

Unit 6: Momentum

What is momentum?

- Momentum is “matter in motion”

Definition of
Momentum

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

- Momentum is a vector quantity (direction is the same as velocity)
- Units -> kg m/s (kilogram-meter per second)

- A baseball ($m = 0.14 \text{ kg}$) has an initial velocity of -38 m/s as it approaches a bat. After being hit by the batter, the ball has a final velocity of $+58 \text{ m/s}$. Determine the baseball's (a) initial momentum, (b) final momentum, and (c) change in momentum.

$$(a) \ p = mv = (0.14 \text{ kg})(-38 \text{ m/s}) = -5.32 \text{ kg m/s}$$

$$(b) \ p = mv = (0.14 \text{ kg})(+58 \text{ m/s}) = +8.12 \text{ kg m/s}$$

$$(c) \ \Delta p = p_f - p_i = (+8.12 \text{ kg m/s}) - (-5.32 \text{ kg m/s}) \\ = +13.4 \text{ kg m/s}$$

Impulse

- An impulse deals with a force and the amount of time it is applied for.

Definition of
Impulse

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

- Impulse is a vector quantity (direction is the same as the force)
- Units -> N s (Newton-second)

- A hockey player strikes a stationary puck ($m = 0.5 \text{ kg}$) with an average force of $+250 \text{ N}$. Determine the impulse delivered to the puck if the force is applied for: (a) 0.05 s , and (b) 0.10 s .

$$(a) J = F\Delta t = (+250 \text{ N})(0.05 \text{ s}) = +12.5 \text{ N} \cdot \text{s}$$

$$(b) J = F\Delta t = (+250 \text{ N})(0.10 \text{ s}) = +25 \text{ N} \cdot \text{s}$$

The Impulse-Momentum Theorem

- Newton's 2nd Law was originally written in terms of momentum:
 - $\sum \vec{F} = \Delta \vec{p} / \Delta t$

Impulse-Momentum
Theorem

$$\vec{J} = \Delta \vec{p}$$
$$\vec{F} \Delta t = m \Delta \vec{v}$$

The impulse delivered to an object is equal to the object's change in momentum.

- The baseball from the previous problem experienced a change in momentum of +13.4 kg m/s. If the bat was in contact with the ball for 0.0016 s, how much force did it exert during this time period?

$$\Delta p = J = +13.4 \text{ kg m/s} = F\Delta t$$

$$F = (+13.4 \text{ kg m/s}) / (0.0016 \text{ s})$$

$$= +8400 \text{ N}$$

- The stationary puck ($m = 0.5 \text{ kg}$) from the previous example experienced an impulse of either $+12.5 \text{ N} \cdot \text{s}$ or $+25 \text{ N} \cdot \text{s}$. Determine the final velocity of the puck for each situation.

$$(a) J = +12.5 \text{ N} \cdot \text{s} = \Delta p = p_f - p_i$$

$$v_f = (+12.5 \text{ N} \cdot \text{s}) / (0.5 \text{ kg}) = +25 \text{ m/s}$$

$$(b) J = 25 \text{ N} \cdot \text{s} = \Delta p = p_f - p_i$$

$$v_f = (+25 \text{ N} \cdot \text{s}) / (0.5 \text{ kg}) = +50 \text{ m/s}$$

- A 240-kg snowmobile accelerates from +6 m/s to +28 m/s.
 - (a) Determine the snowmobile's initial momentum and final momentum.
 - (b) What impulse does the snowmobile experience.
 - (c) If the acceleration took 60 s, what average force acted on the snowmobile?
 - (d) If the acceleration took 30 s, what average force acted on the snowmobile?

$$(a) p_i = (240 \text{ kg})(+6 \text{ m/s}) = +1440 \text{ kg m/s}$$

$$p_f = (240 \text{ kg})(+28 \text{ m/s}) = +6720 \text{ kg m/s}$$

$$(b) J = \Delta p = +6720 \text{ kg m/s} - (+1440 \text{ kg m/s}) = +5280 \text{ N} \cdot \text{s}$$

$$(c) F = (+5280 \text{ N} \cdot \text{s}) / (60 \text{ s}) = +88 \text{ N}$$

$$(d) F = (+5280 \text{ N} \cdot \text{s}) / (30 \text{ s}) = +176 \text{ N}$$

Conservation of Momentum

- In any collision or explosion, the total momentum of all objects involved is conserved.
- To prove this we start with Newton's Third Law

Each object feels this force during the same time interval

$$-F_{B \text{ on } A} = F_{A \text{ on } B}$$

$$-F_{B \text{ on } A} \Delta t = F_{A \text{ on } B} \Delta t$$

$$-\Delta p_A = \Delta p_B$$

$$-(p_{Af} - p_{Ai}) = p_{Bf} - p_{Bi}$$

$$-p_{Af} + p_{Ai} = p_{Bf} - p_{Bi}$$

$$p_{Ai} + p_{Bi} = p_{Af} + p_{Bf}$$

Momentum_{BEFORE} = Momentum_{AFTER}

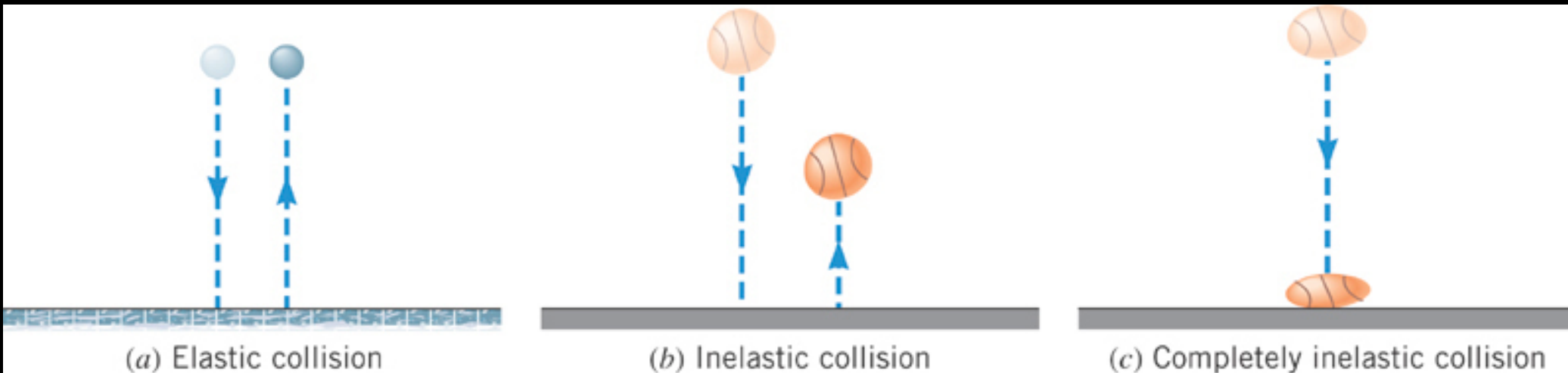
Collision Example

- A 2500-kg SUV traveling at +32 m/s strikes a stationary car (mass = 1100 kg). After the collision, the SUV is traveling at +15 m/s. Determine the velocity of the car after the collision.

Explosion Example

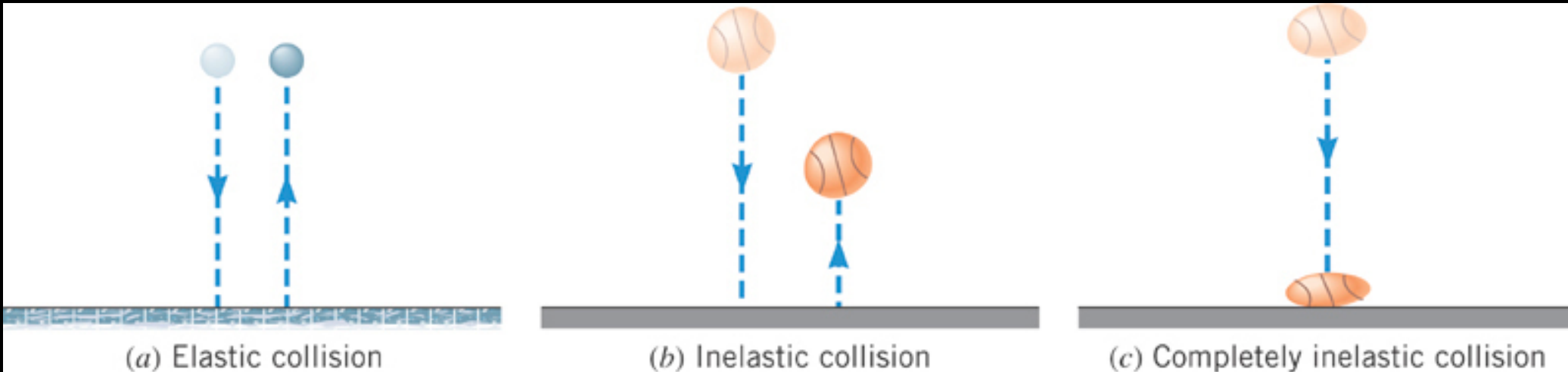
- A 5-kg rifle fires a 4.2-g bullet at +956 m/s. Determine the recoil velocity of the rifle.

Types of Collisions



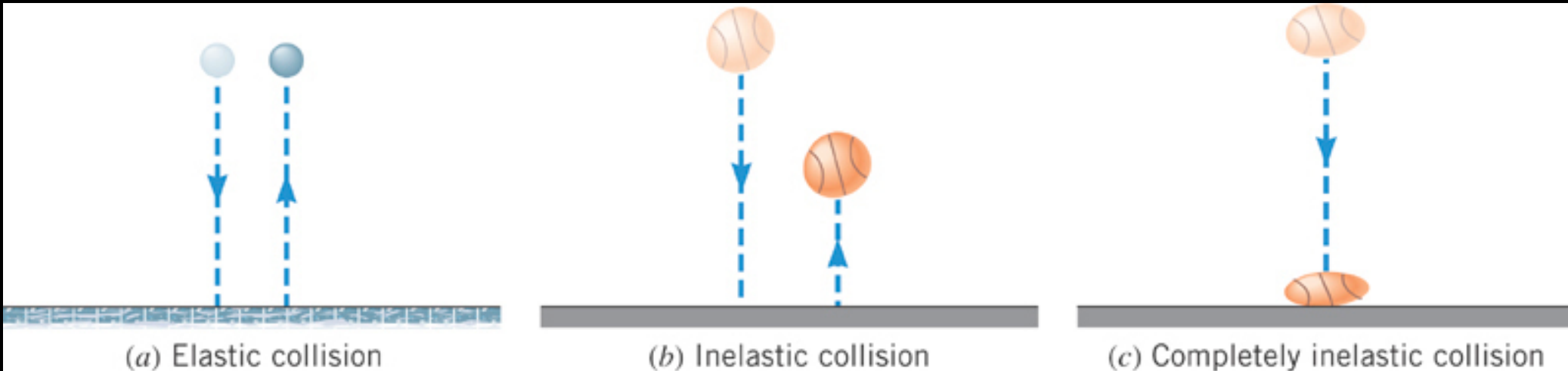
- Elastic: Momentum and kinetic energy is conserved (total of each is the same before and after collision)
- Examples: Air molecules, billiard balls

Types of Collisions



- Inelastic: Momentum is conserved, but some kinetic energy is “lost”
 - Examples: Bouncing ball, car accidents
 - “Lost” kinetic energy was used to create sound, change objects’ shapes, etc.

Types of Collisions



- Completely inelastic: Momentum is conserved; objects colliding “stick together” after collision (same final velocity)
- Examples: Flat basketball; Velcro air track gliders

- A 0.5-kg ball traveling at +6.0 m/s collides head-on with a 1.0-kg ball traveling at -12.0 m/s. The 0.5-kg ball bounces backwards at -14.0 m/s after the collision.

(a) How much total momentum do the balls have before the collision?

-9.0 kg m/s

(b) What is the 1.0-kg ball's velocity after the collision?

-2.0 m/s

(c) How much total KE did the balls have before the collision?

81 J

(d) How much total KE did the balls have after the collision?

51 J

(e) What type of collision was this?

Inelastic