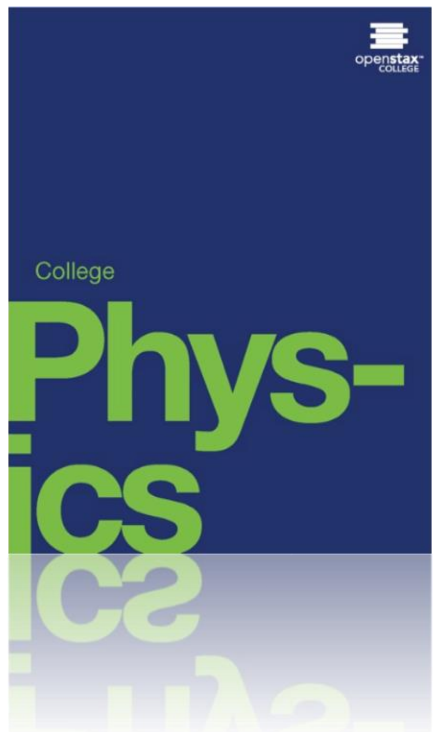
COLLEGE PHYSICS

Chapter 8 LINEAR MOMENTUM AND COLLISIONS

PowerPoint Image Slideshow



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Chapter 8

- Momentum and Its Relation to Force
- Conservation of Momentum
- Collisions and Impulse
- Conservation of Energy and Momentum in Collisions
- Elastic Collisions in One Dimension

Chapter 8

- Inelastic Collisions
- Collisions in Two or Three Dimensions
- Center of Mass (CM)
- CM for the Human Body
- Center of Mass and Translational Motion

Momentum and Its Relation to Force

Momentum is a vector symbolized by the symbol p, and is defined as

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

The rate of change of momentum is equal to the net force:

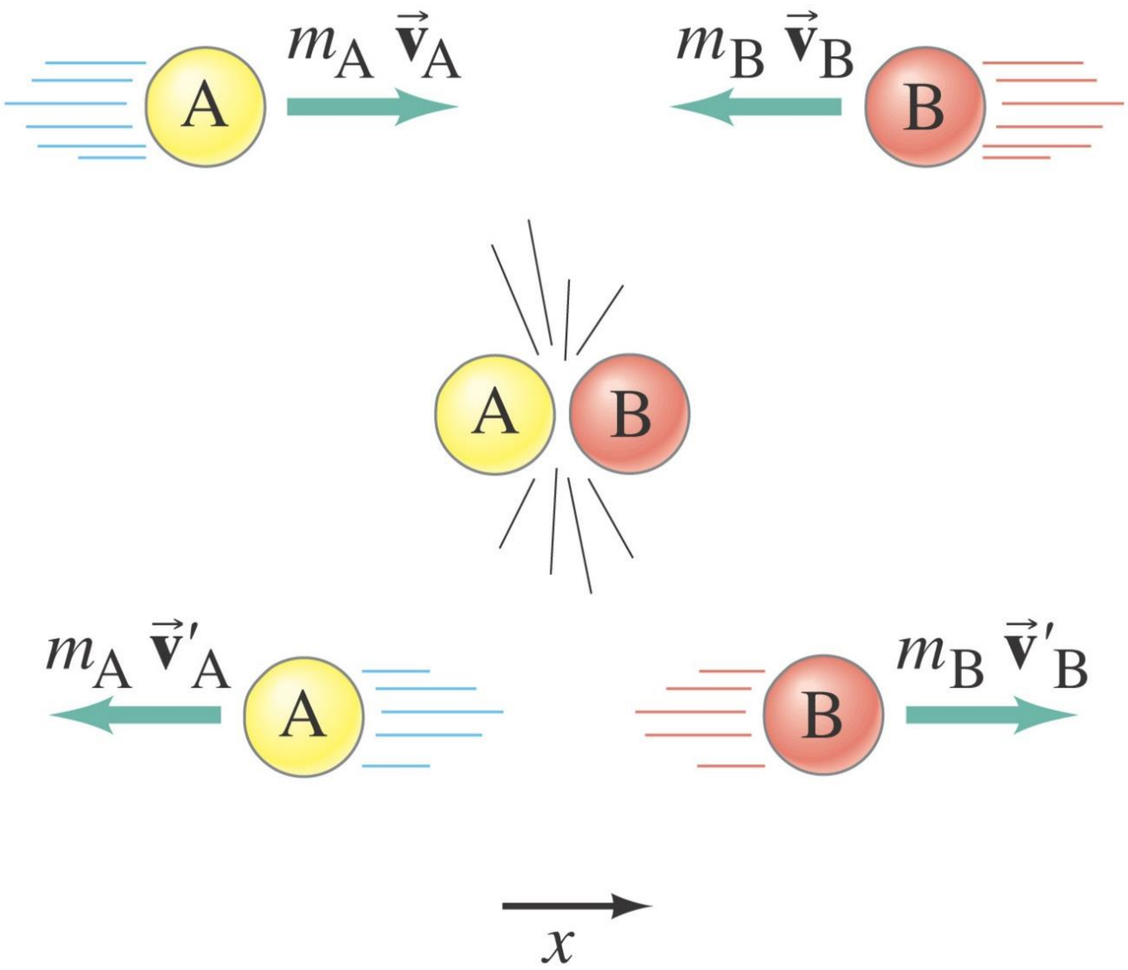
$$\mathbf{F}_{\mathrm{NET}} = \Delta\mathbf{p}/\Delta t$$

This can be shown using Newton's second law.

Conservation of Momentum

During a collision, measurements show that the total momentum does not change:

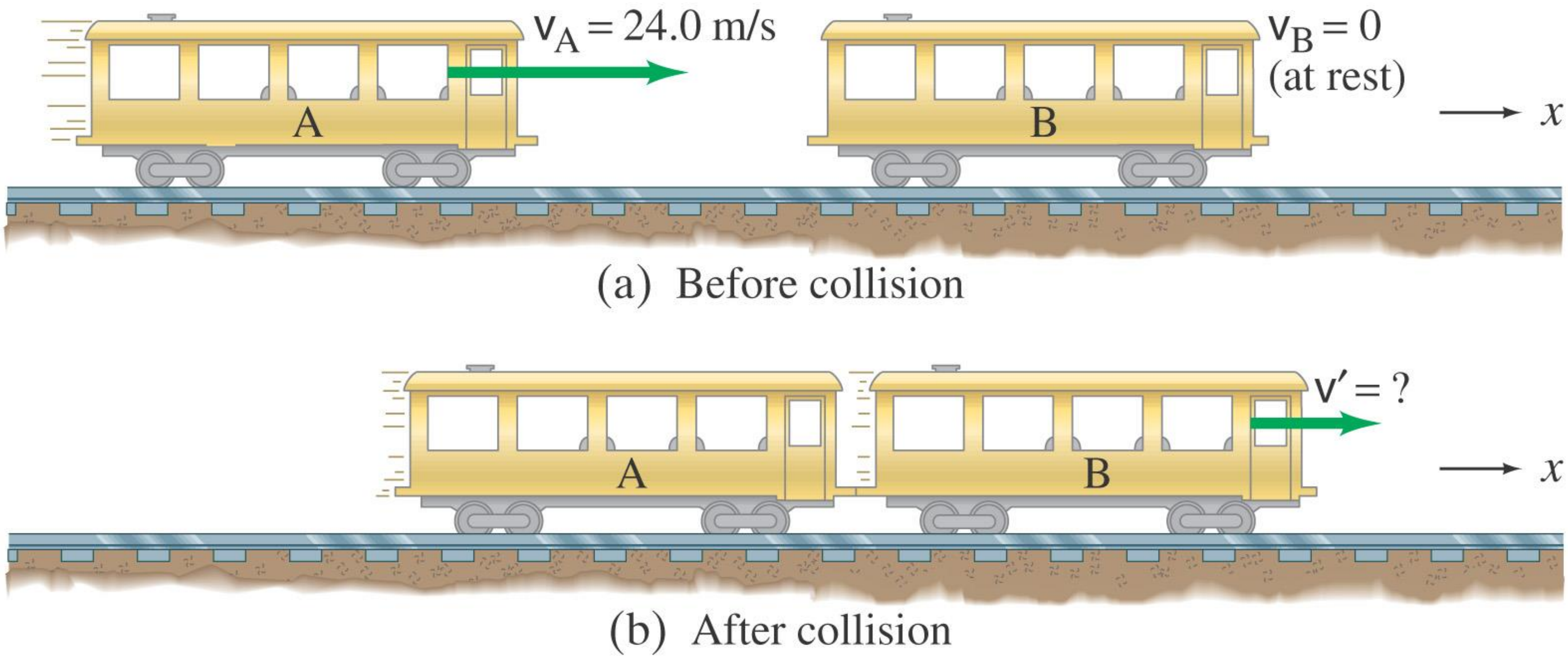
$$m_A \vec{\mathbf{v}}_A + m_B \vec{\mathbf{v}}_B = m_A \vec{\mathbf{v}}'_A + m_B \vec{\mathbf{v}}'_B$$



Conservation of Momentum

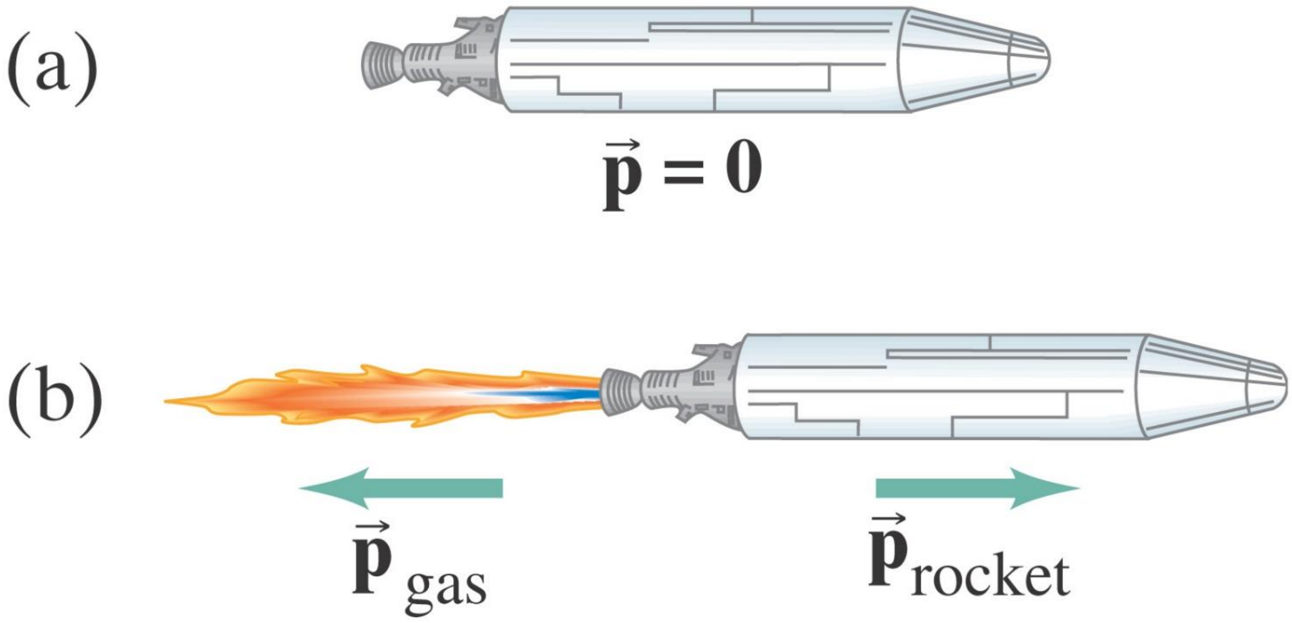
More formally, the law of conservation of momentum states:

The total momentum of an isolated system of objects remains constant.

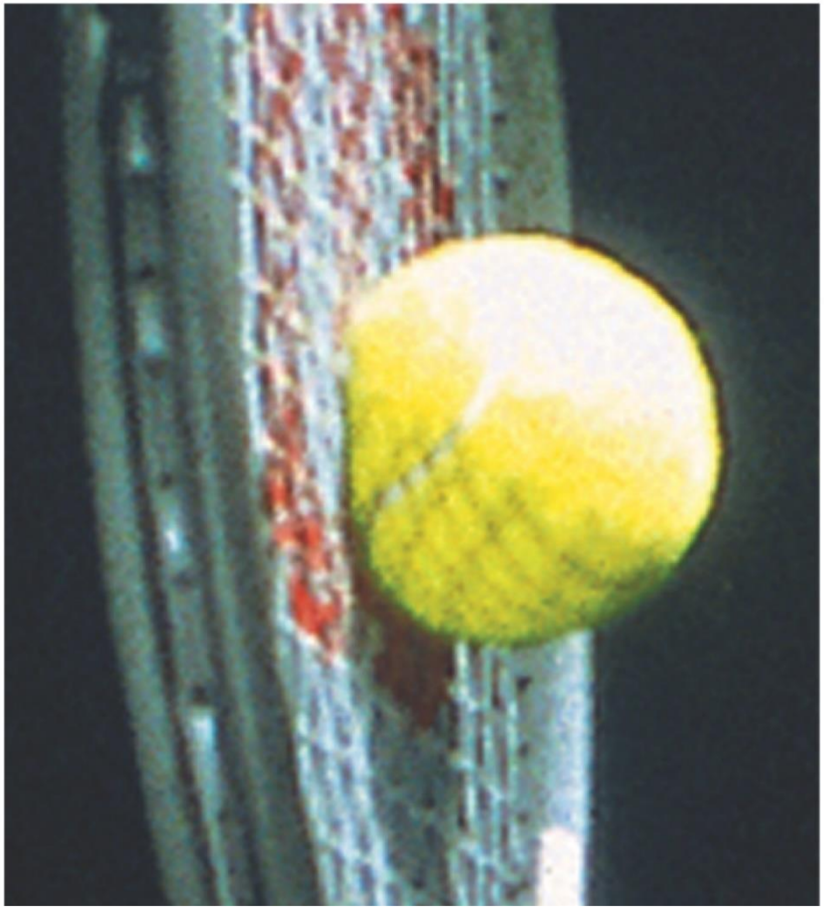


Conservation of Momentum

Momentum conservation works for a rocket as long as we consider the rocket and its fuel to be one system, and account for the mass loss of the rocket.



Collisions and Impulse



During a collision, objects are deformed due to the large forces involved.

Since $\vec{\mathbf{F}} = \dfrac{\Delta \vec{\mathbf{p}}}{\Delta t}$, we can

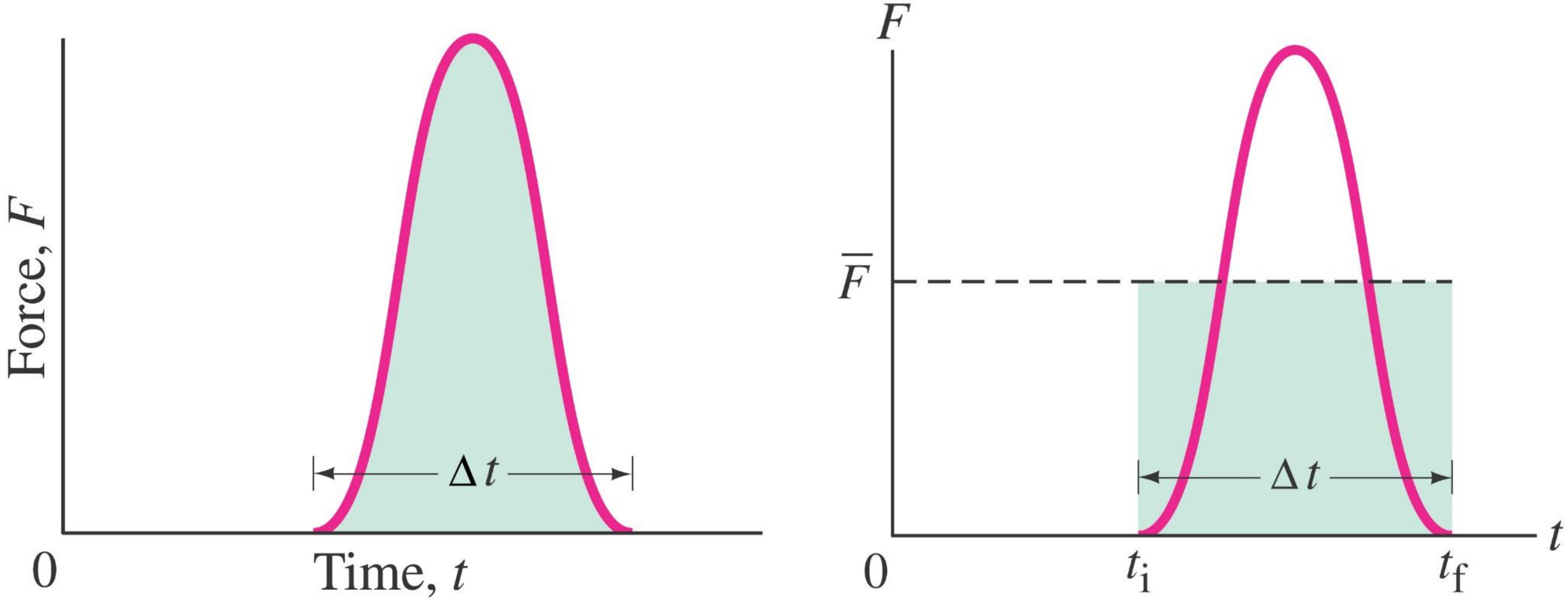
write $\vec{\mathbf{F}}\,\Delta t = \Delta \vec{\mathbf{p}}$

The definition of impulse:

$$\text{Impulse} = \vec{\mathbf{F}}\,\Delta t$$

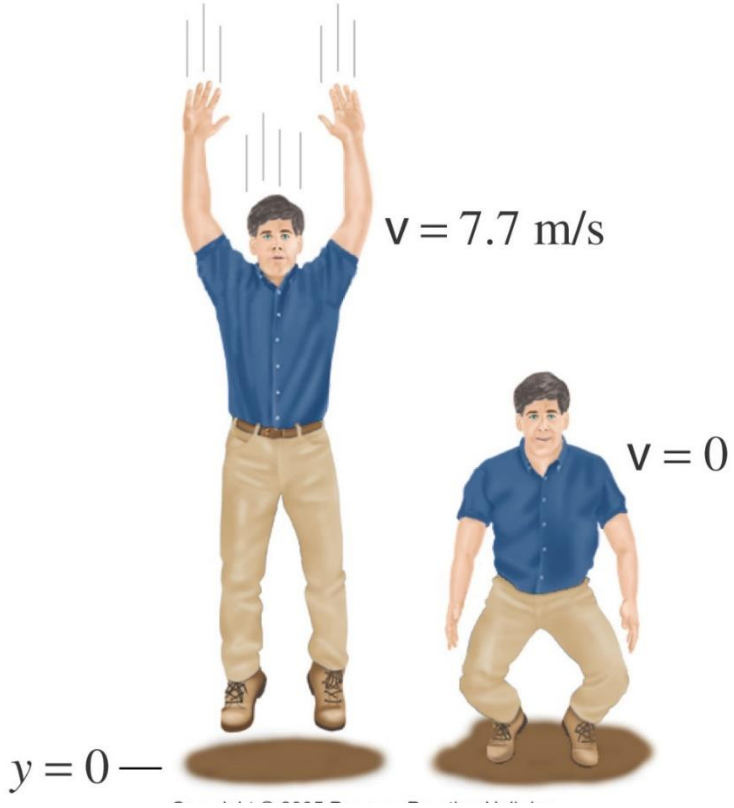
Collisions and Impulse

Since the time of the collision is very short, we need not worry about the exact time dependence of the force, and can use the average force.



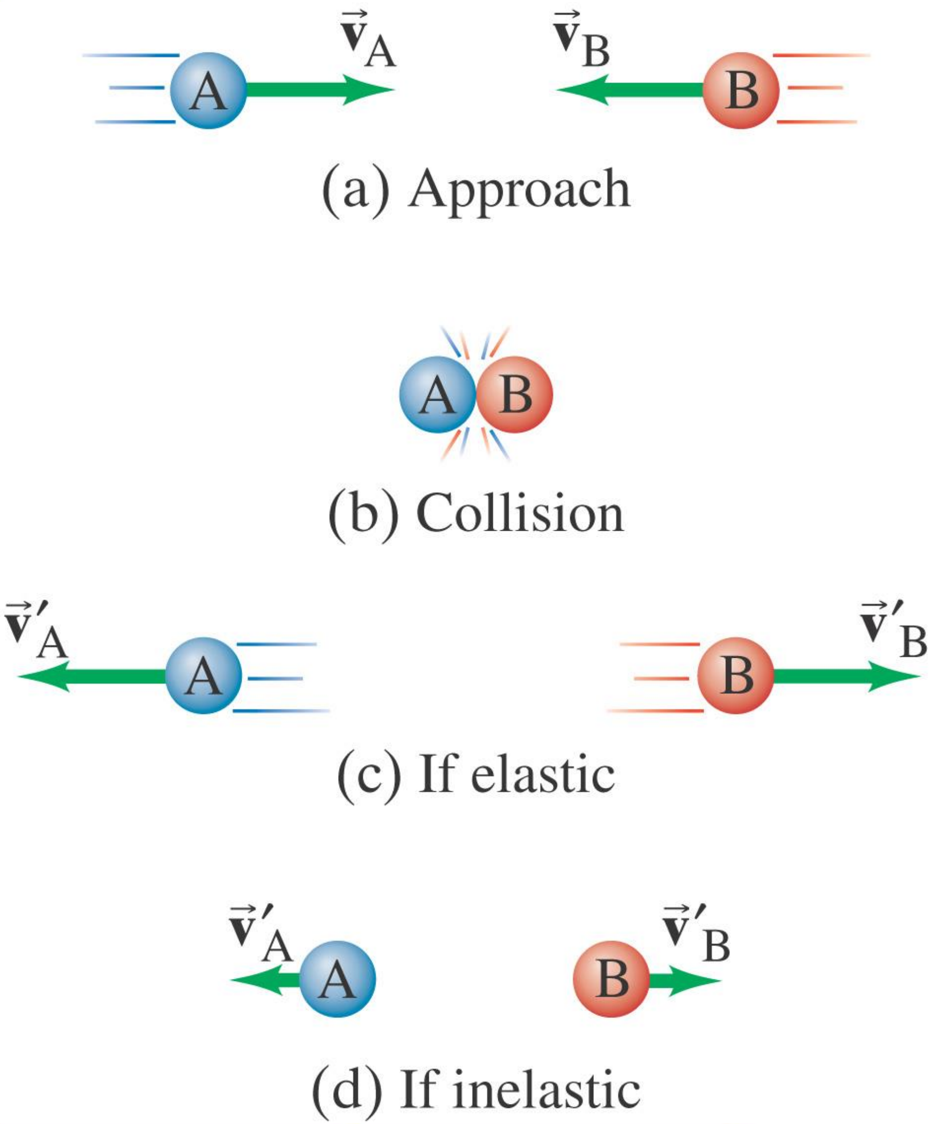
Collisions and Impulse

The impulse tells us that we can get the same change in momentum with a large force acting for a short time, or a small force acting for a longer time.



This is why you should bend your knees when you land; why airbags work; and why landing on a pillow hurts less than landing on concrete.

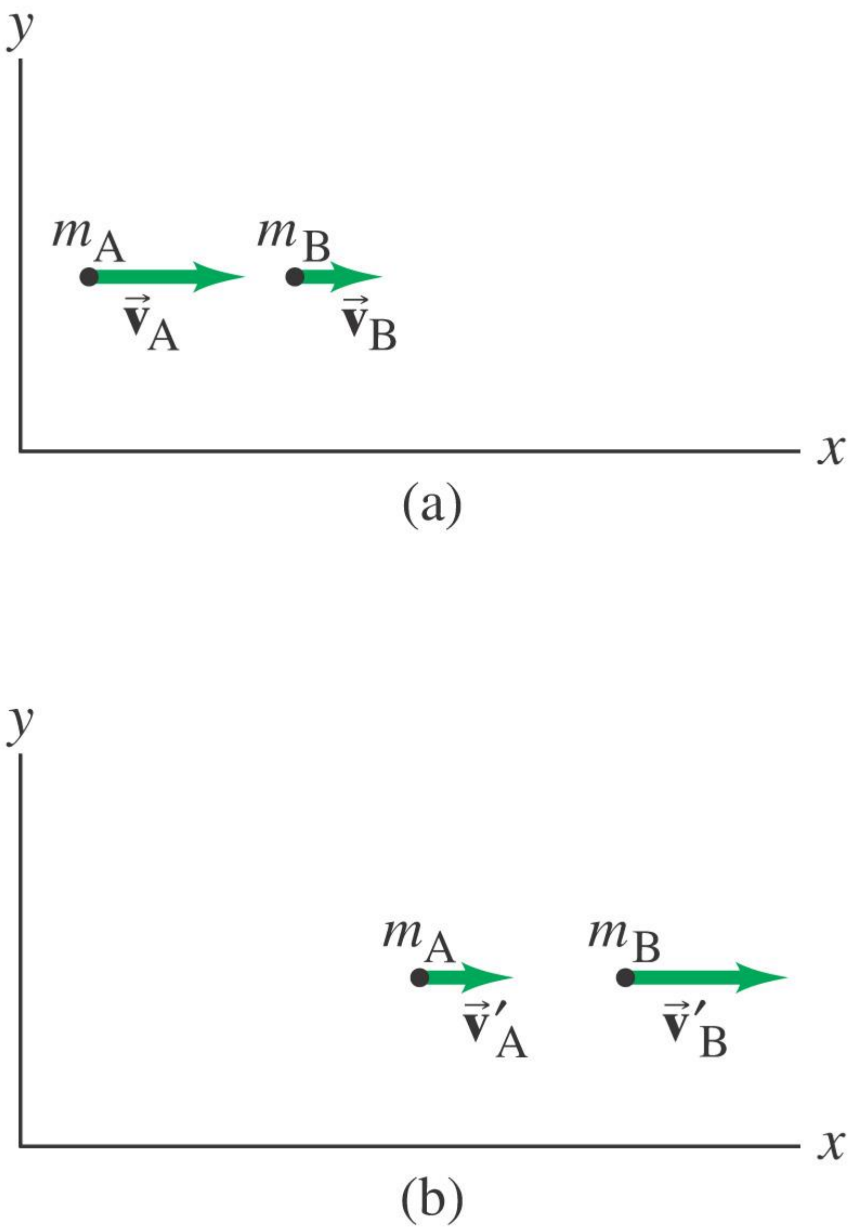
Conservation of Energy and Momentum in Collisions



Momentum is conserved in all collisions.

Collisions in which kinetic energy is conserved as well are called elastic collisions, and those in which it is not are called inelastic.

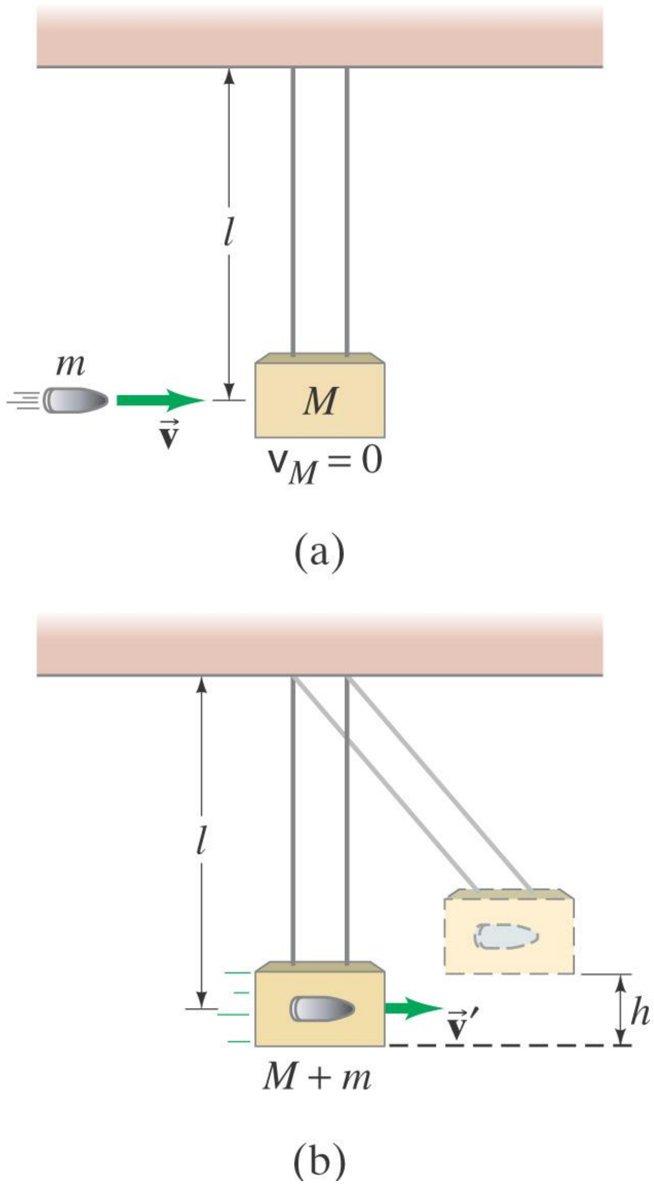
Elastic Collisions in One Dimension



Here we have two objects colliding elastically. We know the masses and the initial speeds.

Since both momentum and kinetic energy are conserved, we can write two equations. This allows us to solve for the two unknown final speeds.

Inelastic Collisions

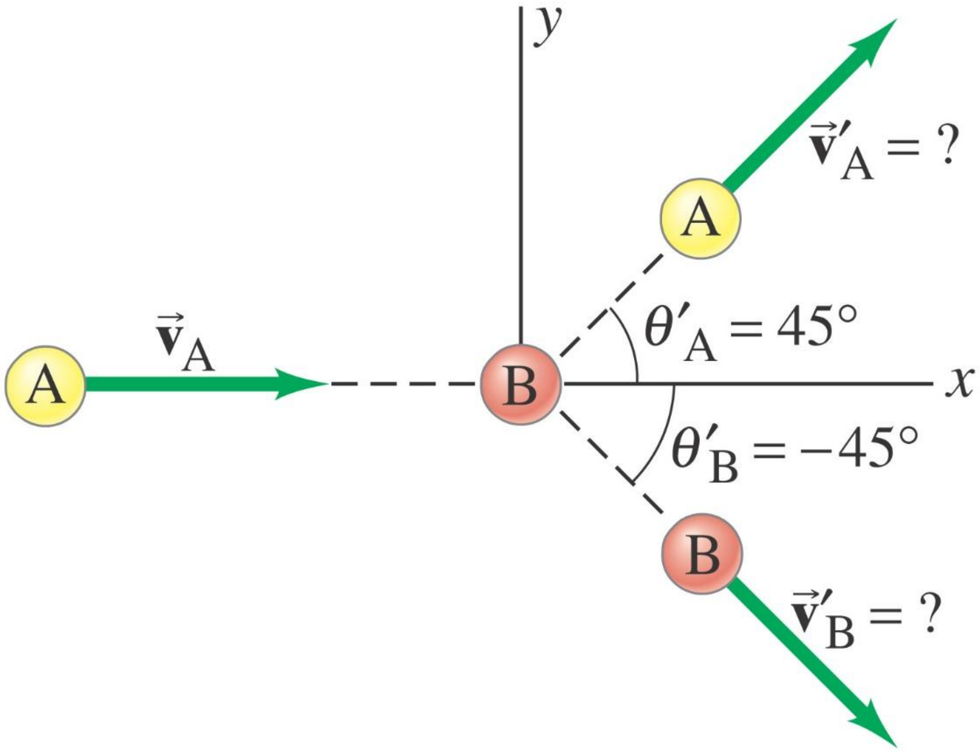


With inelastic collisions, some of the initial kinetic energy is lost to thermal or potential energy. It may also be gained during explosions, as there is the addition of chemical or nuclear energy.

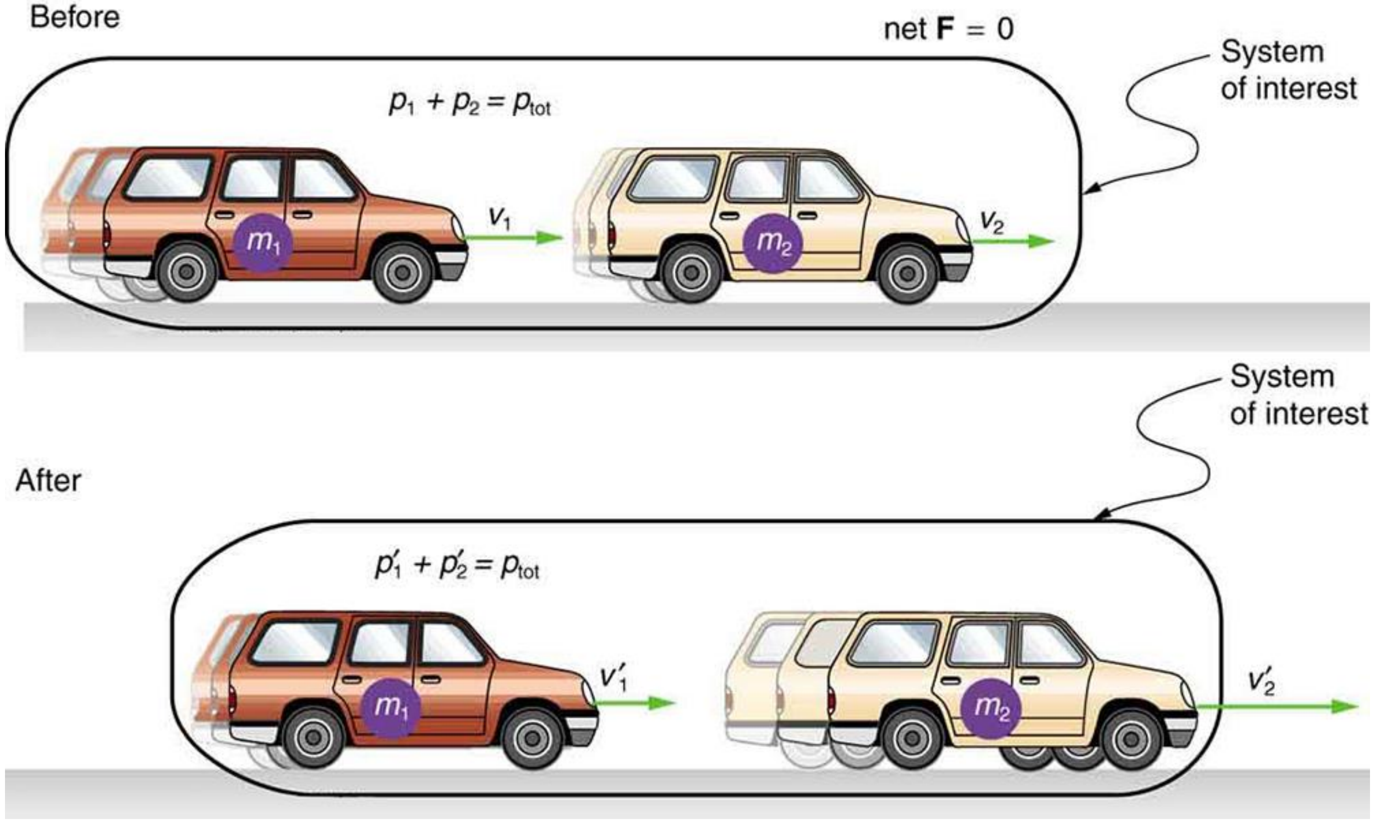
A completely inelastic collision is one where the objects stick together afterwards, so there is only one final velocity.

Collisions in Two or Three Dimensions

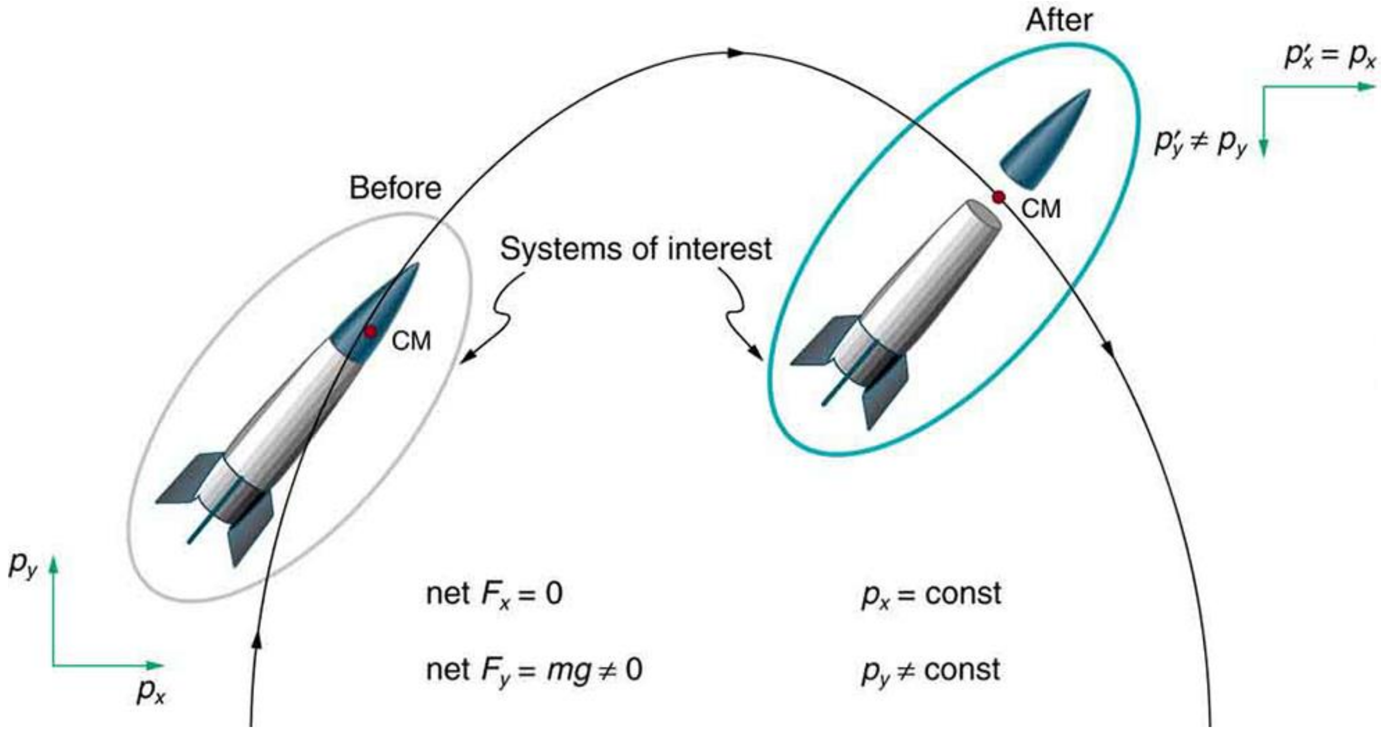
Conservation of energy and momentum can also be used to analyze collisions in two or three dimensions, but unless the situation is very simple, the math quickly becomes unwieldy.



Here, a moving object collides with an object initially at rest. Knowing the masses and initial velocities is not enough; we need to know the angles as well in order to find the final velocities.

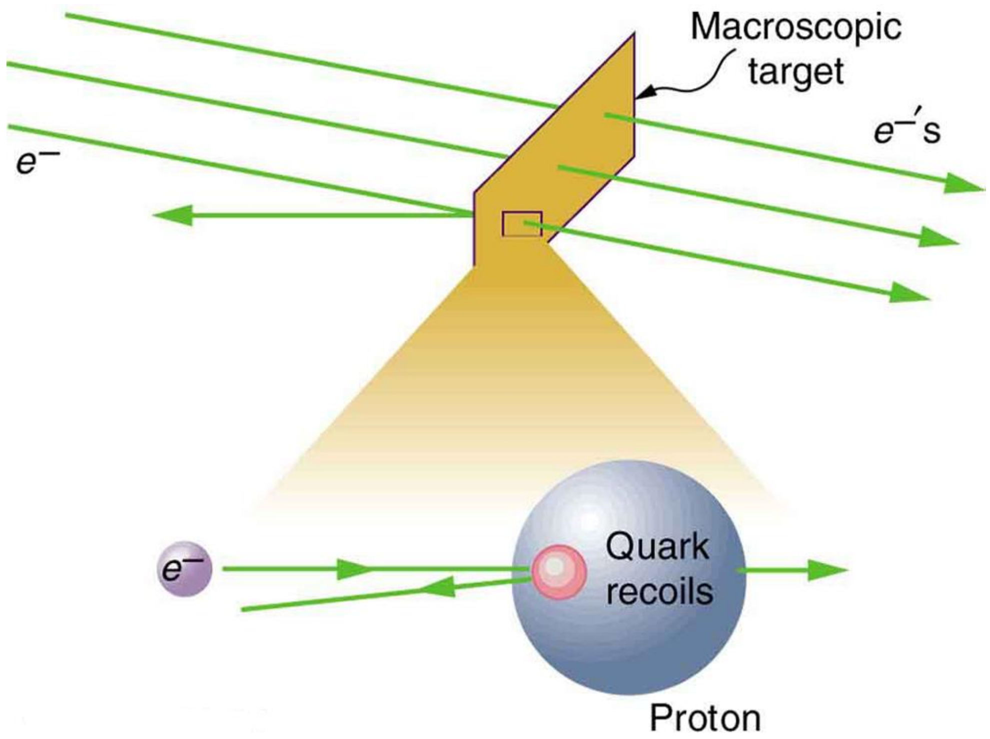


A car of mass m_1 moving with a velocity of v_1 bumps into another car of mass m_2 and velocity v_2 that it is following. As a result, the first car slows down to a velocity of v'_1 and the second speeds up to a velocity of v'_2 . The momentum of each car is changed, but the total momentum p_{tot} of the two cars is the same before and after the collision (if you assume friction is negligible).



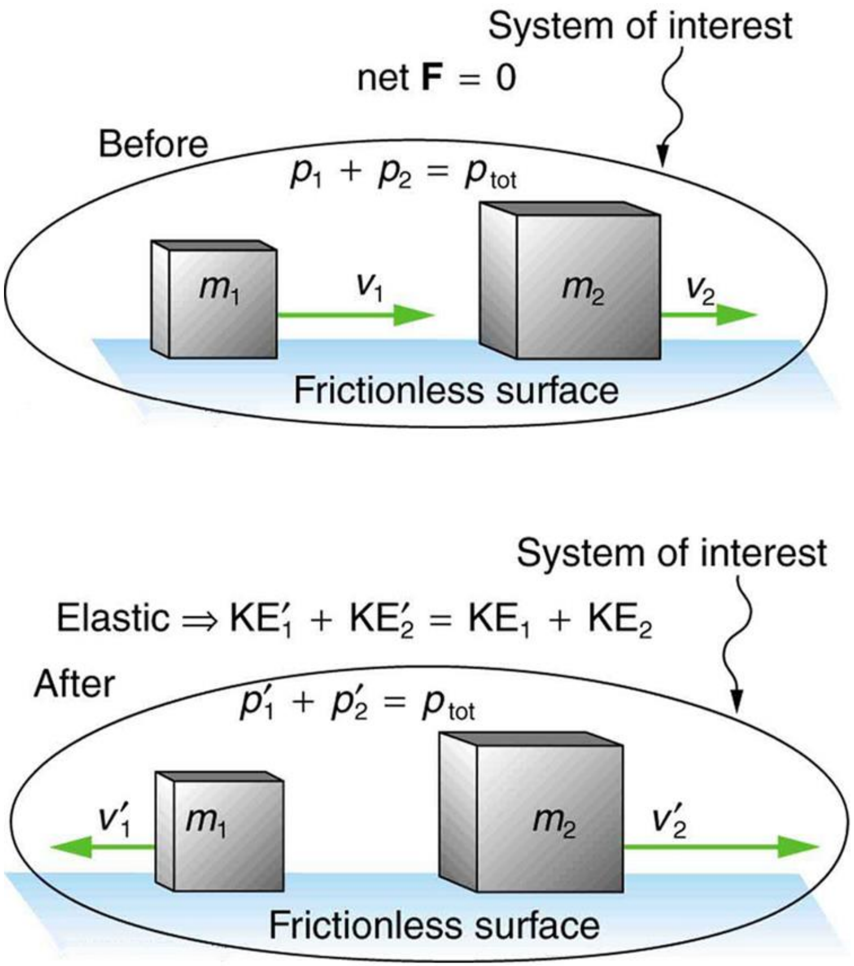
The horizontal component of a projectile's momentum is conserved if air resistance is negligible, even in this case where a space probe separates. The forces causing the separation are internal to the system, so that the net external horizontal force F_{x_net} is still zero. The vertical component of the momentum is not conserved, because the net vertical force F_{y_net} is not zero. In the vertical direction, the space probe-Earth system needs to be considered and we find that the total momentum is conserved. The center of mass of the space probe takes the same path it would if the separation did not occur.

FIGURE 8.5



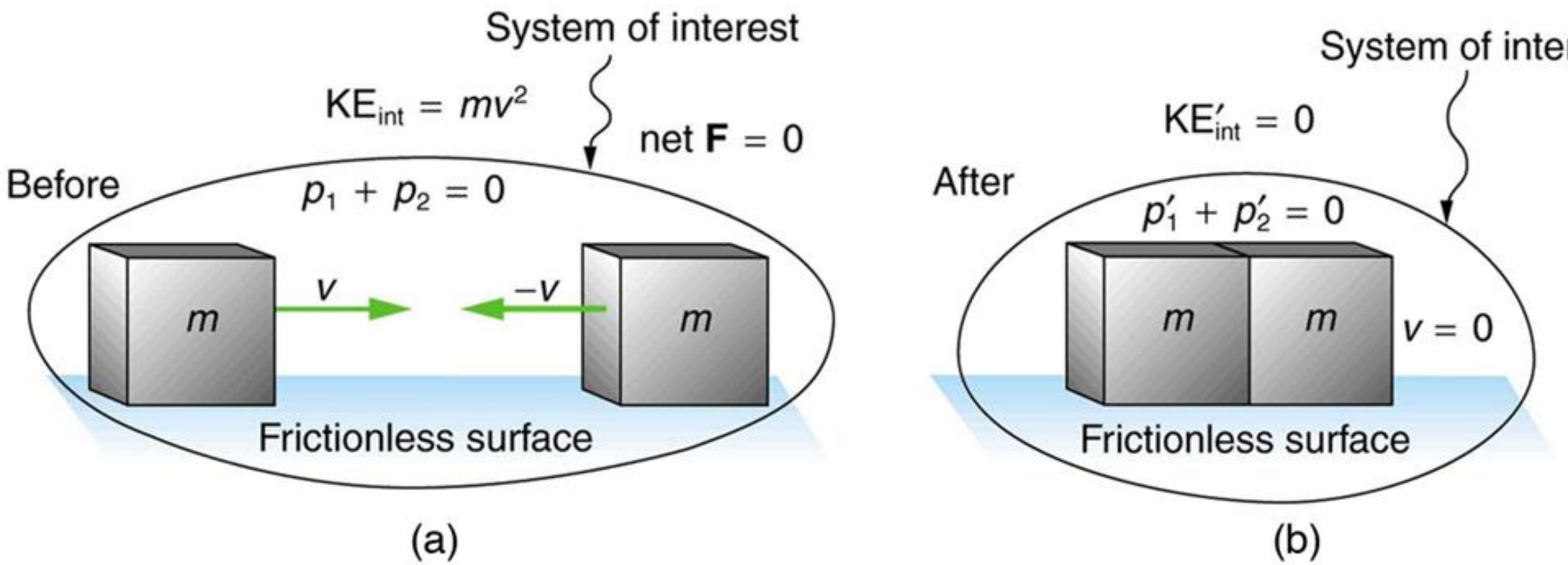
A subatomic particle scatters straight backward from a target particle. In experiments seeking evidence for quarks, electrons were observed to occasionally scatter straight backward from a proton.

FIGURE 8.6



An elastic one-dimensional two-object collision. Momentum and internal kinetic energy are conserved.

FIGURE 8.8

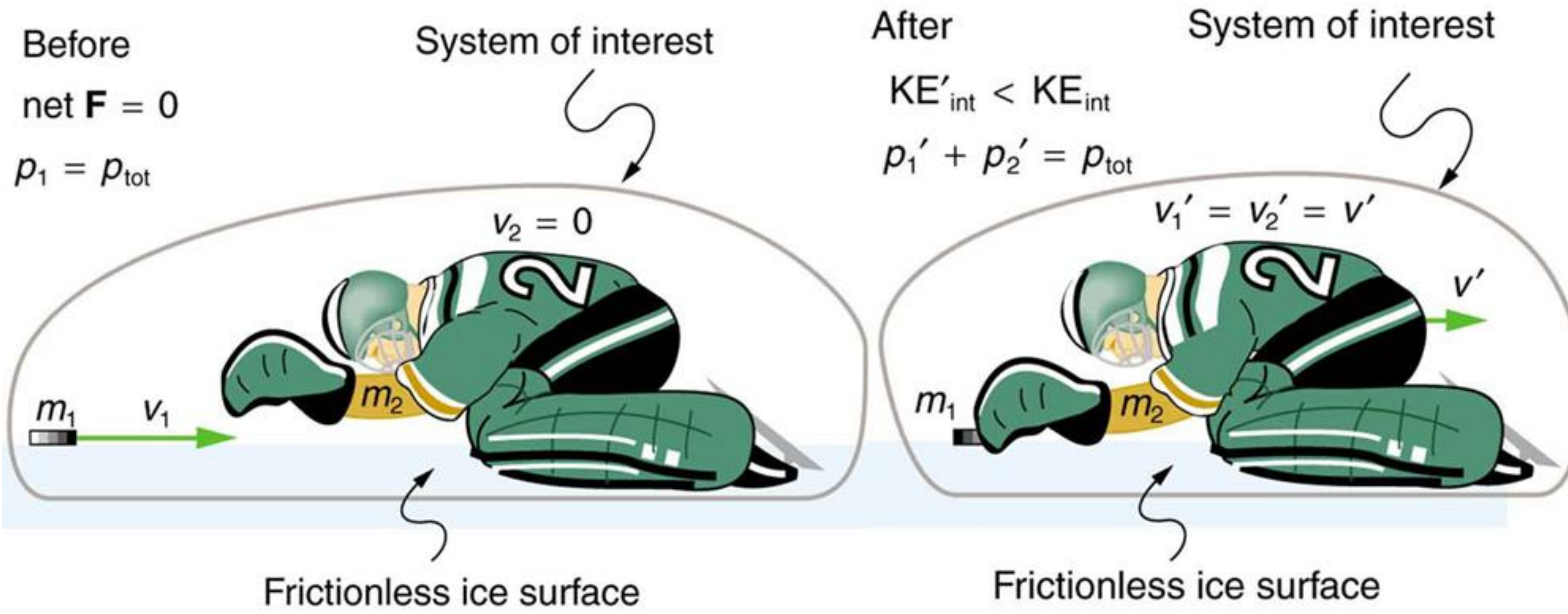


An inelastic one-dimensional two-object collision. Momentum is conserved, but internal kinetic energy is not conserved.

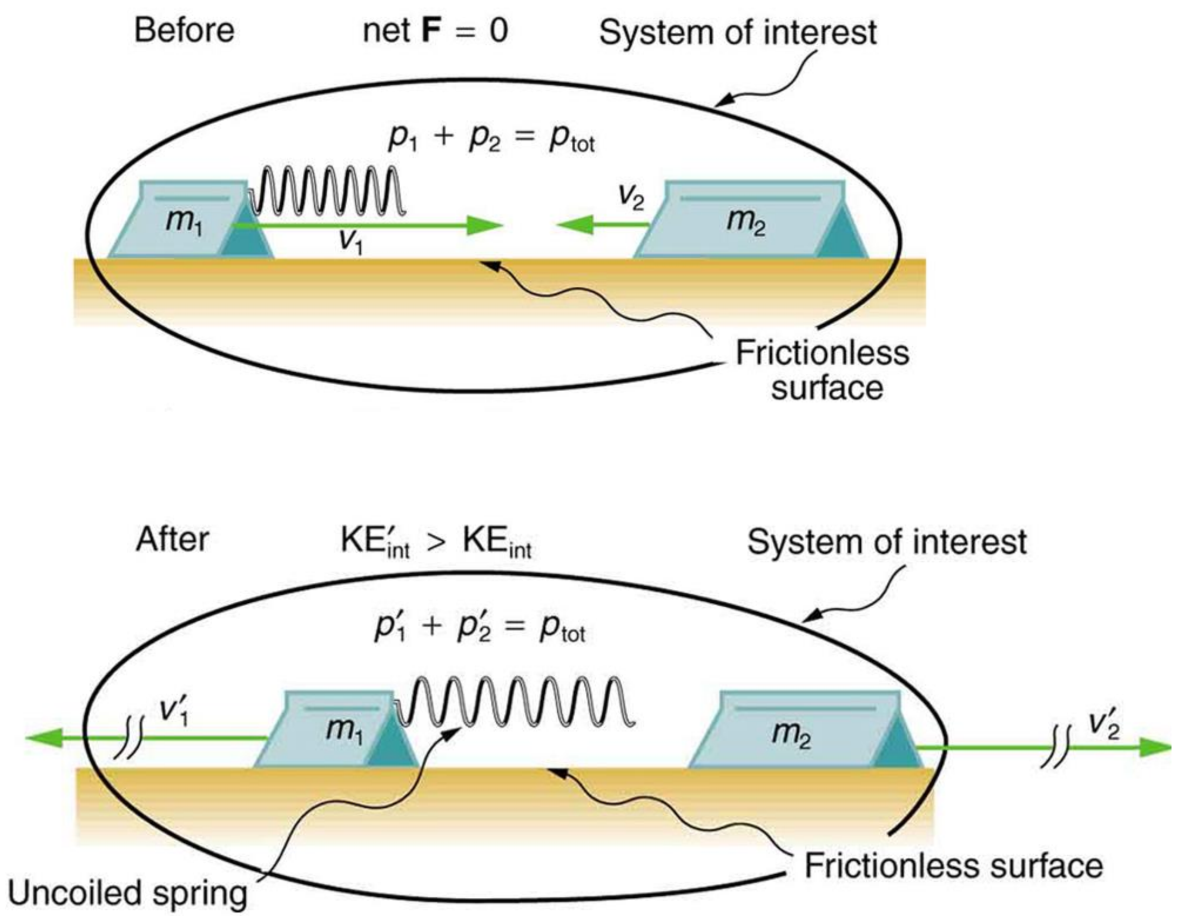
(a) Two objects of equal mass initially head directly toward one another at the same speed.

(b) The objects stick together (a perfectly inelastic collision), and so their final velocity is zero. The internal kinetic energy of the system changes in any inelastic collision and is reduced to zero in this example.

FIGURE 8.9

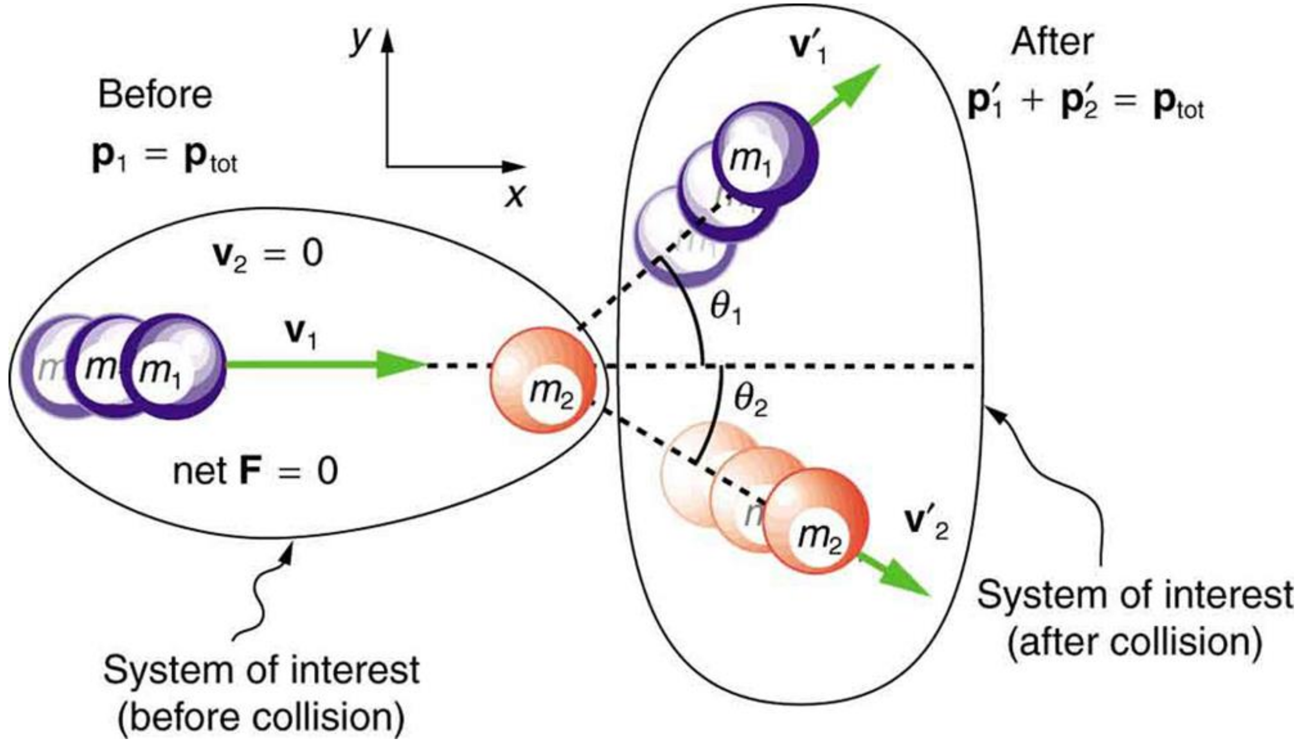


An ice hockey goalie catches a hockey puck and recoils backward. The initial kinetic energy of the puck is almost entirely converted to thermal energy and sound in this inelastic collision.



An air track is nearly frictionless, so that momentum is conserved. Motion is one-dimensional. In this collision, the potential energy of a compressed spring is released during the collision and is converted to internal kinetic energy.

FIGURE 8.11



A two-dimensional collision with the coordinate system chosen so that $\boldsymbol{m}_2$ is initially at rest and v_1 is parallel to the x -axis. This coordinate system is sometimes called the laboratory coordinate system, because many scattering experiments have a target that is stationary in the laboratory, while particles are scattered from it to determine the particles that make-up the target and how they are bound together. The particles may not be observed directly, but their initial and final velocities are.

FIGURE 8.12

The incoming object $\boldsymbol{m}_1$ is scattered by an initially stationary object. Only the stationary object's mass $\boldsymbol{m}_2$ is known. By measuring the angle and speed at which $\boldsymbol{m}_1$ emerges from the room, it is possible to calculate the magnitude and direction of the initially stationary object's velocity after the collision.

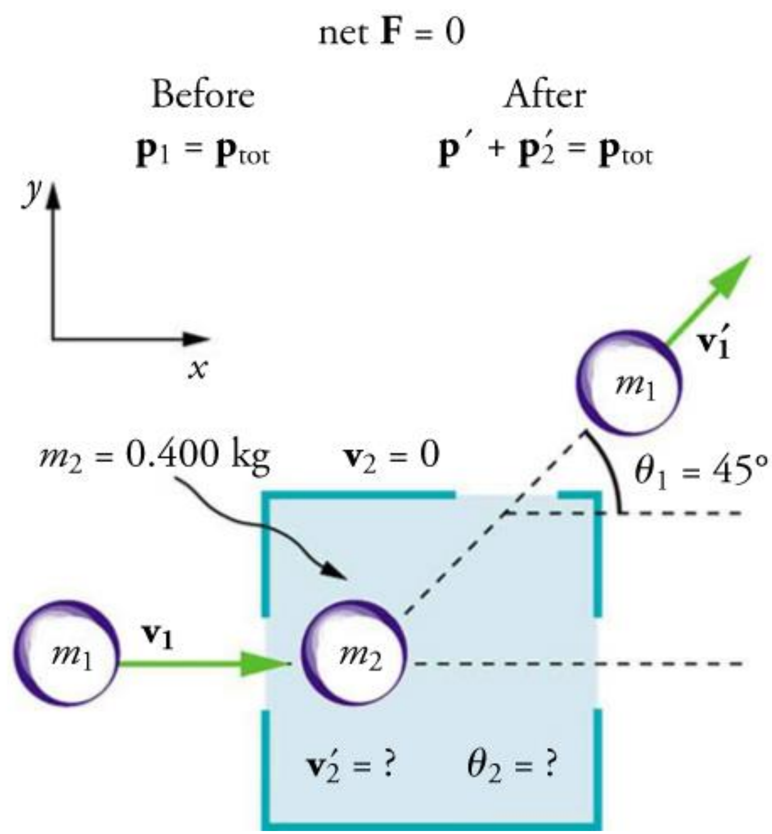
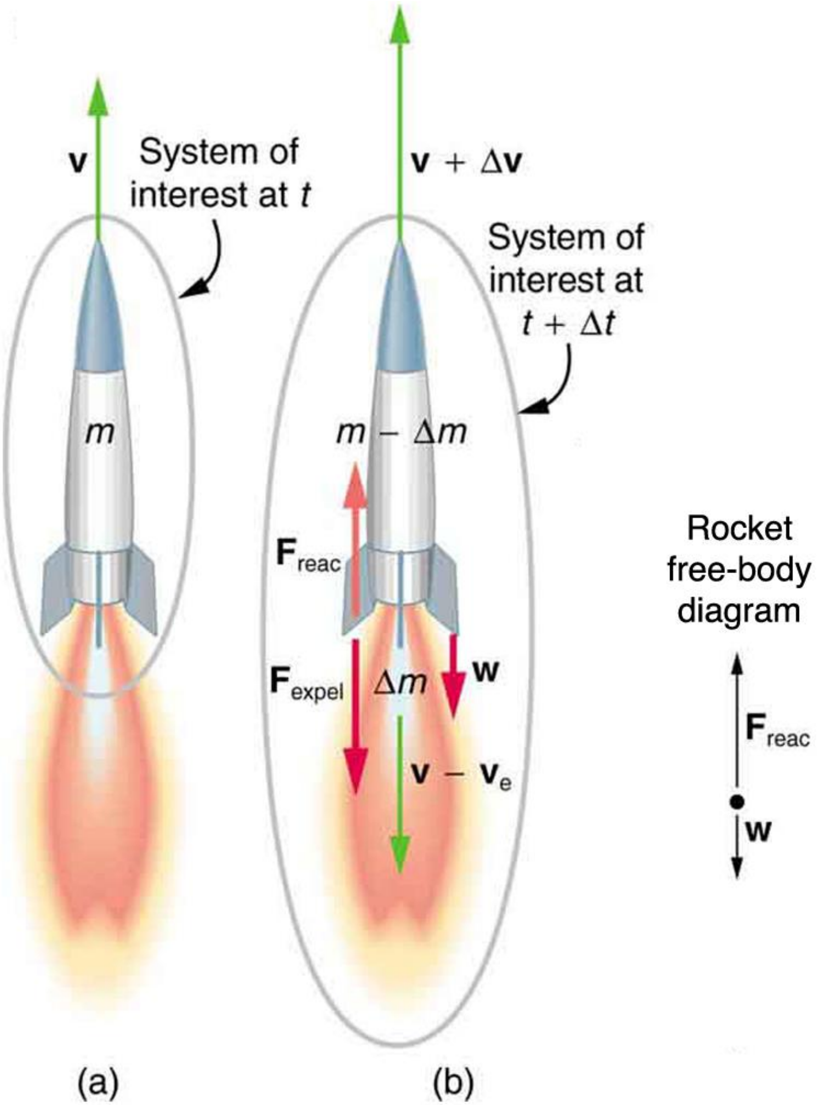


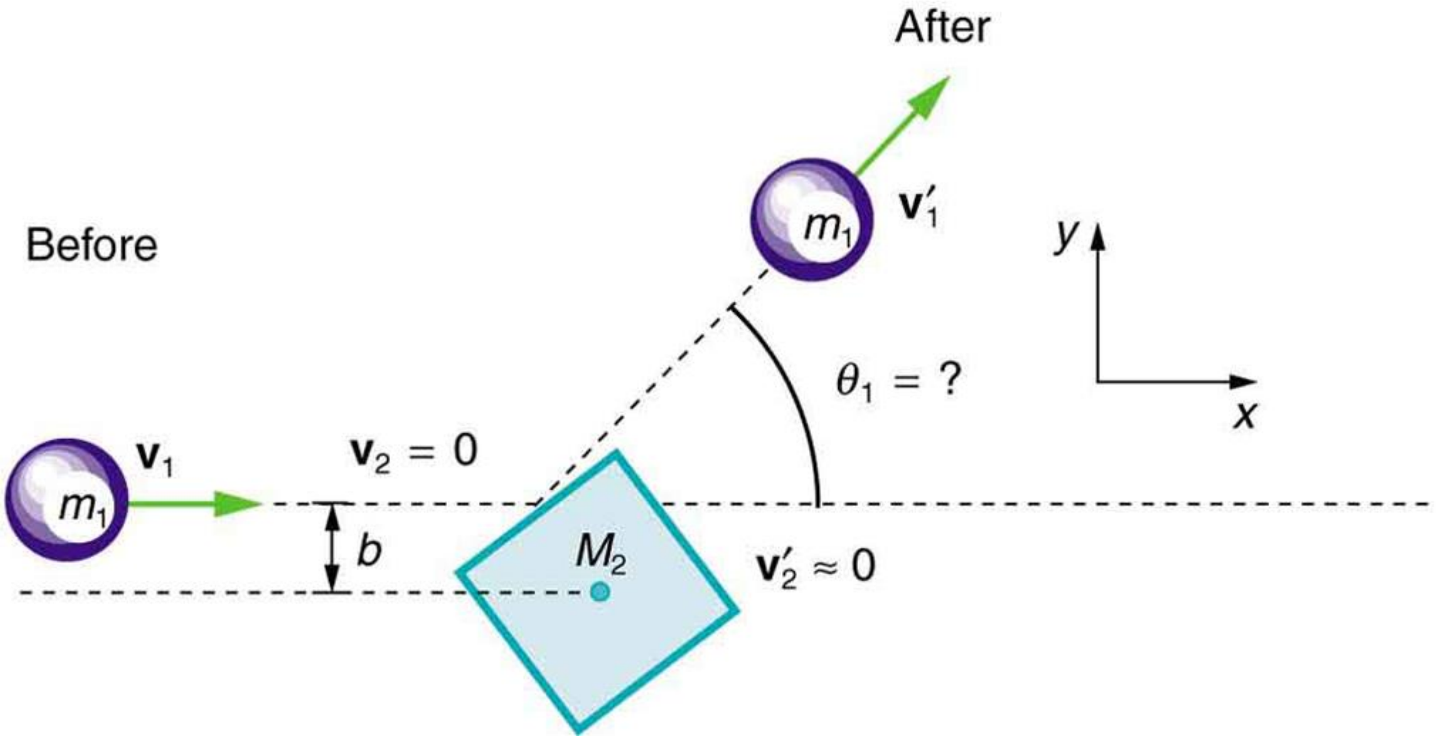
FIGURE 8.13



(a) This rocket has a mass *m* and an upward velocity *v* . The net external force on the system is −*mg* , if air resistance is neglected.

(b) A time Δ*t* later the system has two main parts, the ejected gas and the remainder of the rocket. The reaction force on the rocket is what overcomes the gravitational force and accelerates it upward.

FIGURE 8.16

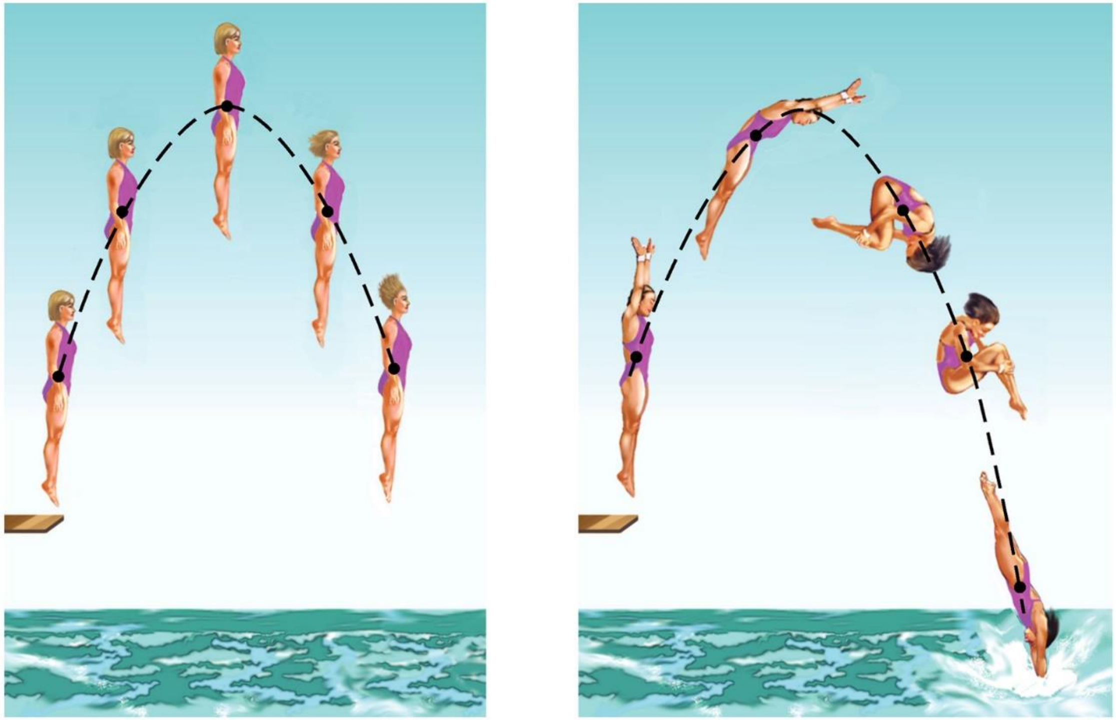


A small object approaches a collision with a much more massive cube, after which its velocity has the direction $\boldsymbol{\theta}_1$. The angles at which the small object can be scattered are determined by the shape of the object it strikes and the impact parameter $\boldsymbol{b}$.

Center of Mass

In (a), the diver's motion is pure translation; in (b) it is translation plus rotation.

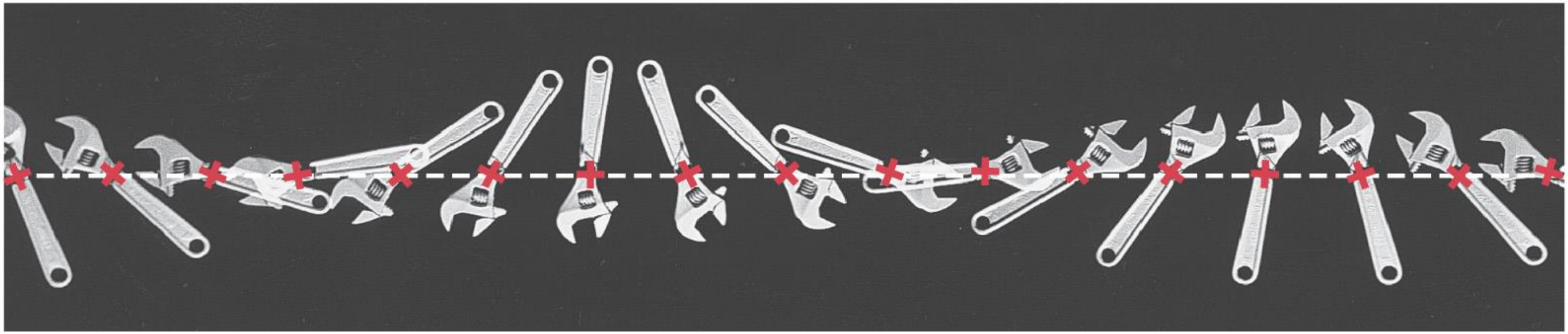
There is one point that moves in the same path a particle would take if subjected to the same force as the diver. This point is called the center of mass (CM).



(a) (b)

Center of Mass

The general motion of an object can be considered as the sum of the translational motion of the CM, plus rotational, vibrational, or other forms of motion about the CM.

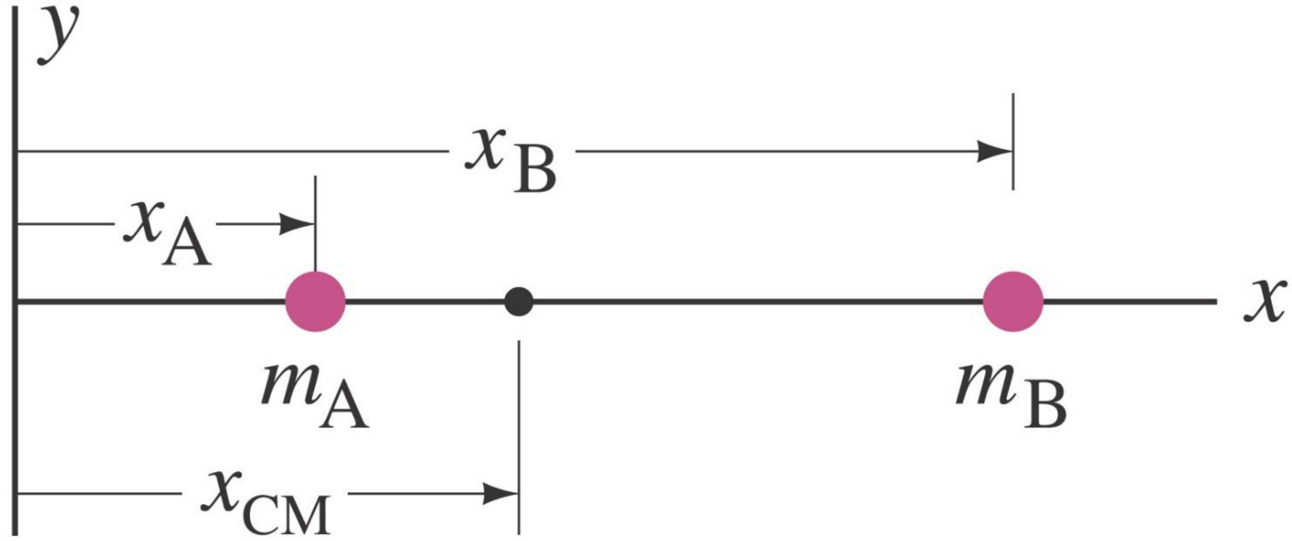


Center of Mass

For two particles, the center of mass lies closer to the one with the most mass:

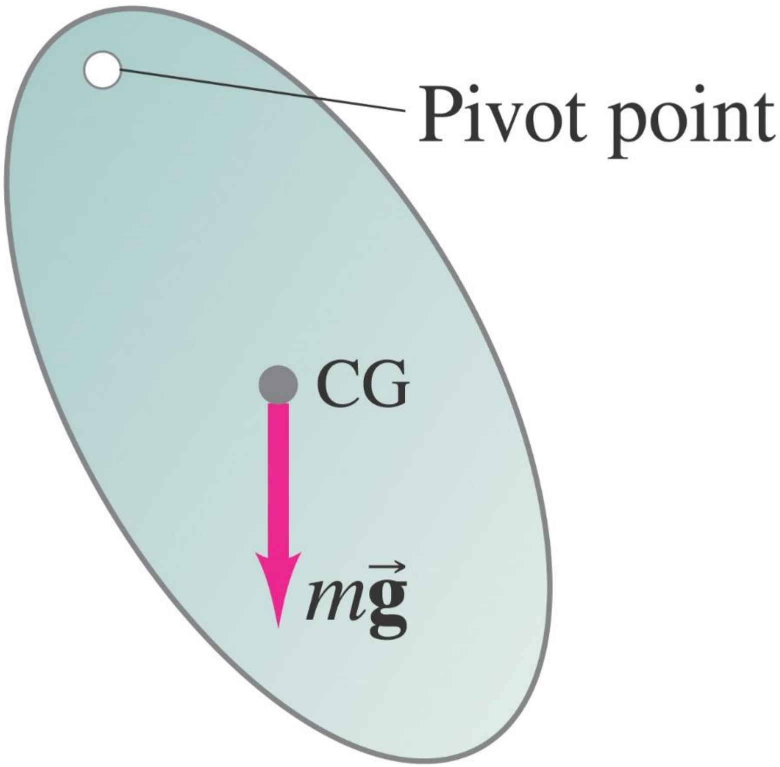
$$x_{\mathrm{CM}} = \frac{m_{\mathrm{A}} x_{\mathrm{A}} + m_{\mathrm{B}} x_{\mathrm{B}}}{m_{\mathrm{A}} + m_{\mathrm{B}}} = \frac{m_{\mathrm{A}} x_{\mathrm{A}} + m_{\mathrm{B}} x_{\mathrm{B}}}{M}$$

where *M* is the total mass.



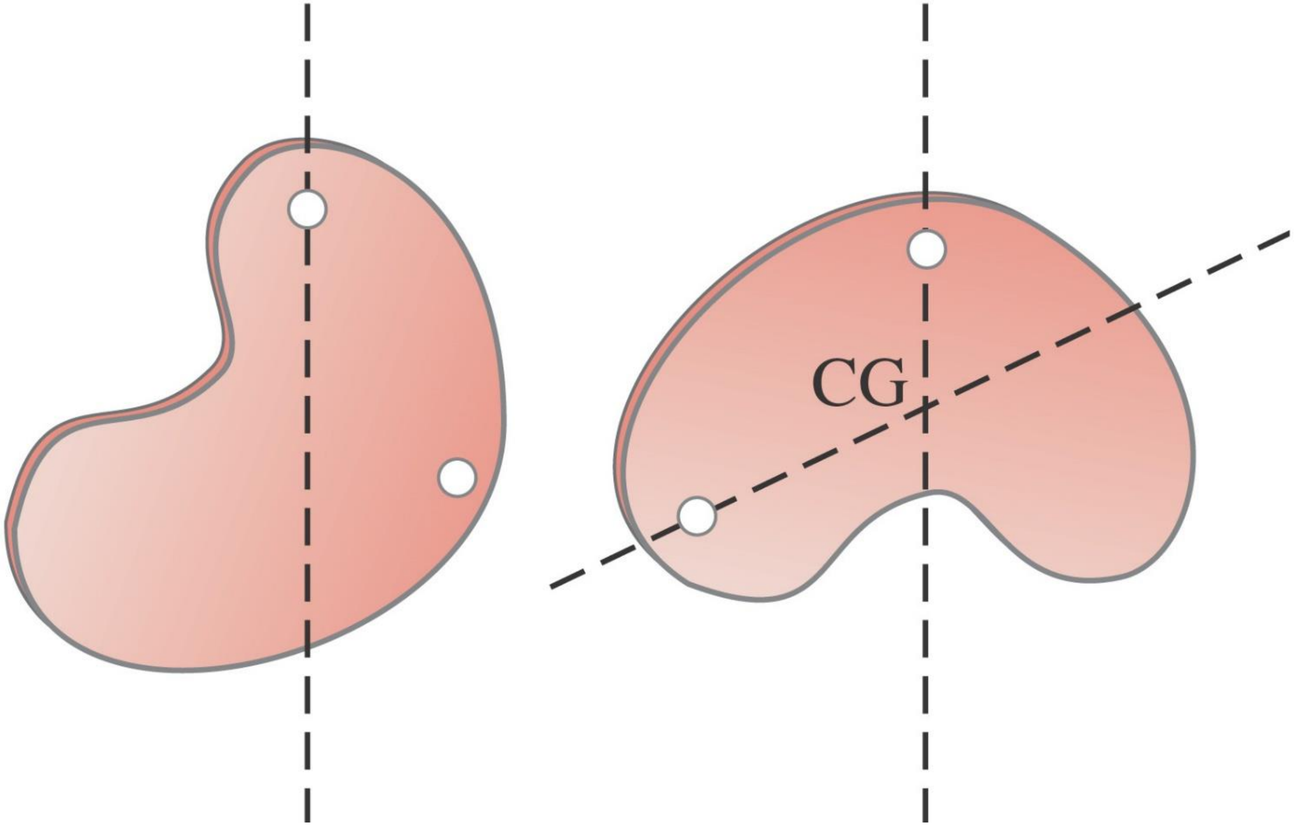
Center of Mass

The center of gravity is the point where the gravitational force can be considered to act. It is the same as the center of mass as long as the gravitational force does not vary among different parts of the object.

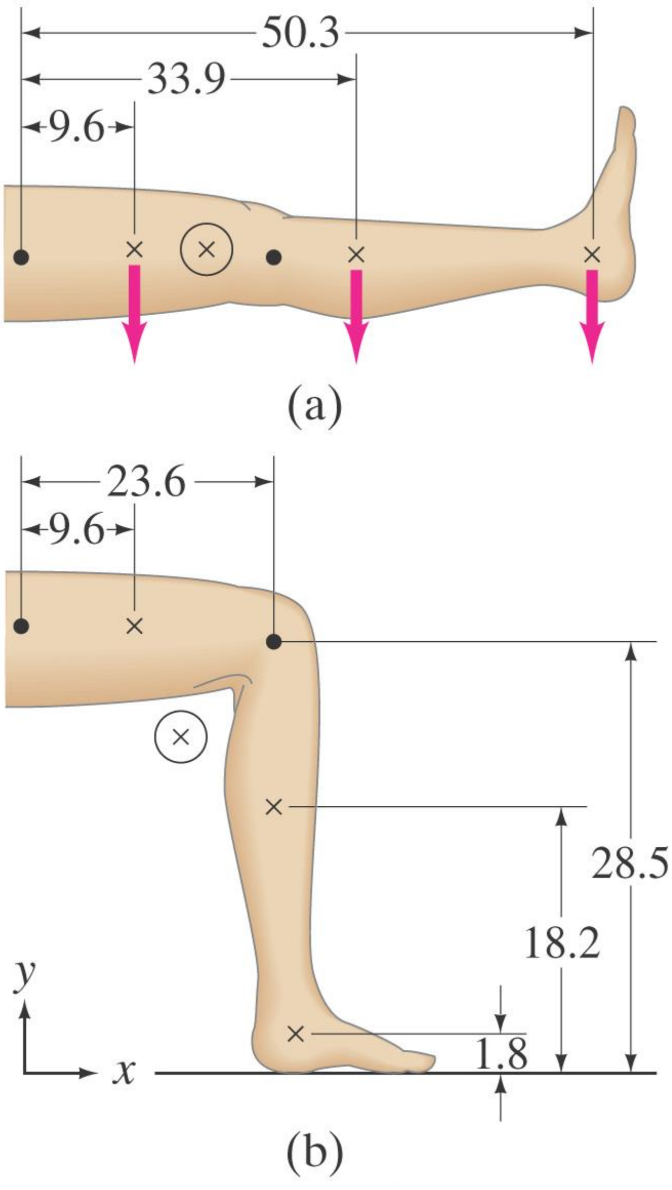


Center of Mass

The center of gravity can be found experimentally by suspending an object from different points. The CM need not be within the actual object – a doughnut's CM is in the center of the hole.



CM for the Human Body



The location of the center of mass of the leg (circled) will depend on the position of the leg.

CM for the Human Body

High jumpers have developed a technique where their CM actually passes under the bar as they go over it. This allows them to clear higher bars.

Center of Mass and Translational Motion

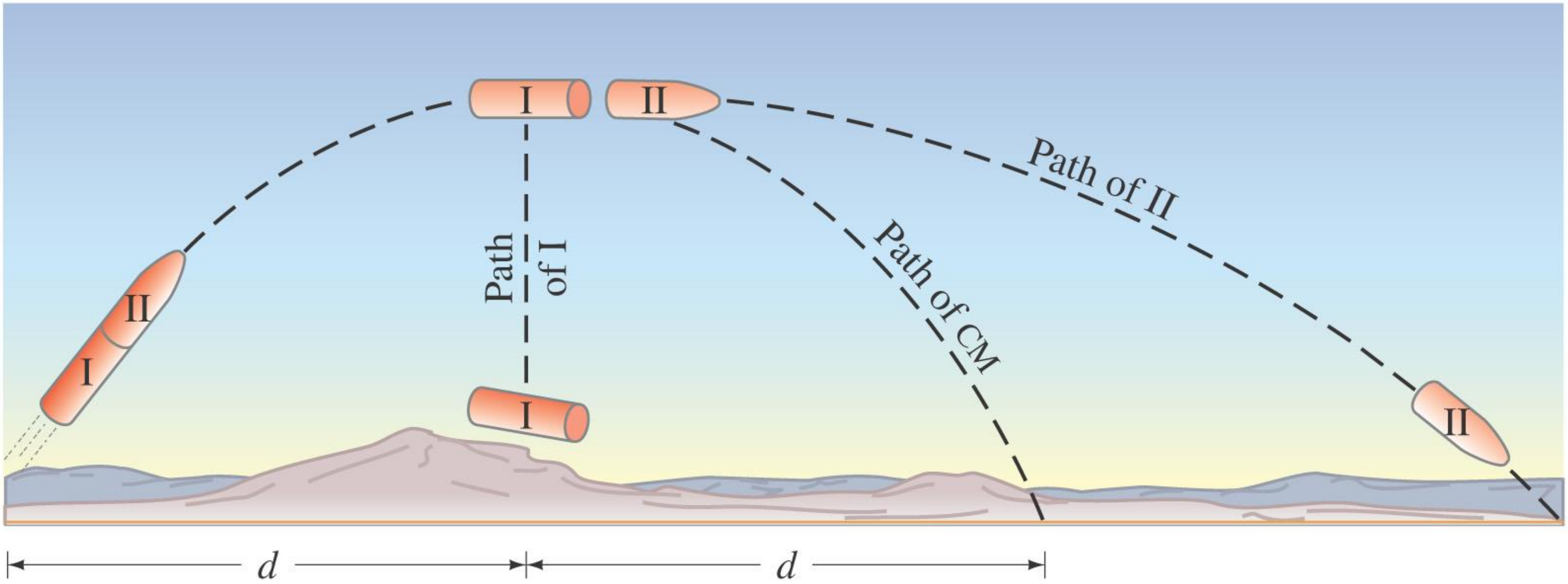
The total momentum of a system of particles is equal to the product of the total mass and the velocity of the center of mass.

The sum of all the forces acting on a system is equal to the total mass of the system multiplied by the acceleration of the center of mass:

$$M a_{\mathrm{CM}} = F_{\mathrm{net}}$$

Center of Mass and Translational Motion

This is particularly useful in the analysis of separations and explosions; the center of mass (which may not correspond to the position of any particle) continues to move according to the net force.



Summary of Chapter 8

- Momentum of an object: $\vec{\mathbf{p}} = m\vec{\mathbf{v}}$.

- Newton's second law:

$$\Sigma\vec{\mathbf{F}} = \frac{\Delta\vec{\mathbf{p}}}{\Delta t}$$

•Total momentum of an isolated system of objects is conserved.

- During a collision, the colliding objects can be considered to be an isolated system even if external forces exist, as long as they are not too large.

- Momentum will therefore be conserved during collisions.

Summary of Chapter 8, cont.

- $\text{Impulse} = \vec{\mathbf{F}}\,\Delta t = \Delta\vec{\mathbf{p}}$

- In an elastic collision, total kinetic energy is also conserved.

- In an inelastic collision, some kinetic energy is lost.

- In a completely inelastic collision, the two objects stick together after the collision.

- The center of mass of a system is the point at which external forces can be considered to act.