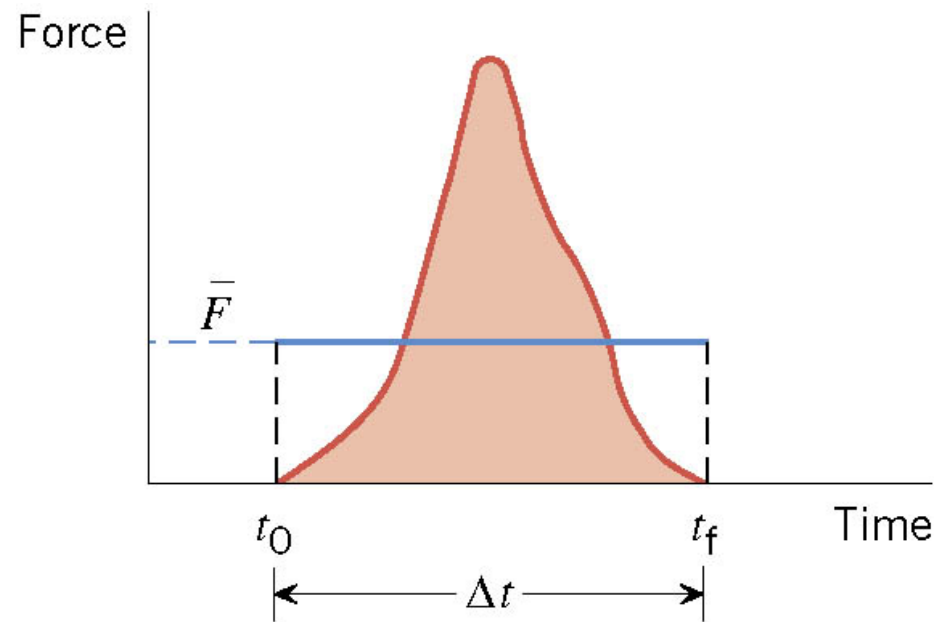
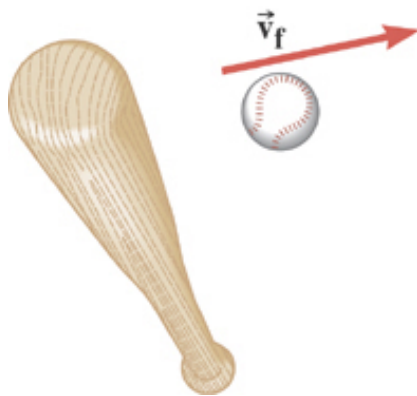
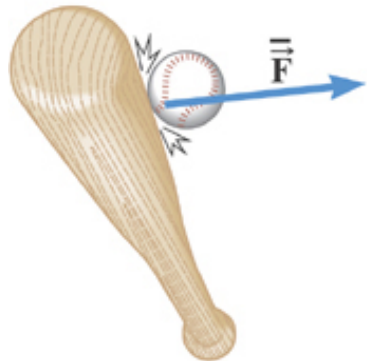


Chapter 7

Impulse and Momentum

7.1 The Impulse-Momentum Theorem



(b)

There are many situations when the force on an object is not constant.

7.1 *The Impulse-Momentum Theorem*

DEFINITION OF IMPULSE

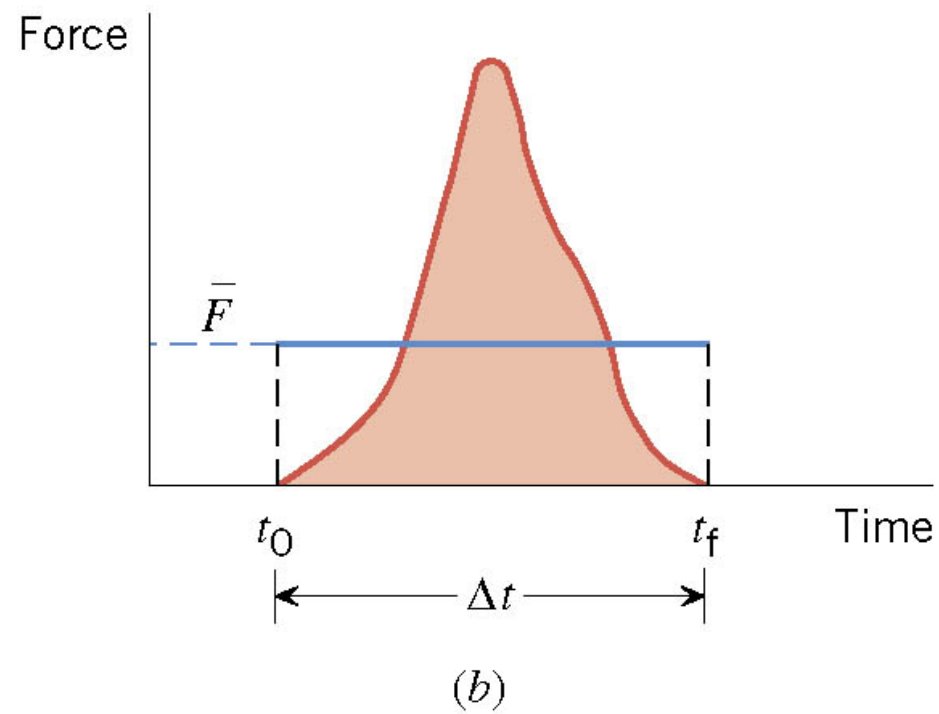
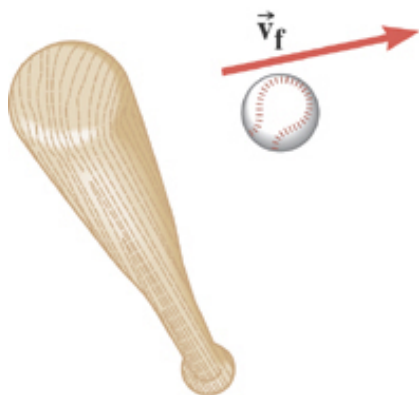
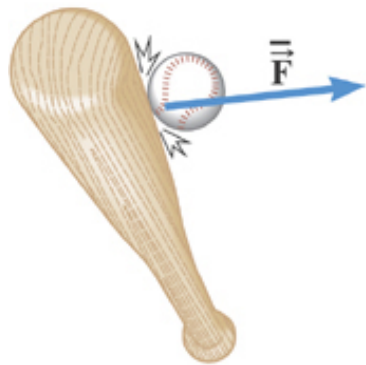
The impulse of a force is the product of the average force and the time interval during which the force acts:

$$\vec{\mathbf{J}} = \vec{\mathbf{F}} \Delta t$$

Impulse is a vector quantity and has the same direction as the average force.

newton · seconds (N · s)

7.1 The Impulse-Momentum Theorem



$$\vec{J} = \bar{\vec{F}} \Delta t$$

7.1 *The Impulse-Momentum Theorem*

DEFINITION OF LINEAR MOMENTUM

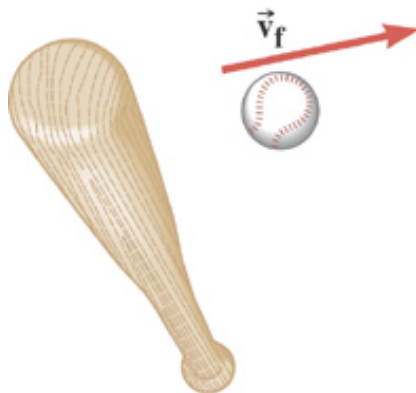
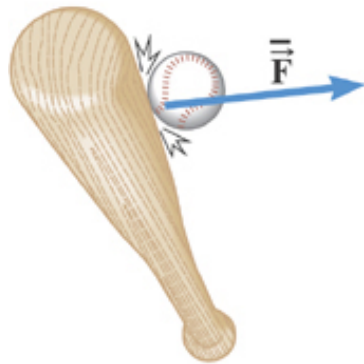
The linear momentum of an object is the product of the object's mass times its velocity:

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

Linear momentum is a vector quantity and has the same direction as the velocity.

kilogram · meter/second (kg · m/s)

7.1 The Impulse-Momentum Theorem



$$\vec{a} = \frac{\vec{v}_f - \vec{v}_0}{\Delta t}$$

$$\sum \vec{F} = m\vec{a}$$

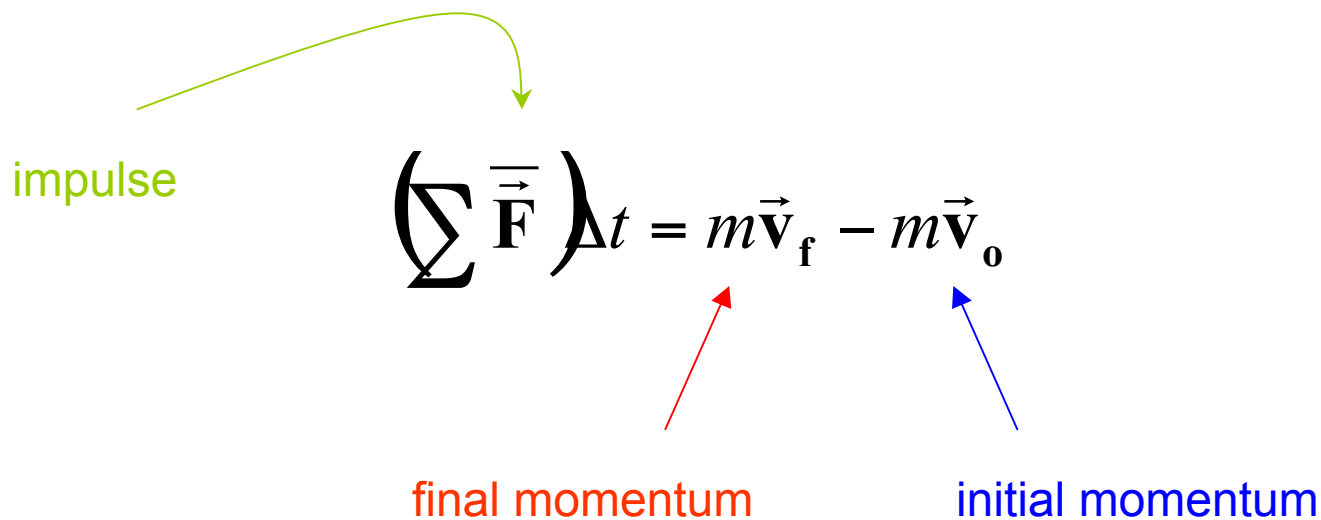
$$\sum \vec{F} = \frac{m\vec{v}_f - m\vec{v}_0}{\Delta t}$$

$$\left(\sum \vec{F}\right)\Delta t = m\vec{v}_f - m\vec{v}_0$$

7.1 *The Impulse-Momentum Theorem*

IMPULSE-MOMENTUM THEOREM

When a net force acts on an object, the impulse of this force is equal to the change in the momentum of the object



The diagram shows the equation $(\sum \vec{F}) \Delta t = m\vec{v}_f - m\vec{v}_o$. A green curved arrow points from the word "impulse" to the term $(\sum \vec{F}) \Delta t$. A red arrow points from the text "final momentum" to the term $m\vec{v}_f$. A blue arrow points from the text "initial momentum" to the term $m\vec{v}_o$.

impulse

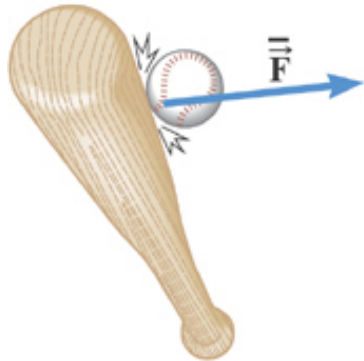
$$(\sum \vec{F}) \Delta t = m\vec{v}_f - m\vec{v}_o$$

final momentum initial momentum

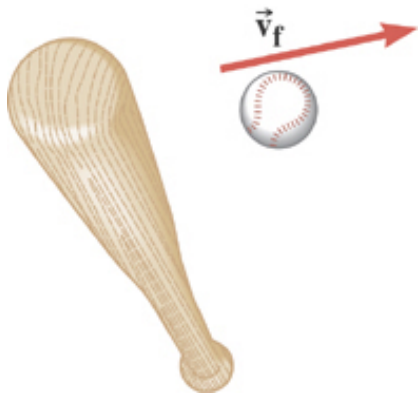
7.1 The Impulse-Momentum Theorem



Example: Hitting a pitched baseball. A baseball of mass 0.14 kg is pitched at a batter with an initial velocity of -38 m/s (negative is towards the bat). The bat applies an average force that is much greater than the weight of the ball, and the ball departs from the bat with a final velocity of +58 m/s. Assuming that the time of contact with the bat is 1.6×10^{-3} s, find the average force exerted on the ball by the bat.



$$\begin{aligned}\vec{J} &= \vec{F} \Delta t = m\vec{v}_f - m\vec{v}_o \\ &= (0.14)(58) - (0.14)(-38) = +13.4 \text{ kg m/s}\end{aligned}$$



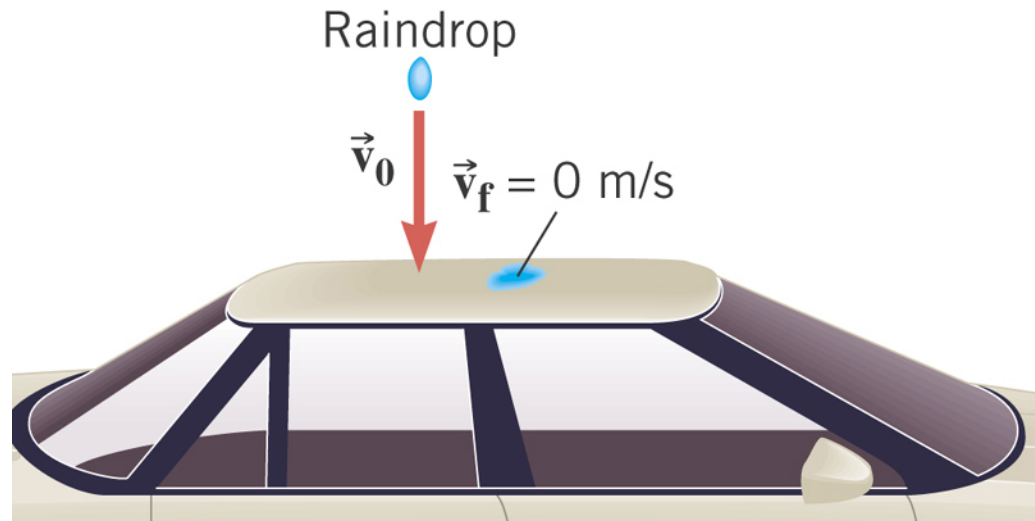
$$\begin{aligned}\vec{F} &= \vec{J} / \Delta t \\ &= (13.4) / (1.6 \times 10^{-3}) = +8400 \text{ N}\end{aligned}$$

7.1 The Impulse-Momentum Theorem

Example: A Rain Storm

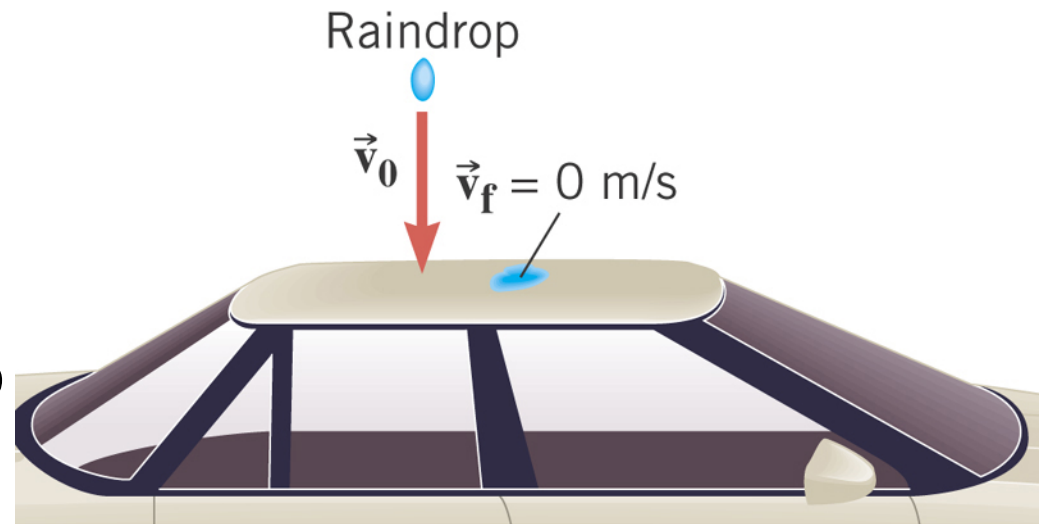
Rain comes down with a velocity of -15 m/s and hits the roof of a car. The mass of rain per second that strikes the roof of the car is 0.060 kg/s . Assuming that rain comes to rest upon striking the car, find the average force exerted by the rain on the roof.

$$\left(\sum \vec{F} \right) \Delta t = m\vec{v}_f - m\vec{v}_o$$



7.1 The Impulse-Momentum Theorem

Neglecting the weight of the raindrops, the net force on a raindrop is simply the force on the raindrop due to the roof.



$$\vec{F} \Delta t = m \vec{v}_f - m \vec{v}_o \quad \longrightarrow \quad \vec{F} = -\left(\frac{m}{\Delta t}\right) \vec{v}_o$$

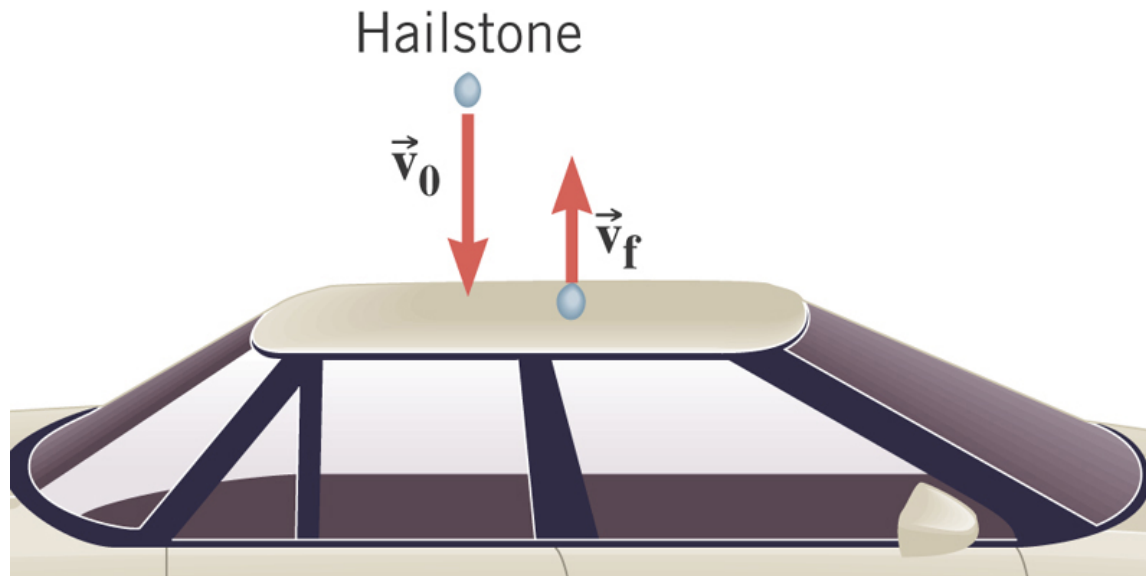
$$\vec{F} = -(0.060 \text{ kg/s})(-15 \text{ m/s}) = +0.90 \text{ N}$$

7.1 *The Impulse-Momentum Theorem*

Conceptual Example: Hailstones Versus Raindrops

Instead of rain, suppose hail is falling. Unlike rain, hail usually bounces off the roof of the car.

If hail fell instead of rain, would the force be smaller than, equal to, or greater than that calculated in the previous Example?



7.2 *The Principle of Conservation of Linear Momentum*

WORK-ENERGY THEOREM $\Leftrightarrow$ CONSERVATION OF ENERGY

IMPULSE-MOMENTUM THEOREM $\Leftrightarrow$???

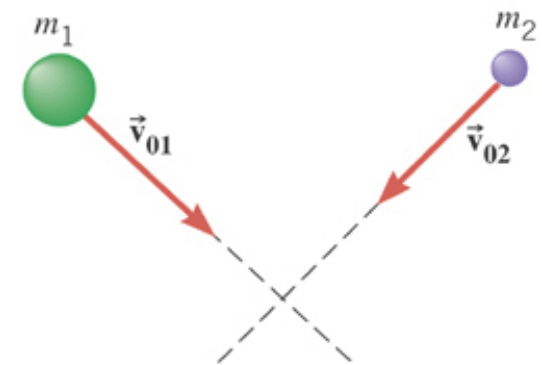
Apply the impulse-momentum theorem to the midair collision between two objects.....

7.2 The Principle of Conservation of Linear Momentum

The midair collision between two objects.

Internal forces – Forces that objects within the system exert on each other.

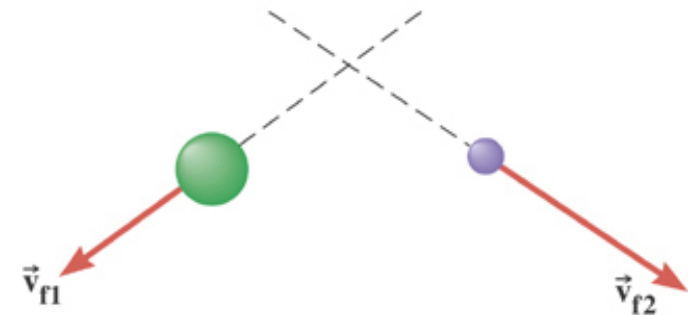
External forces – Forces exerted on objects by agents external to the system.



(a) Before collision



(b) During collision



(c) After collision

7.2 The Principle of Conservation of Linear Momentum

$$\left(\sum \vec{F}\right) \Delta t = m\vec{v}_f - m\vec{v}_o$$

OBJECT 1

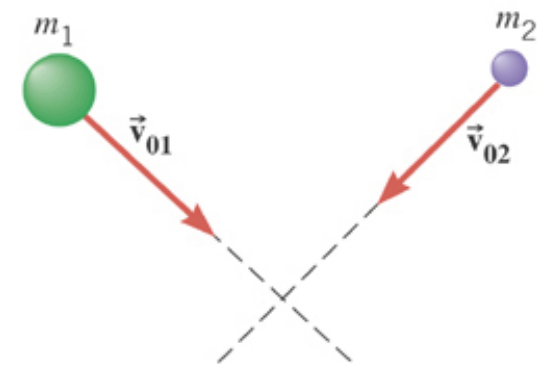
$$\left(\vec{W}_1 + \vec{F}_{12}\right) \Delta t = m_1 \vec{v}_{f1} - m_1 \vec{v}_{o1}$$

External
forces
(gravity)

Internal
forces

OBJECT 2

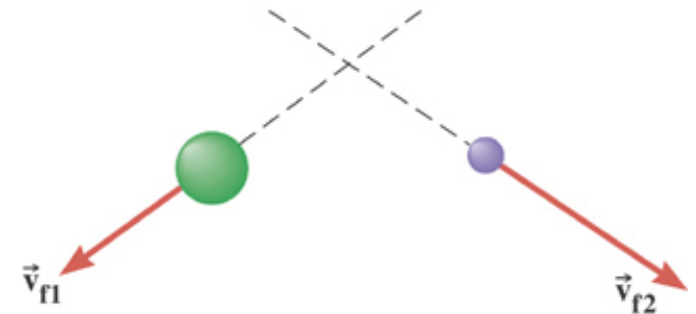
$$\left(\vec{W}_2 + \vec{F}_{21}\right) \Delta t = m_2 \vec{v}_{f2} - m_2 \vec{v}_{o2}$$



(a) Before collision



(b) During collision



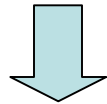
(c) After collision

7.2 The Principle of Conservation of Linear Momentum

$$(\vec{W}_1 + \vec{F}_{12}) \Delta t = m_1 \vec{v}_{f1} - m_1 \vec{v}_{o1}$$

+

$$(\vec{W}_2 + \vec{F}_{21}) \Delta t = m_2 \vec{v}_{f2} - m_2 \vec{v}_{o2}$$



$$(\vec{W}_1 + \vec{W}_2 + \vec{F}_{12} + \vec{F}_{21}) \Delta t = (m_1 \vec{v}_{f1} + m_2 \vec{v}_{f2}) - (m_1 \vec{v}_{o1} + m_2 \vec{v}_{o2})$$



$$\vec{F}_{12} = -\vec{F}_{21}$$

Internal forces cancel
from Newton's 3rd law



$$\vec{P}_f$$

Total final
momentum



$$\vec{P}_o$$

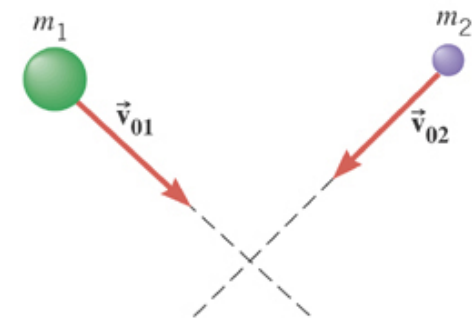
Total initial
momentum

7.2 The Principle of Conservation of Linear Momentum

The internal forces cancel out.

$$(\vec{W}_1 + \vec{W}_2)\Delta t = \vec{P}_f - \vec{P}_o$$

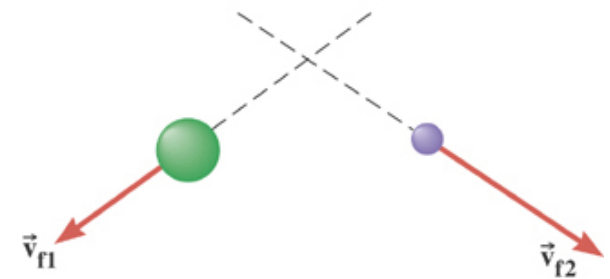
$$(\text{sum of average external forces})\Delta t = \vec{P}_f - \vec{P}_o$$



(a) Before collision



(b) During collision



(c) After collision

7.2 *The Principle of Conservation of Linear Momentum*

$$(\text{sum of average external forces})\Delta t = \vec{P}_f - \vec{P}_o$$

If the sum of the external forces is zero, then

$$0 = \vec{P}_f - \vec{P}_o \quad \longrightarrow \quad \vec{P}_f = \vec{P}_o$$

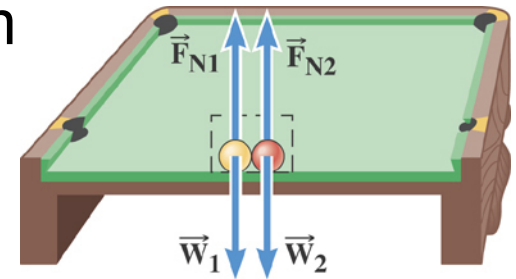
PRINCIPLE OF CONSERVATION OF LINEAR MOMENTUM

The total linear momentum of an isolated system is constant (conserved). An isolated system is one for which the sum of the average external forces acting on the system is zero.

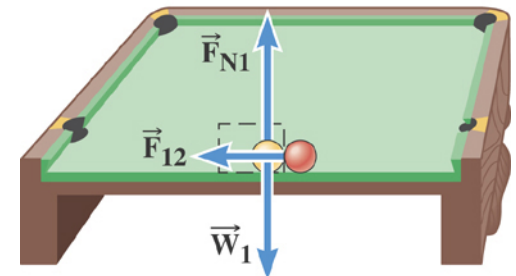
7.2 *The Principle of Conservation of Linear Momentum*

Conceptual Example: Is the Total Momentum Conserved?

Imagine two balls colliding on a billiard table that is friction-free. Use the momentum conservation principle in answering the following questions. (a) Is the total momentum of the two-ball system the same before and after the collision? (b) Answer part (a) for a system that contains only one of the two colliding balls.



(a)



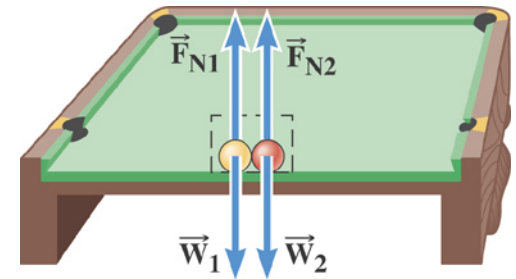
(b)

7.2 *The Principle of Conservation of Linear Momentum*

PRINCIPLE OF CONSERVATION OF LINEAR MOMENTUM

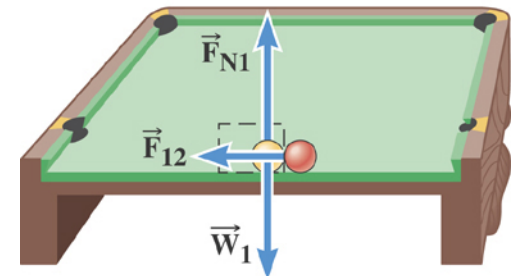
The total linear momentum of an isolated system is constant (conserved). An isolated system is one for which the sum of the average external forces acting on the system is zero.

In the top picture the net external force on the system is zero.



(a)

In the bottom picture the net external force on the system is not zero.



(b)

7.2 *The Principle of Conservation of Linear Momentum*

Applying the Principle of Conservation of Linear Momentum

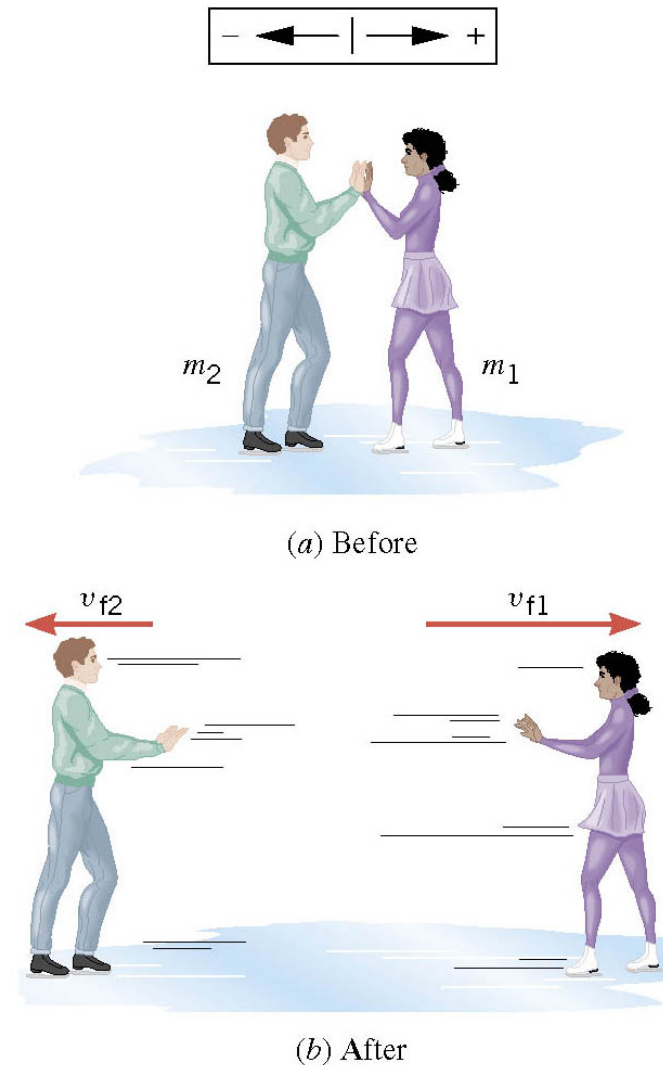
1. Decide which objects are included in the system.
2. Relative to the system, identify the internal and external forces.
3. Verify that the system is isolated.
4. Set the final momentum of the system equal to its initial momentum.
Remember that momentum is a vector.

7.2 The Principle of Conservation of Linear Momentum

Example: Ice Skaters

Starting from rest, two skaters push off against each other on ice where friction is negligible.

One is a 54-kg woman and one is a 88-kg man. The woman moves away with a speed of +2.5 m/s. Find the recoil velocity of the man.



7.2 The Principle of Conservation of Linear Momentum

$$\vec{\mathbf{P}}_f = \vec{\mathbf{P}}_o$$

$$m_1 v_{f1} + m_2 v_{f2} = 0$$

$$v_{f2} = -\frac{m_1 v_{f1}}{m_2}$$

$$v_{f2} = -\frac{(54 \text{ kg})(+2.5 \text{ m/s})}{88 \text{ kg}} = -1.5 \text{ m/s}$$

