullet is fired into a 2.5 kg pendulum bob, which is initially at rest and becomes embedded in the bob. The pendulum then rises a vertical distance of 6.0 cm.

14. What will be the kinetic energy of the pendulum when the pendulum swings back to its lowest point? Show your work.

Short Response, *continued*

Base your answers to questions 13–14 on the information below.

An 8.0 g bullet is fired into a 2.5 kg pendulum bob, which is initially at rest and becomes embedded in the bob. The pendulum then rises a vertical distance of 6.0 cm.

14. What will be the kinetic energy of the pendulum when the pendulum swings back to its lowest point? Show your work.

Answer: 1.5 J

Extended Response

15. An engineer working on a space mission claims that if momentum concerns are taken into account, a spaceship will need far less fuel for the return trip than for the first half of the mission.Write a paragraph to explain and support this hypothesis.

Extended Response, *continued*

15. An engineer working on a space mission claims that if momentum concerns are taken into account, a spaceship will need far less fuel for the return trip than for the first half of the mission.Write a paragraph to explain and support this hypothesis.

Hint: Recognize that the ship will have used some of the fuel and thus will have less mass on the return trip.

Momentum is Conserved