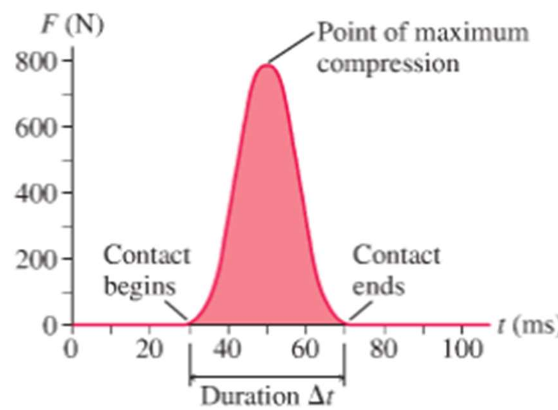
MOMENTUM

IMPULSE

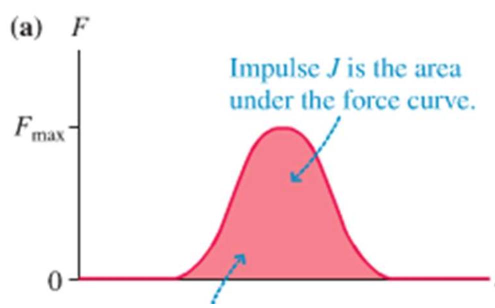
- **Collision** → short-duration impact between two objects.
  - Every collision results in some amount of compression, even if too small/quick for the human eye to notice it.

  - The material the object is made of dictates collision time.
  - Typically 1 to 10 ms long
  - Harder objects = shorter impact times
  - More compression = greater impact force



- **Impulsive force** → a large force exerted during a short period of time.
  - Examples: baseball and bat, fist and face, hammer and nail, etc.
  - Take the soccer example above: A stronger force or a force of longer duration will result in a larger velocity on the kicked object.
  - A harder force would result in a taller F v. t curve, a longer impact time would result in a wider F v. t graph. Either one results in a larger area under the curve.
  - **The effect of an impulsive force is proportional to the area under the force versus time curve.**
  - Called **IMPULSE** (J) of the force.

$$J = F\Delta t$$



- The force is an average force exerted on the object.
  - Units: N·s, but kg·m/s are preferable and equivalent

- Impulse is a vector quantity. +/- depends on direction of the average force

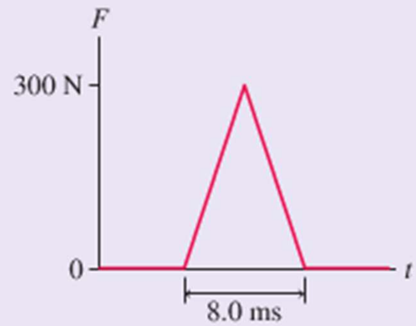
EXAMPLE 9.1 **Finding the impulse on a bouncing ball**

A rubber ball experiences the force shown in FIGURE 9.4 as it bounces off the floor.

a. What is the impulse on the ball?

b. What is the average force on the ball?

FIGURE 9.4 The force of the floor on a bouncing ball.



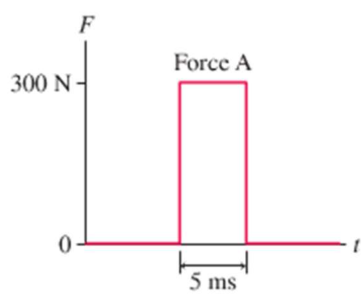
PREPARE The impulse is the area under the force curve. Here the shape of the graph is triangular, so we'll need to use the fact that the area of a triangle is $\frac{1}{2} \times$ height $\times$ base.

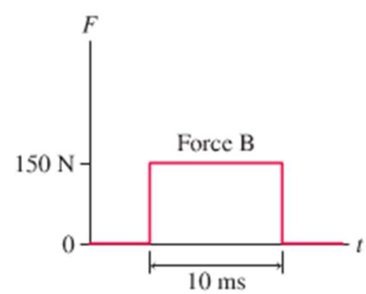
STOP TO THINK 9.1 Graph A is the force-versus-time graph for a hockey stick hitting a 160 g puck. Graph B is the force-versus-time graph for a golf club hitting a 46 g golf ball. Which force delivers the greater impulse?

A. Force A

B. Force B

C. Both forces deliver the same impulse.





<u>IMPULSE-MOMENTUM THEOREM</u>

- **Momentum→** the product of an object's mass and velocity

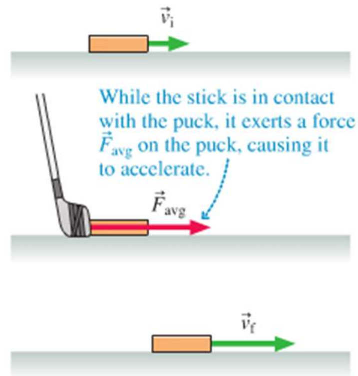
$$p = mv$$

- Experience teaches us that kicking a medicine ball will result in lower velocity than kicking a soccer ball with the same amount of force.

$$J = \Delta p$$

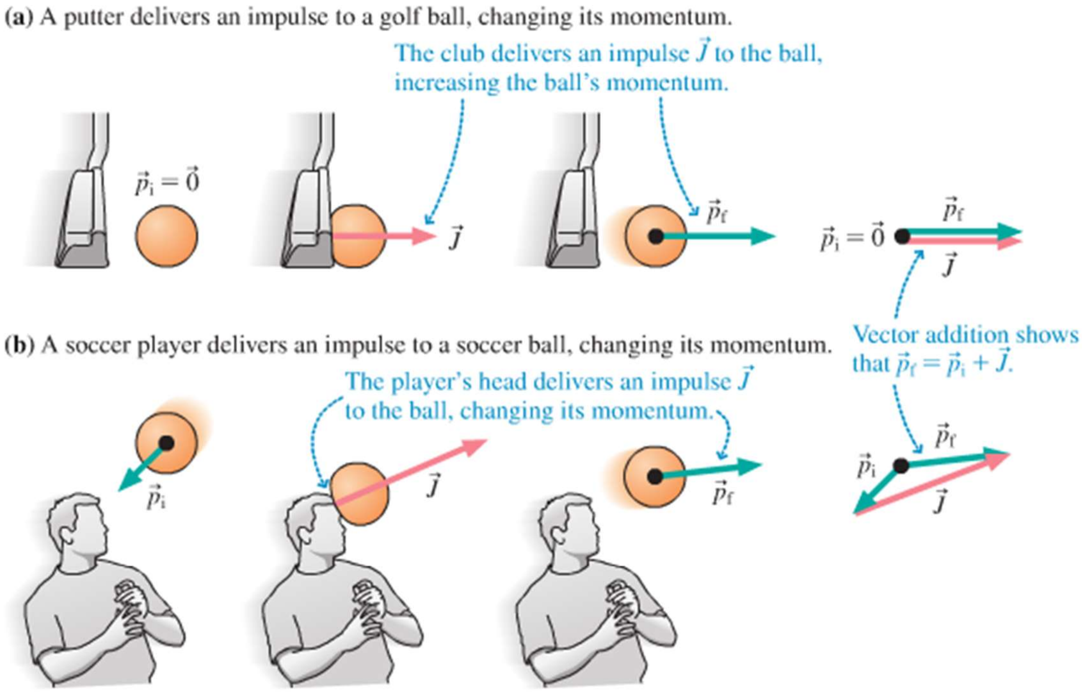
$$F\Delta t = m\Delta v$$

FIGURE 9.5 The stick exerts an impulse on the puck, changing its speed.

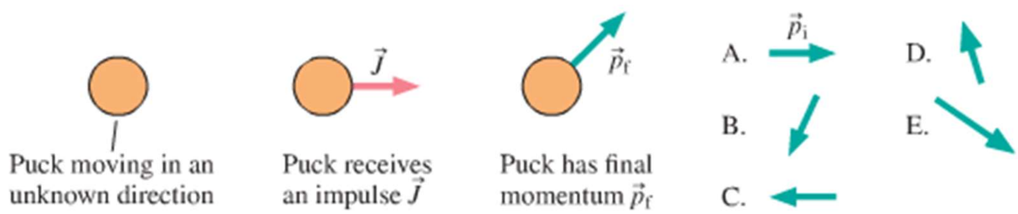


Legging it BIO A frog making a jump wants to gain as much momentum as possible before leaving the ground. This means that he wants the greatest impulse $J = F_{avg}\,\Delta t$ delivered to him by the ground. There is a maximum force that muscles can exert, limiting F_{avg}. But the time interval Δt over which the force is exerted can be greatly increased by having long legs. Many animals that are good jumpers have particularly long legs.

- **Impulse-momentum theorem→** an impulse delivered to an object causes its momentum to change.



STOP TO THINK 9.2 A puck, seen from above, was moving with an initial momentum when it received an impulse $\vec{J}$ from a hockey stick, giving it the final momentum shown. Using the ideas of Figure 9.7, which arrow best represents the puck's initial momentum?



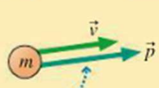
SYNTHESIS 9.1 Momentum and impulse

A moving object has momentum. A force acting on an object delivers an *impulse* that changes the object's momentum.

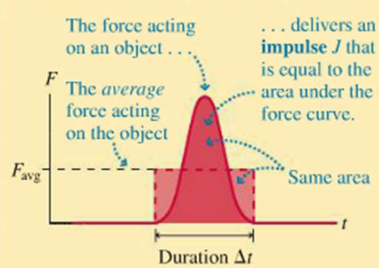
The **momentum** of an object is the product of its mass and its velocity.

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

Momentum (kg · m/s); Mass (kg); Velocity (m/s)

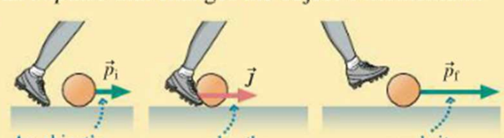


The *direction* of an object's momentum is the same as its velocity.



$$\vec{J} = \vec{F}_{avg}\,\Delta t$$

Impulse (kg · m/s); Duration (s); Average force (N)



An object's initial momentum . . . . . . plus the impulse delivered to it . . . . . . equals its final momentum.

$$\vec{p}_i + \vec{J} = \vec{p}_f$$

This relationship can also be written in terms of the *change* in the object's momentum:

$$\vec{J} = \vec{p}_f - \vec{p}_i = \Delta\vec{p}$$

The impulse delivered . . . . . . equals the change in the momentum.

STOP TO THINK 9.4 A 10 g rubber ball and a 10 g clay ball are each thrown at a wall with equal speeds. The rubber ball bounces; the clay ball sticks. Which ball receives the greater impulse from the wall?

A. The clay ball receives a greater impulse because it sticks.
B. The rubber ball receives a greater impulse because it bounces.
C. They receive equal impulses because they have equal momenta.
D. Neither receives an impulse because the wall doesn't move.

CONSERVATION OF MOMENTUM

- **Law of Conservation of Momentum→** the momentum of a system remains constant. There is no change in the *total* momentum of a system.

$$p_i = p_f$$

  - This holds true for *isolated systems*.
  - **Isolated system→** no net external forces acting on the objects.
  - All forces are internal to the system.

EXAMPLE 9.5 Speed of ice skaters pushing off

Two ice skaters, Sandra and David, stand facing each other on frictionless ice. Sandra has a mass of 45 kg, David a mass of 80 kg. They then push off from each other. After the push, Sandra moves off at a speed of 2.2 m/s. What is David's speed?

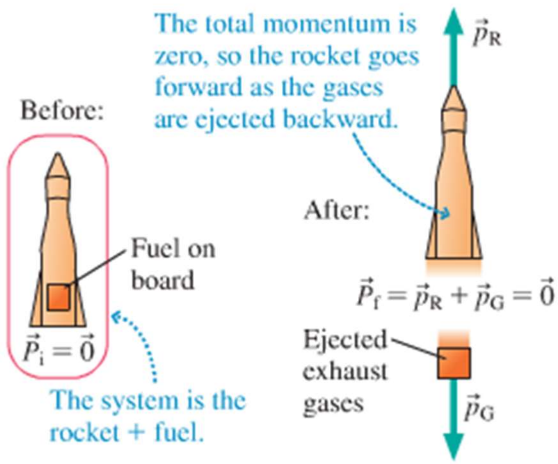
EXAMPLE 9.6 Getaway speed of a cart

Bob is running from the police and thinks he can make a faster getaway by jumping on a stationary cart in front of him. He runs toward the cart, jumps on, and rolls along the horizontal street. Bob has a mass of 75 kg and the cart's mass is 25 kg. If Bob's speed is 4.0 m/s when he jumps onto the cart, what is the cart's speed after Bob jumps on?

EXPLOSIONS

- **Explosion →** when the particles/objects move apart after a brief, intense interaction.
- Opposite of a collision.
- The explosive forces (ex: expanding spring or expanding gases) are internal forces.
- If the system is isolated, its total momentum will be conserved.

FIGURE 9.21 Rocket propulsion is an example of conservation of momentum.



EXAMPLE 9.7 **Recoil speed of a rifle**

A 30 g ball is fired from a 1.2 kg spring-loaded toy rifle with a speed of 15 m/s. What is the recoil speed of the rifle?

Squid propulsion BIO Squids use a form of "rocket propulsion" to make quick movements to escape enemies or catch prey. The squid draws in water through a pair of valves in its outer sheath, or mantle, and then quickly expels the water through a funnel, propelling the squid backward.

STOP TO THINK 9.5 An explosion in a rigid pipe shoots three balls out of its ends. A 6 g ball comes out the right end. A 4 g ball comes out the left end with twice the speed of the 6 g ball. From which end, left or right, does the third ball emerge?

INELASTIC COLLISIONS

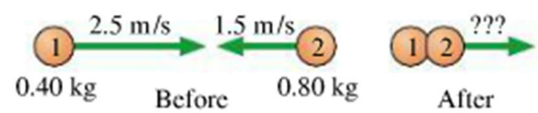
- **Elastic collisions →** when the objects bounce off of each other. Ex: a ball bouncing off a wall.
- **Perfectly inelastic collisions →** a collision in which two objects stick together and move with a common final velocity. Ex: a bullet embedding itself in a piece of wood.

EXAMPLE 9.8 **A perfectly inelastic collision of railroa**

In assembling a train from several railroad cars, two of the cars, with masses 2.0×10^4 kg and 4.0×10^4 kg, are rolled toward each other. When they meet, they couple and stick together. The lighter car has an initial speed of 1.5 m/s; the collision causes it to reverse direction at 0.25 m/s. What was the initial speed of the heavier car?

STOP TO THINK 9.6 The two particles shown collide and stick together. After the collision, the combined particles

A. Move to the right as shown.
B. Move to the left.
C. Are at rest.



COLLISIONS IN TWO DIMENSIONS

- Most collisions in real life occur in more than one dimension.
- Momentum is conserved if each component of momentum is conserved.

$$p_{ix} = p_{fx}$$

$$p_{iy} = p_{fy}$$

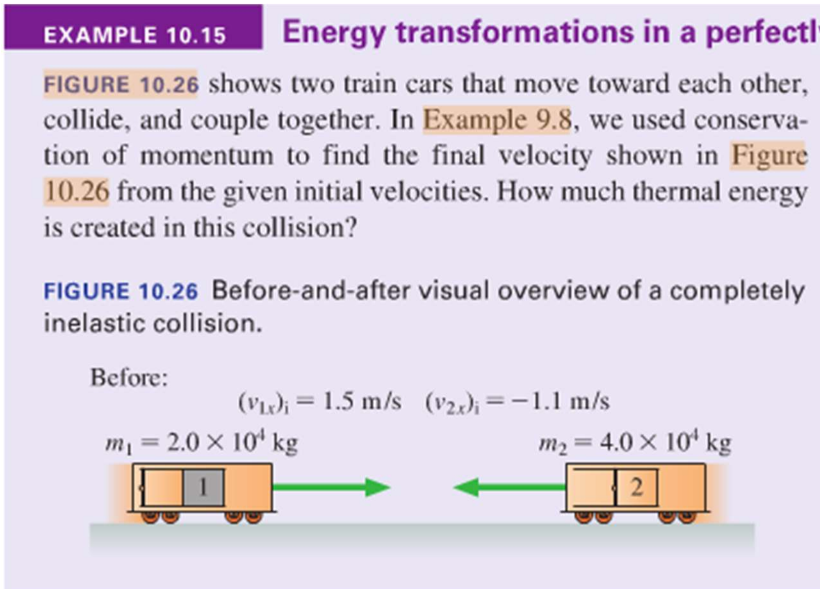
Collisions and explosions often involve motion in two dimensions.

EXAMPLE 9.9 **Analyzing a peregrine falcon strike** BIO

Peregrine falcons often grab their prey from above while both falcon and prey are in flight. A falcon, flying at 18 m/s, swoops down at a 45° angle from behind a pigeon flying horizontally at 9.0 m/s. The falcon has a mass of 0.80 kg and the pigeon a mass of 0.36 kg. What are the speed and direction of the falcon (now holding the pigeon) immediately after impact?

ENERGY IN COLLISIONS

- Kinetic energy is not perfectly conserved in inelastic collisions.
    - ➢ Some is transformed into *thermal* energy (i.e., HEAT).



EXAMPLE 10.15 Energy transformations in a perfectly

FIGURE 10.26 shows two train cars that move toward each other, collide, and couple together. In Example 9.8, we used conservation of momentum to find the final velocity shown in Figure 10.26 from the given initial velocities. How much thermal energy is created in this collision?

FIGURE 10.26 Before-and-after visual overview of a completely inelastic collision.

- If kinetic energy is perfectly conserved, it's called a **perfectly elastic collision**.
    - ➢ Ex: tennis ball hits a racket, K is stored as elastic potential energy, then converted back into K without any heat loss.
    - ➢ Most collisions fall somewhere between perfectly elastic and perfectly inelastic.