MOMENTUM AND COLLISION

Pre-class Assignment: Momentum and Collision

Instruction: Complete each statement by filling in the blanks from the given *list of words/phrases.

1. The SI unit of momentum is kg · m/s.
2. Conservation of the total momentum of a system is equivalent to Newton’s third law.
3. A rocket is propelled forward by ejecting gas at high speed. The forward motion is a consequence of conservation of momentum.
4. The impulse delivered to a body by a force is equal to the change in momentum of the body.
5. In an inelastic collision, kinetic energy is not conserved.

* coefficient of restitution, first, momentum, conserved, second, energy, not conserved, third, kg · m/s, N, J, kg/s

A. Impulse and Momentum

1. Linear Momentum (SI unit: kg·m/s) is the product of an object's mass and velocity.

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

2. The impulse (SI unit: N·s or kg·m/s) of a constant force $\vec{F}$ delivered to an object is equal to the product of the force and the time interval during which the force acts:

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

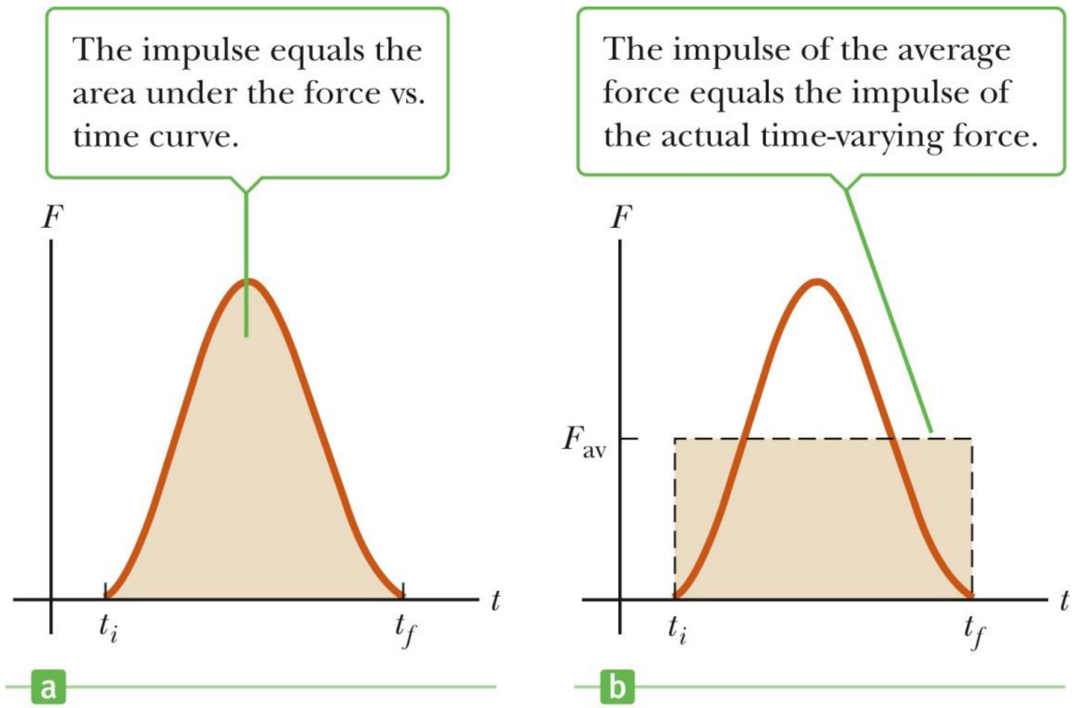
3. The Impulse-momentum theorem, which is equivalent to Newton’s second law, states that an impulse delivered to an object changes the object’s momentum.

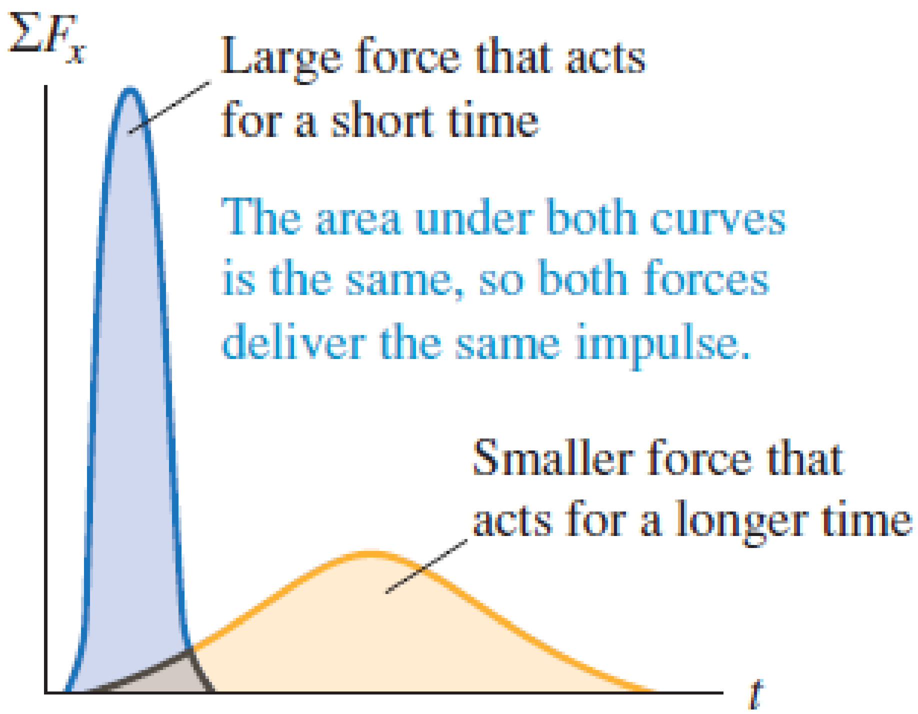
$$\vec{I} = \Delta\vec{p}$$

Impulse is a measure of the degree to which an external force changes the momentum of an object.

In real-life situations, the force on an object is only rarely constant. The force on an object can be replaced with the average force. This average force is the constant force delivering the same impulse to the object in the time interval as the actual time-varying force.

$$\vec{I} = \vec{F}_{av}\Delta t = \Delta\vec{p}$$




ΣF_x
Large force that acts for a short time
The area under both curves is the same, so both forces deliver the same impulse.
Smaller force that acts for a longer time
t


HBO 1:59
PPV
5 of 12

4. Momentum and Kinetic Energy

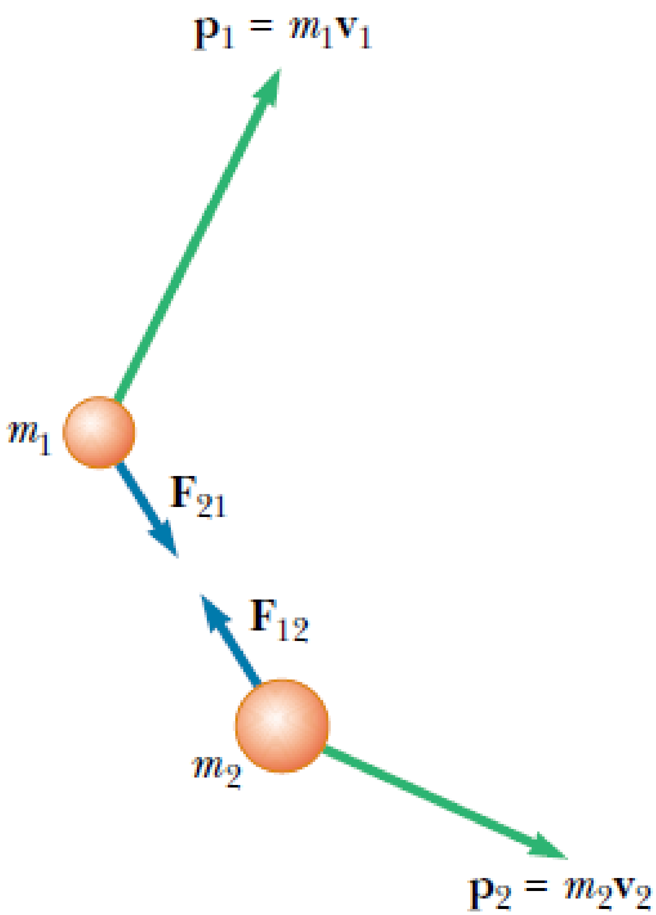
$$KE = \frac{1}{2}mv^2 = \frac{mv \cdot mv}{2m} = \frac{p^2}{2m}$$

Suppose you have a choice between catching a 0.50 kg ball moving at 4.0 m/s or a 0.10 kg ball moving at 20 m/s. Which will be easier to catch?

B. Conservation of Momentum

The principle of conservation of momentum is based on Newton's third law. It states that if the vector sum of the external forces on a system is zero (called an isolated system), the total momentum of the system is constant.

For example, consider two objects



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

C. Collisions

Total momentum is conserved for any collisions in an isolated system.

1. Elastic Collision
2. Super-elastic collision
3. Perfectly (completely) inelastic collision
4. Inelastic collision

Checkpoint Questions:

1. What is the SI unit of impulse?
2. Two identical automobiles have the same speed, one traveling east and one travelling west. Do these cars have the same momentum?
3. Two objects have the same momentum. Do the velocities of these objects necessarily have (a) the same directions and (b) the same magnitudes?
4. (a) Can a single object have a kinetic energy but no momentum? (b) Can a group of two or more objects have

a total kinetic energy that is not zero but a total momentum that is zero?

5. Suppose you are standing on the edge of a dock and jump straight down. If you land on sand your stopping time is much shorter than if you land on water. In bringing you to a halt, the sand and the water exert the same impulse on you, but the _____ [sand, water] exerts a greater average force.

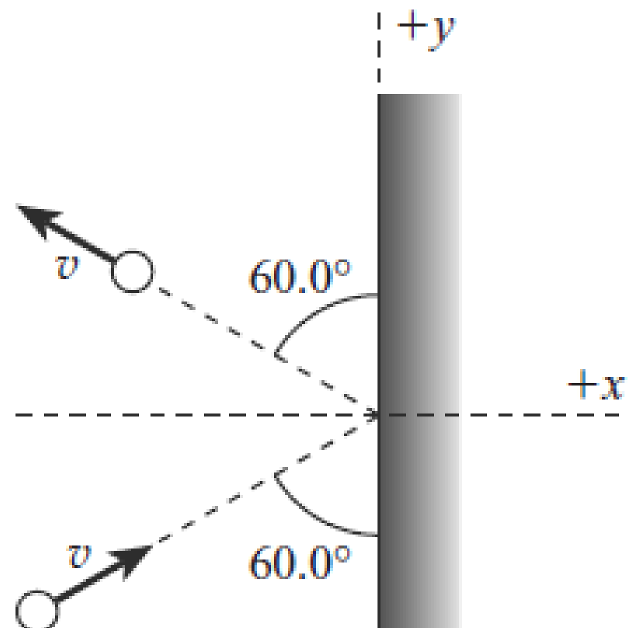
* A 46-kg skater is standing still in front of a wall. By pushing against the wall she propels herself backward with a velocity of -1.2 m/s. Her hands are in contact with the wall for 0.80 s. Ignore friction and wind resistance. Find the magnitude and direction of the average force she exerts on the wall (which has the same magnitude as, but opposite direction to, the force that the wall applies to her).

* In a performance test, each of two cars takes 9.0 s to accelerate from rest to 27 m/s. Car A has a mass of 1400 kg, and car B has a mass of 1900 kg. Find the net average force that acts on each car during the test.

* A basketball (m = 0.60 kg) is dropped from rest. Just before striking the floor, the ball has a momentum whose magnitude is 3.1 kg m/s. At what height was the basketball dropped?

* An 85-kg jogger is heading due east at a speed of 2.0 m/s. A 55-kg jogger is heading 32 degrees north of east at a speed of 3.0 m/s. Find the magnitude and direction of the sum of the momenta of the two joggers.

* A 3-kg steel ball strikes a massive wall at 10 m/s at an angle of 60 degrees with the plane of the wall. It bounces off the wall with the same speed and angle. If the ball is in contact with the wall for 0.200 s, what is the average force exerted by the wall on the ball?



* A rifle with a weight of 30 N fires a 5-g bullet with a speed of 300 m/s.

(a) Find the recoil speed of the rifle.

(b) If a 700-N man holds the rifle firmly against his shoulder, find the recoil speed of the man and rifle.

* $\vec{F} = \dfrac{m\vec{v}_f - m\vec{v}_i}{\Delta t} = \dfrac{(46)(-1.2) - (46)(0)}{0.80} \simeq -69N$

By Newton's 3rd law

force exerted on wall = $\boxed{+69N}$

$\boxed{\text{opposite to velocity}}$

* Car A:

$$\Sigma \vec{F} = \frac{m\vec{v}_f - m\vec{v}_i}{\Delta t} = \frac{(1400)(+27) - (1400)(0)}{9.0}$$

$$\simeq \boxed{+4\,200\text{ N}}$$

Car B:

$$\Sigma \vec{F} = \frac{m\vec{v}_f - m\vec{v}_i}{\Delta t} = \frac{(1900)(+27) - (1900)(0)}{9.0}$$

$$\simeq \boxed{+5\,700\text{ N}}$$

* $v_y^2 = \cancel{v_{0y}^2}^{\,0} + 2a_y\,\Delta y$

$$v_y = \frac{p}{m}$$

$$\Delta y = \frac{v_y^2}{2a_y} = \frac{(p/m)^2}{2a_y}$$

$$\Delta y = \frac{[(3.1)/(0.60)]^2}{2(9.8)} \simeq \boxed{1.4\text{ m}}$$

* $\Sigma P_x = P_{Ax} + P_{Bx}$

$$= (85)(2) + (55)(3)\cos 32^\circ$$

$$= 170 + 140$$

$\Sigma P_x = 310$ kg·m/s

$$\Sigma P_y = P_{Ay} + P_{By} = 0 + (55)(3)\sin 32^\circ \simeq 87\text{ kg·m/s}$$

$$P = \sqrt{310^2 + 87^2} \simeq \boxed{322\text{ kg·m/s}}$$

$$\theta = \tan^{-1}(87/310) \simeq \boxed{16^\circ}$$

* $\vec{F}_{av} = \dfrac{\Delta \vec{p}}{\Delta t}$

$$(F_{av})_x = \frac{\Delta p_x}{\Delta t} \quad \text{and} \quad (F_{av})_y = \frac{\Delta p_y}{\Delta t}$$

$$(F_{av})_y = \frac{m[(v_y)_f - (v_y)_i]}{\Delta t}$$

$$= \frac{m[v\cos 60^\circ - v\cos 60^\circ]}{\Delta t}$$

$(F_{av})_y = 0$

$$(F_{av})_x = \frac{m[(v_x)_f - (v_x)_i]}{\Delta t}$$

$$= \frac{m[(-v\sin 60^\circ) - (+\sin 60^\circ)]}{\Delta t}$$

$$= \frac{-2mv\sin 60^\circ}{\Delta t}$$

$$= \frac{-2(3)(10)\sin 60^\circ}{0.2}$$

$(F_{av})_x = -260$ N

$$\vec{F}_{av} = \boxed{260\text{ N along the } -x\text{-direction}}$$

* (a) $m = \dfrac{W}{g} = \dfrac{30}{9.8}$

$$(m_{rifle}v_{rifle} + m_{bullet}v_{bullet})_f = (m_{rifle}v_{rifle} + m_{bullet}v_{bullet})_i$$

$$[(30/9.8)]\,v_{rifle} + (5\times10^{-3})(-300) = 0 + 0$$

$$v_{rifle} = \frac{(9.8)(5\times10^{-3})(300)}{30} \simeq \boxed{0.49\text{ m/s}}$$

(b) $m = \dfrac{730}{9.8} = 74.5$ kg $\quad v = \left(\dfrac{5\times10^{-3}}{74.5}\right)300 \simeq \boxed{2\times10^{-2}\text{ m/s}}$