

Impulse & Momentum

November 10, 2025

Momentum and Impulse

- By definition,

$$F = \frac{dp}{dt}$$

where momentum $p = mv$.

- Impulse is defined as the accumulated effect of force over time:

$$J = Ft$$

- If F is a function of time, impulse = area under F vs. t graph

Impulse-Momentum Theorem

- Analogous to work-energy theorem; always holds

$$J = Ft = \Delta p = \Delta(mv)$$

- Can be applied to one object or system of objects
- Impulse and momentum are vectors, define and keep track of sign/direction

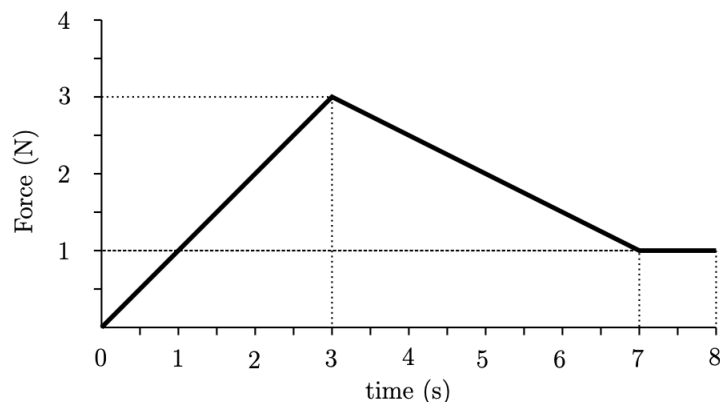
Practice Problems

A truck is initially moving at velocity v . The driver presses the brake in order to slow the truck to a stop. The brake applies a constant force F to the truck. The truck rolls a distance x before coming to a stop, and the time it takes to stop is t .

Which of the following expressions is equal the initial momentum of the truck (i.e. the momentum before the driver starts braking)?

- (A) Fx
- (B) $Ft/2$
- (C) Fxt
- (D) $2Ft$
- (E) $2Fx/v$

A 5.0 kg object undergoes a time-varying force as shown in the graph below. If the velocity at $t = 0.0$ s is +1.0 m/s, what is the velocity of the object at $t = 7$ s?



- (A) 2.45 m/s
- (B) 2.50 m/s
- (C) 3.50 m/s
- (D) 12.5 m/s
- (E) 15.0 m/s

Conservation of Momentum

- If there is no net external force, momentum is conserved

$$\text{If } F_{net} = 0, \text{ then } \Delta p = 0$$

- Unlike energy, must be applied to a system of interacting objects

For a system of collisions, the impulse on each object is nonzero, and individual momentum changes. However, summing individual changes, the impulses from internal force pairs cancel. Thus in the absence of external forces, total impulses is zero, and total momentum for the collision system is conserved.

Practice Problems

- . A light car and a heavy truck have the same momentum. The truck weighs ten times as much as the car. How do their kinetic energies compare?
 - (A) The truck's kinetic energy is larger by a factor of 100
 - (B) The truck's kinetic energy is larger by a factor of 10
 - (C) They have the same kinetic energy
 - (D) The car's kinetic energy is larger by a factor of 10
 - (E) The car's kinetic energy is larger by a factor of 100

Collisions

- In any type of collision, momentum is always conserved.
- In elastic collisions, the objects bounce off each other, and energy is also conserved
- In perfectly inelastic collisions, the objects stick together, and energy is not conserved
- In real life, most collisions are somewhere in between these two extremes.

Elastic Collisions

- Total energy is conserved: use conservation of momentum and energy equations
- Shortcut replacing somewhat complicated energy equation:

$$v_1 - v_2 = v'_2 - v'_1$$

We can derive the velocity of the two particles after an elastic collision:

$$v'_1 = \frac{m_1 m_2}{m_1 + m_2} v_1 - \frac{2m_2}{m_1 + m_2} v_2$$

$$v'_2 = \frac{2m_1}{m_1 + m_2} v_1 + \frac{m_1 m_2}{m_1 + m_2} v_2$$

Perfectly Inelastic Collisions

- Objects stick together after collision

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

Practice Problems

A 12 kg block moving east at 4 m/s collides head on with a 6 kg block that is moving west at 2 m/s. The blocks move together after the collision. What is the *loss* in kinetic energy in this collision?

- (A) 36 J
- (B) 48 J
- (C) 60 J
- (D) 72 J
- (E) 96 J

A 3.0 kg mass moving at 30 m/s to the right collides elastically with a 2.0 kg mass traveling at 20 m/s to the left. After the collision, the center of mass of the system is moving at a speed of

- (A) 5 m/s
- (B) 10 m/s
- (C) 20 m/s
- (D) 24 m/s
- (E) 26 m/s

A particle at rest explodes into three particles of equal mass in the absence of external forces. Two particles emerge at a right angle to each other with equal speed v . What is the speed of the third particle?

- (A) v
- (B) $\sqrt{2}v$
- (C) $2v$
- (D) $2\sqrt{2}v$
- (E) The third particle can have a range of different speeds.

A 0.650 kg ball moving at 5.00 m/s collides with a 0.750 kg ball that is originally at rest. After the collision, the 0.750 kg ball moves off with a speed of 4.00 m/s, and the 0.650 kg ball moves off at a right angle to the final direction of motion of the 0.750 kg ball.

What is the final speed of the 0.650 kg ball?

- (A) 1.92 m/s
- (B) 2.32 m/s
- (C) 3.00 m/s
- (D) 4.64 m/s
- (E) 5.77 m/s

Let the change in total kinetic energy in this collision be defined by $\Delta K = K_f - K_i$, where K_f is the total final kinetic energy, and K_i is the total initial kinetic energy. Which of the following is true?

- (A) $\Delta K = (K_i + K_f)/2$
- (B) $K_f < \Delta K < K_i$
- (C) $0 < \Delta K < K_f$
- (D) $\Delta K = 0$
- (E) $-K_i < \Delta K < 0$

Suppose there are three spheres of masses m_a, m_b , and m_c such that

$$m_a = 2m_b.$$

$$m_a = m_c.$$

Spheres b and c are initially stationary. Sphere a approaches from the left with speed v and collides with sphere b . Sphere b and sphere c are initially separated by a distance l . All the masses are in a line and all collisions are head on and perfectly elastic.

Find the time between the first and second collisions of spheres a and b .

Challenge Problems

A crew of scientists has built a new space station. The space station is shaped like a wheel of radius R , with essentially all its mass M at the rim. When the crew arrives, the station will be set rotating at a rate that causes an object at the rim to have radial acceleration g , thereby simulating Earth's surface gravity. This is accomplished by two small rockets, each with thrust T newtons, mounted on the station's rim. How long a time t does one need to fire the rockets to achieve the desired condition?

- (A) $t = \sqrt{gR^3} M/(2T)$
- (B) $t = \sqrt{gR} M/(2T)$
- (C) $t = \sqrt{gR} M/T$
- (D) $t = \sqrt{gR/\pi} M/T$
- (E) $t = \sqrt{gR} M/(\pi T)$

A 100 kg astronaut carries a launcher loaded with a 10 kg bowling ball; the launcher and the astronaut's spacesuit have negligible mass. The astronaut discovers that firing the launcher results in the ball moving away from her at a relative speed of 50 m/s.

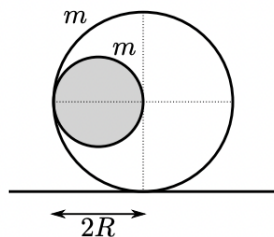
What is the impulse delivered to the astronaut when firing the launcher?

- (A) 455 N s
- (B) 500 N s
- (C) 550 N s
- (D) 5000 N s
- (E) 5500 N s

The astronaut in the previous situation is now moving at 10 m/s (as measured in a certain frame of reference). She wishes to fire the launcher so that her velocity turns through as large an angle as possible (in this frame of reference). What is this maximum angle? (*Hint*: a diagram may be useful.)

- (A) 24.4°
- (B) 26.6°
- (C) 27.0°
- (D) 30.0°
- (E) 180.0°

A ball of radius R and mass m is magically put inside a thin shell of the same mass and radius $2R$. The system is at rest on a horizontal frictionless surface initially. When the ball is, again magically, released inside the shell, it sloshes around in the shell and eventually stops at the bottom of the shell. How far does the shell move from its initial contact point with the surface?



- (A) R .
- (B) $R/2$.
- (C) $R/4$.
- (D) $3R/8$.
- (E) $R/8$.