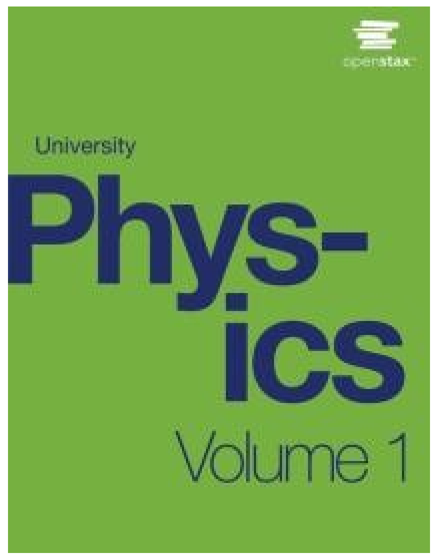
UNIVERSITY PHYSICS

Chapter 9 LINEAR MOMENTUM AND COLLISIONS

PowerPoint Image Slideshow



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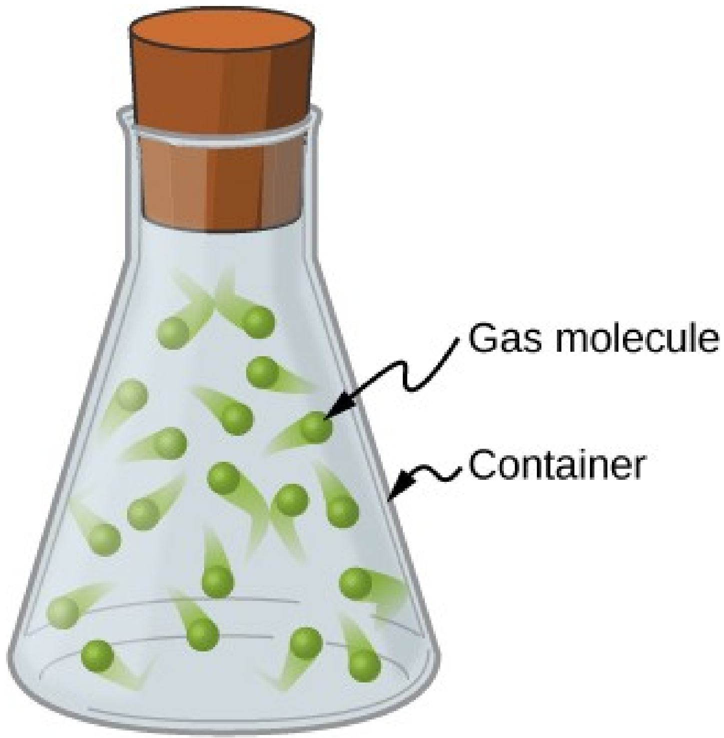
Linear momentum

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

$$\vec{F} = \frac{d\,\vec{p}}{dt}$$

FIGURE 9.4



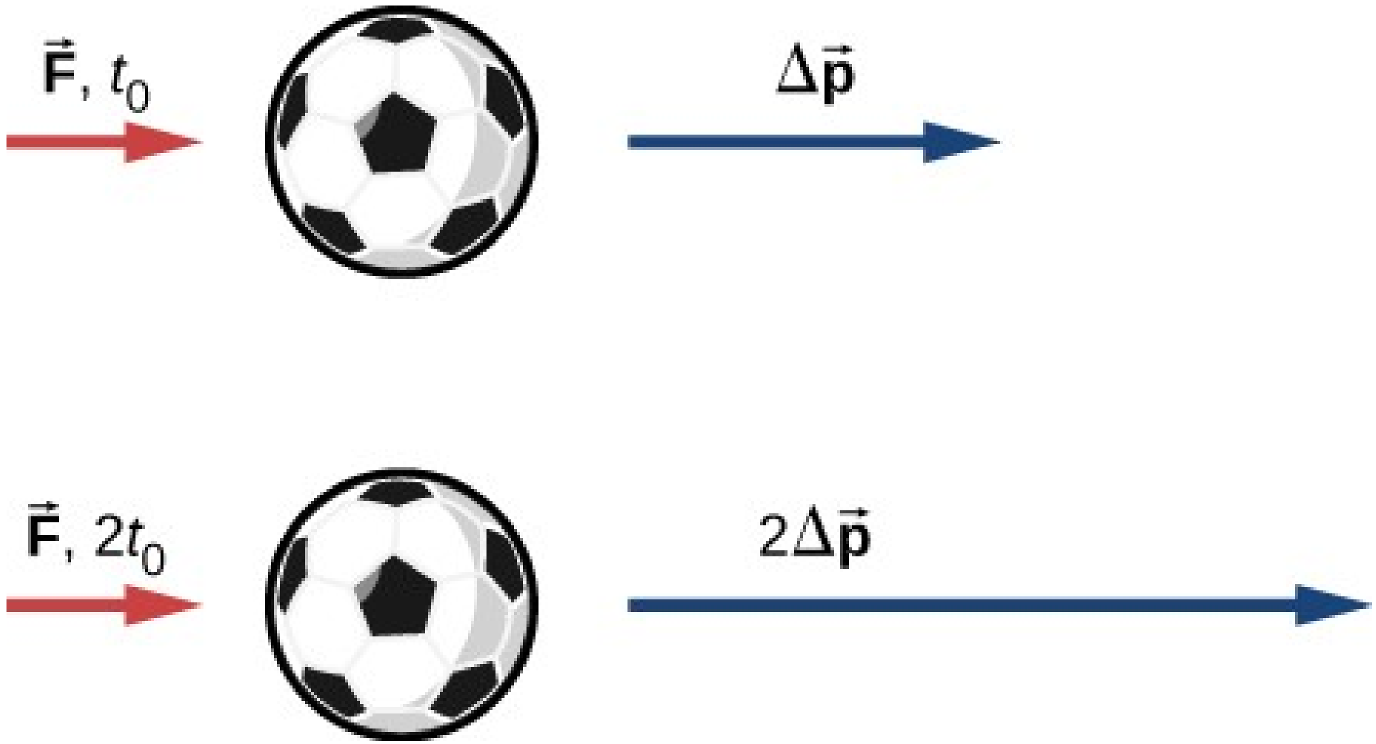
Gas molecules can have very large velocities, but these velocities change nearly instantaneously when they collide with the container walls or with each other. This is primarily because their masses are so tiny.

Impulse

$$\vec{F} = \frac{d\,\vec{p}}{dt}$$

$$\vec{F} = \frac{d\,\vec{J}}{dt}$$

FIGURE 9.5



The change in momentum of an object is proportional to the length of time during which the force is applied. If a force is exerted on the lower ball for twice as long as on the upper ball, then the change in the momentum of the lower ball is twice that of the upper ball.

FIGURE 9.6

A force applied by a tennis racquet to a tennis ball over a time interval generates an impulse acting on the ball.

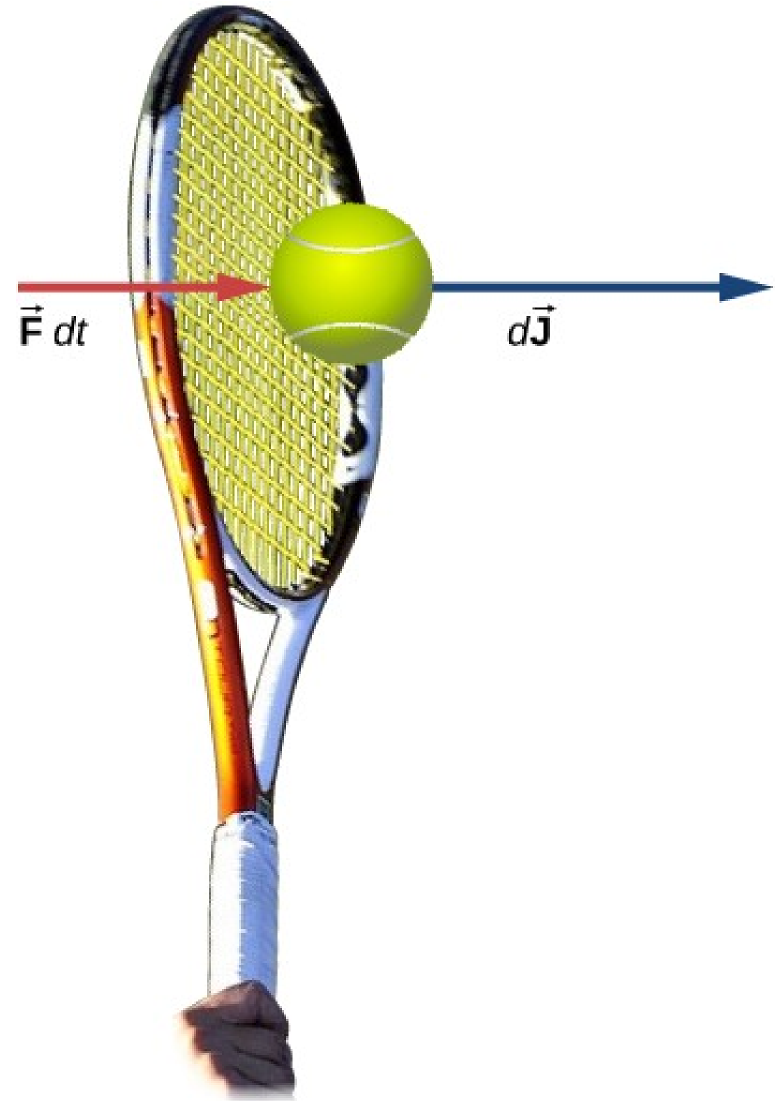


FIGURE 9.10

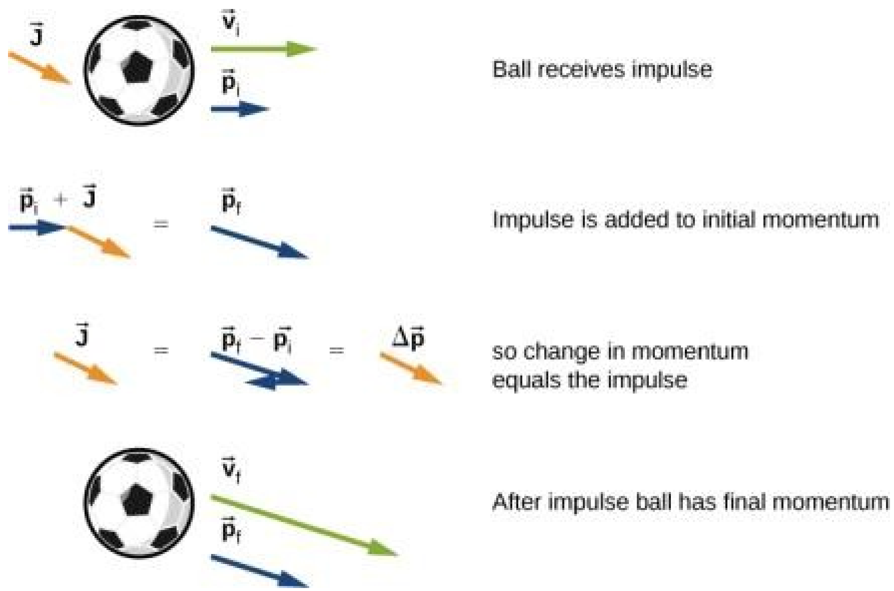


Illustration of impulse-momentum theorem.

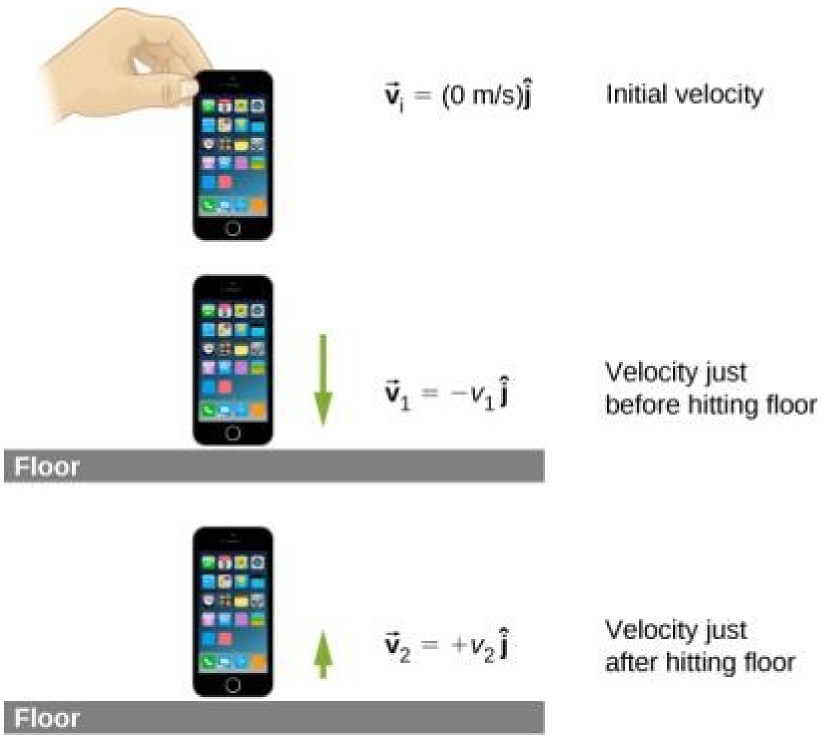
a) A ball with initial velocity and momentum receives an impulse .

b) This impulse is added vectorially to the initial momentum.

c) Thus, the impulse equals the change in momentum, .

d) After the impulse, the ball moves off with its new momentum .

FIGURE 9.12



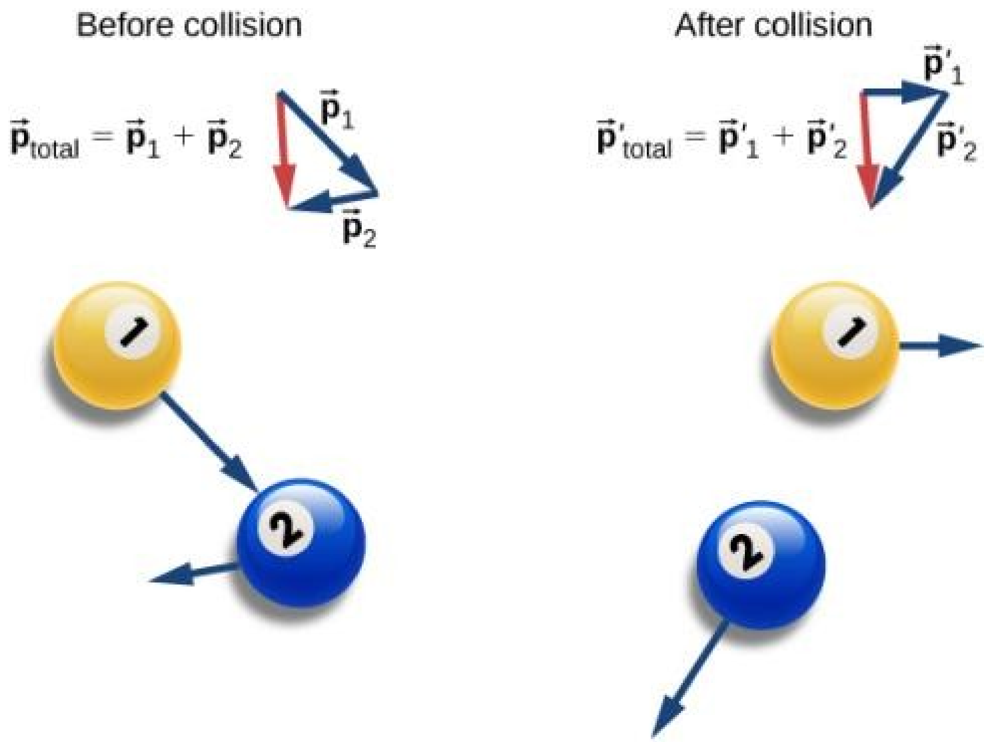
a) The initial velocity of the phone is zero, just after the person drops it.

b) Just before the phone hits the floor, its velocity is , which is unknown at the moment, except for its direction, which is downward ().

c) After bouncing off the floor, the phone has a velocity , which is also unknown, except for its direction, which is upward ().

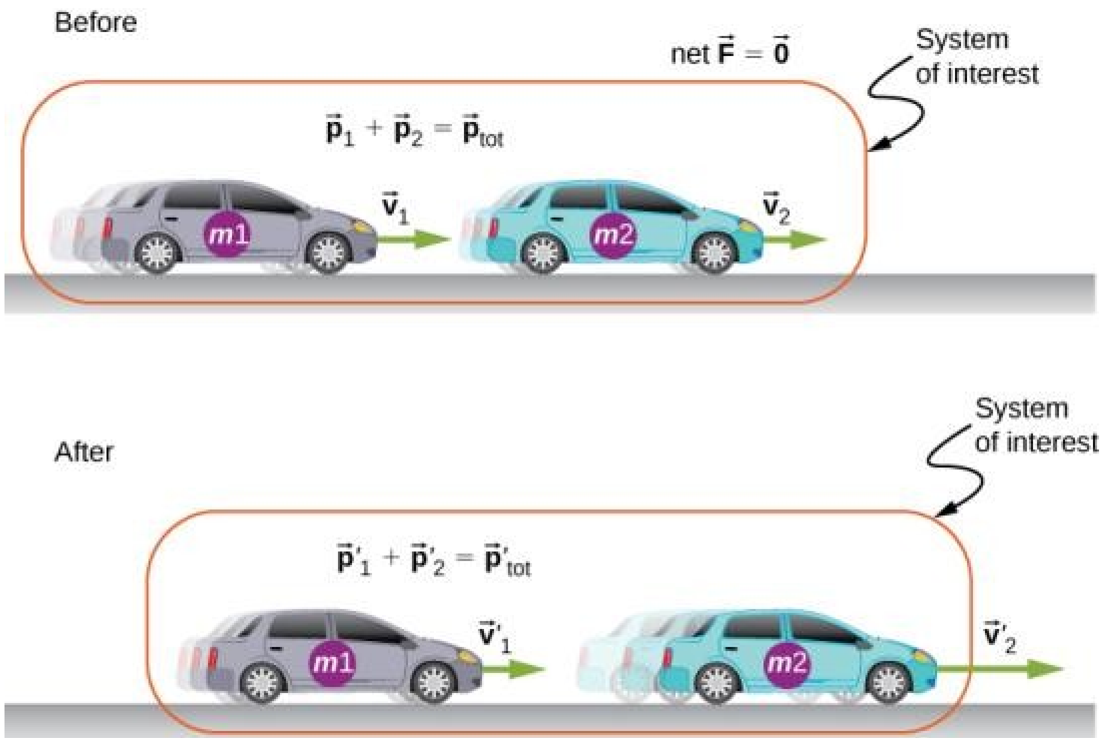
Collisions

FIGURE 9.14



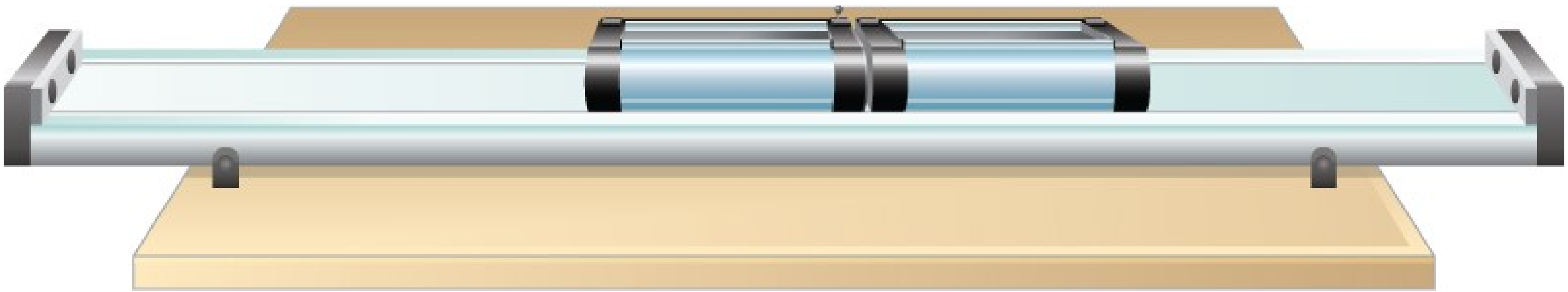
Before the collision, the two billiard balls travel with momenta and . The total momentum of the system is the sum of these, as shown by the red vector labeled on the left. After the collision, the two billiard balls travel with different momenta and . The total momentum, however, has not changed, as shown by the red vector arrow on the right.

FIGURE 9.15



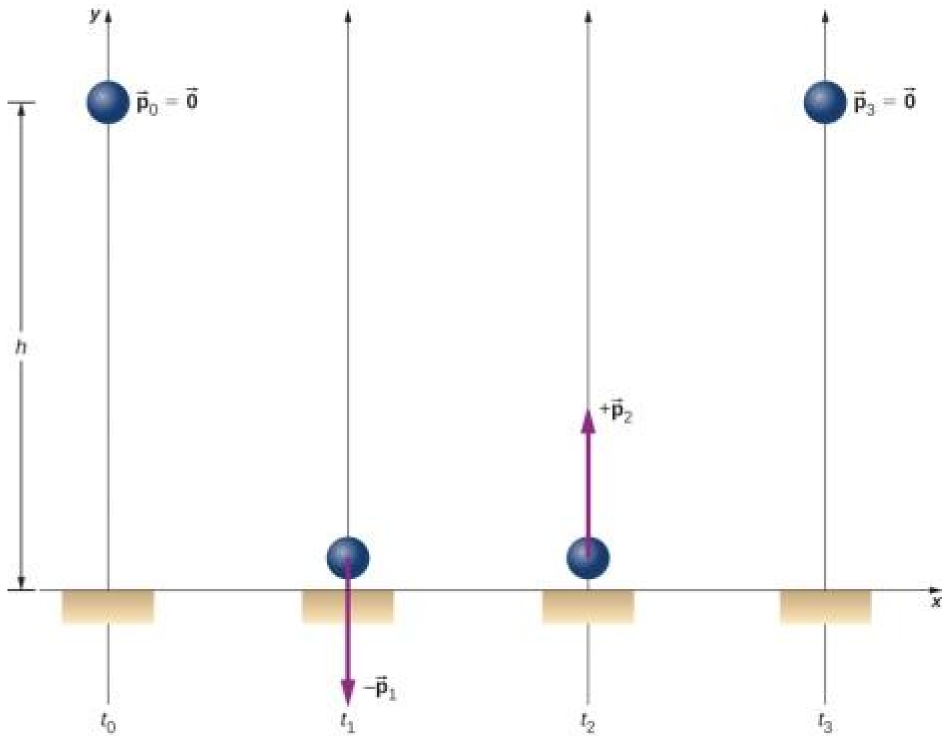
The two cars together form the system that is to be analyzed. It is important to remember that the contents (the mass) of the system do not change before, during, or after the objects in the system interact.

FIGURE 9.16



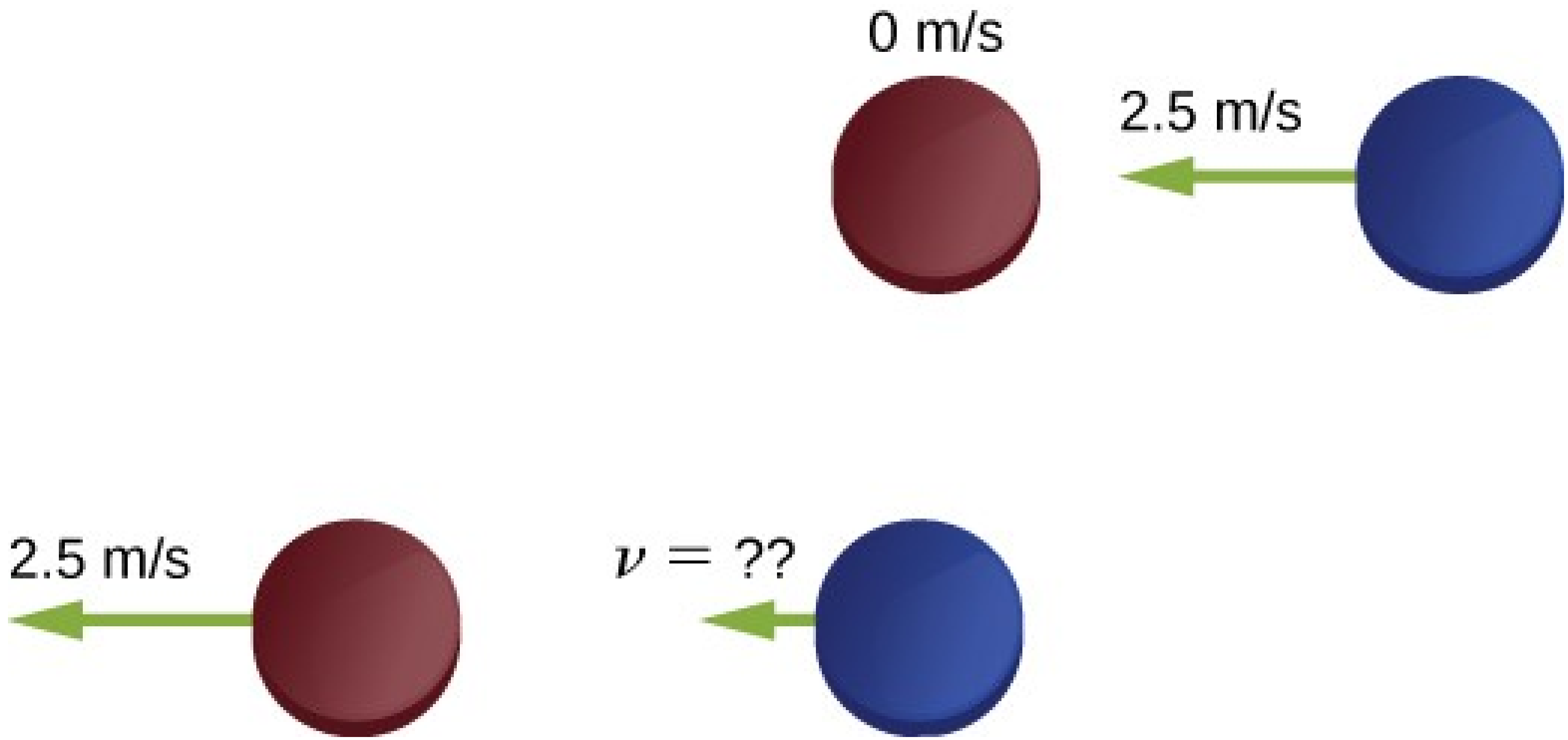
Two lab carts collide and stick together after the collision.

FIGURE 9.17



A superball is dropped to the floor (t_0), hits the floor (t_1), bounces (t_2), and returns to its initial height (t_3).

FIGURE 9.18



Two identical hockey pucks colliding. The top diagram shows the pucks the instant before the collision, and the bottom diagram show the pucks the instant after the collision. The net external force is zero.

Examples

EXAMPLE 9.10

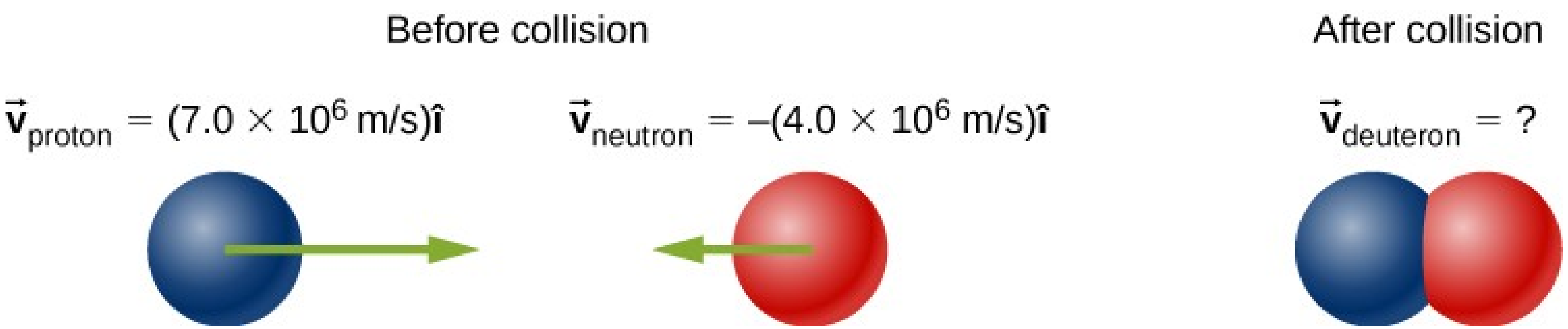
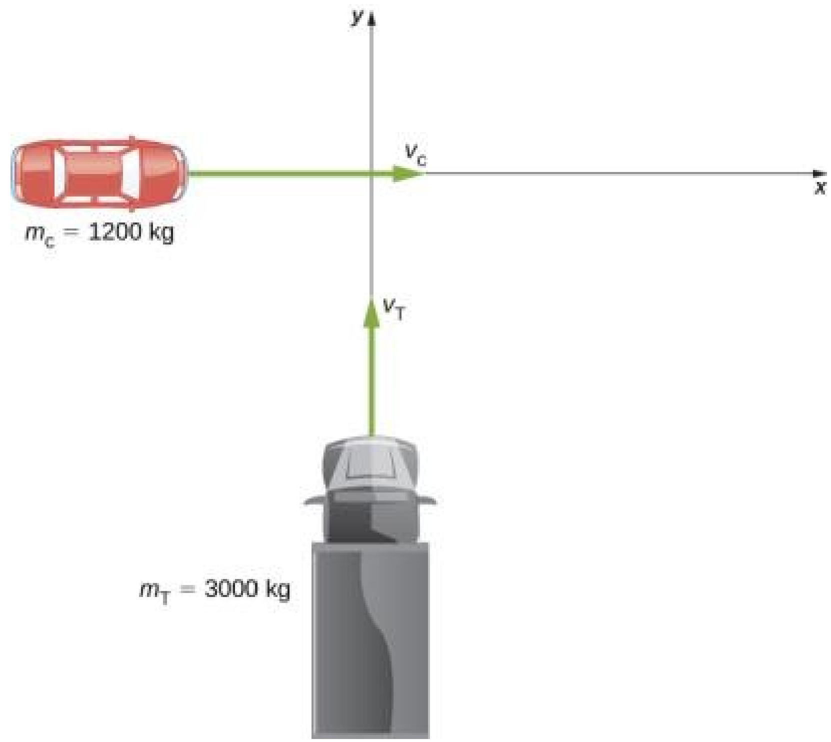
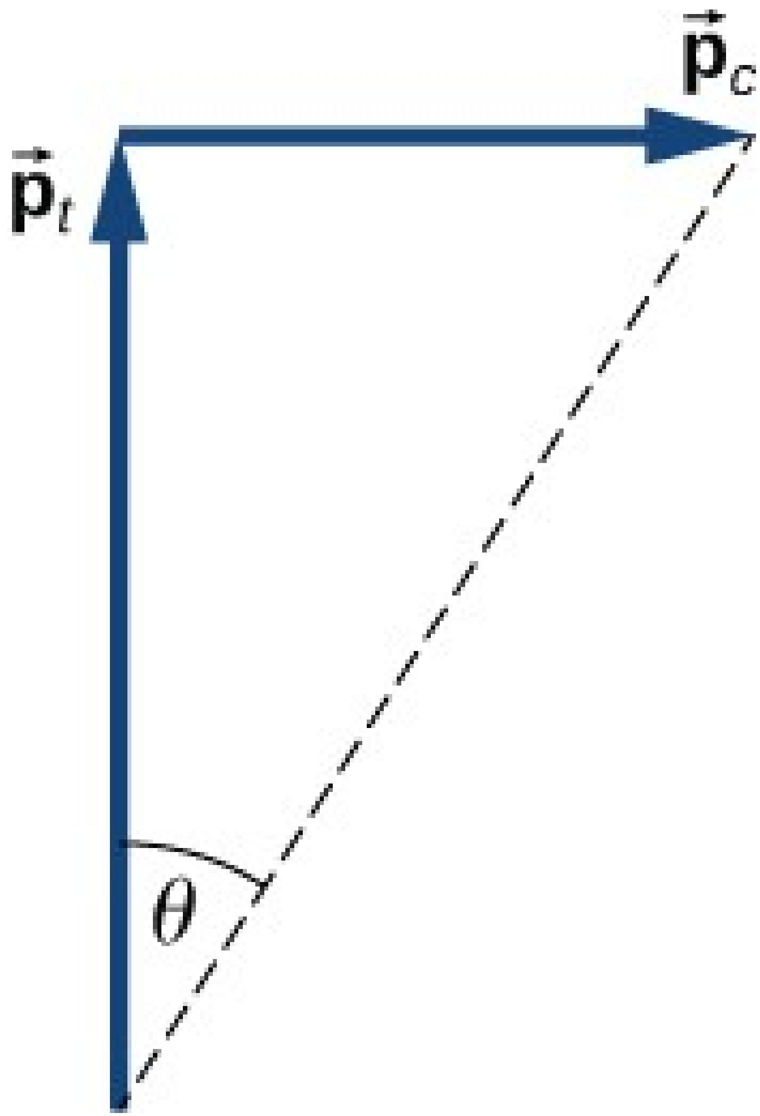

Before collision
After collision
$\vec{\mathbf{v}}_{\text{proton}} = (7.0 \times 10^6 \text{ m/s})\hat{\mathbf{i}}$
$\vec{\mathbf{v}}_{\text{neutron}} = -(4.0 \times 10^6 \text{ m/s})\hat{\mathbf{i}}$
$\vec{\mathbf{v}}_{\text{deuteron}} = ?$

FIGURE 9.23



A large truck moving north is about to collide with a small car moving east. The final momentum vector has both *x*- and *y*-components.

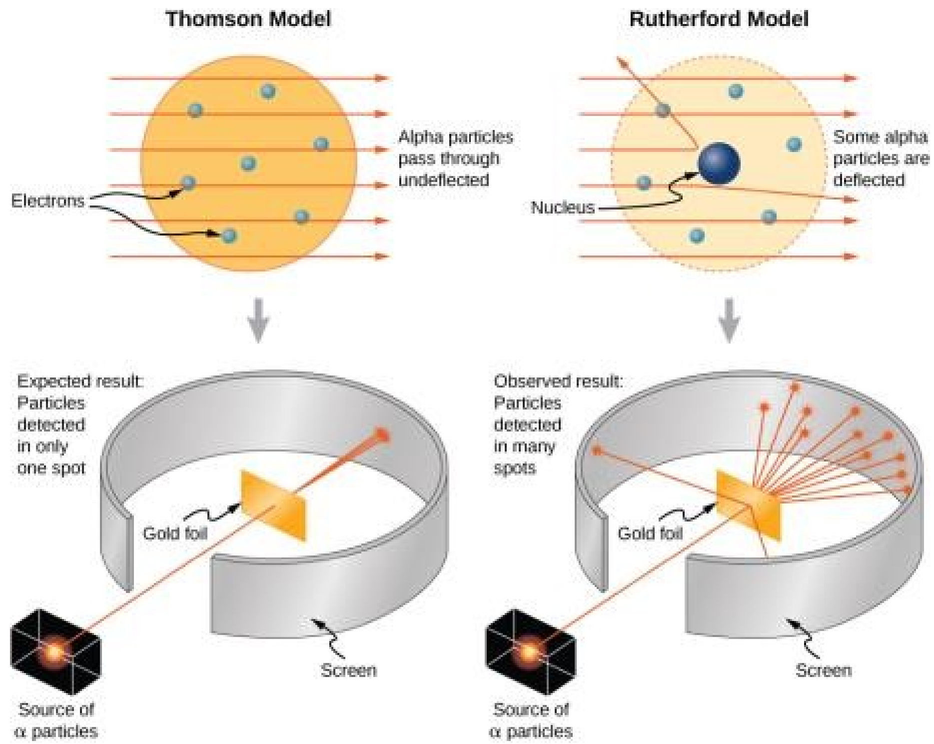
FIGURE 9.24



Graphical addition of momentum vectors. Notice that, although the car's velocity is larger than the truck's, its momentum is smaller.

Rutherford scattering

FIGURE 9.21



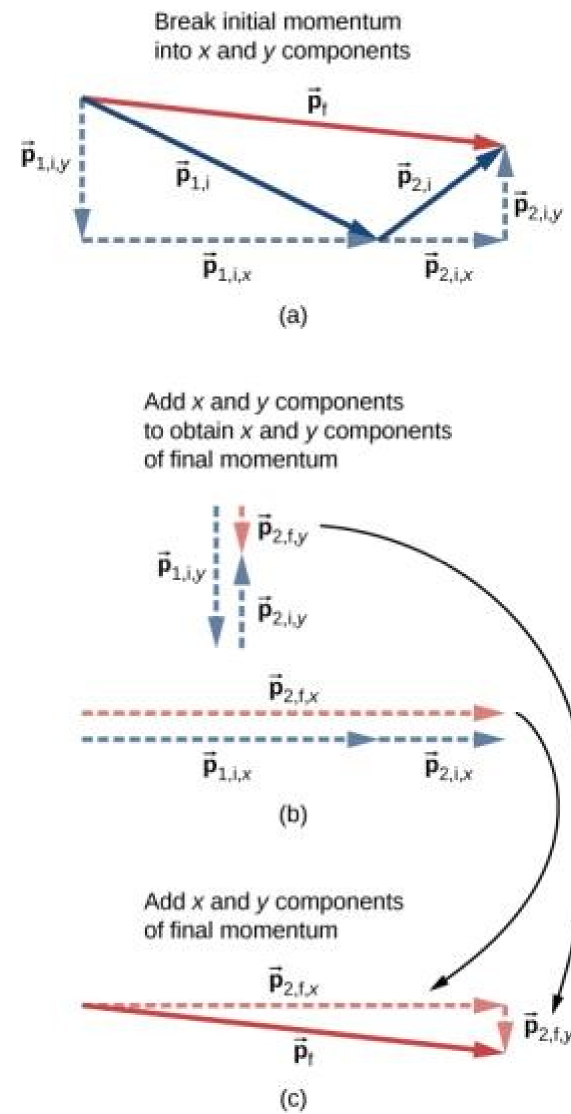
The Thomson and Rutherford models of the atom. The Thomson model predicted that nearly all of the incident alpha-particles would be scattered and at small angles. Rutherford and Geiger found that nearly none of the alpha particles were scattered, but those few that were deflected did so through very large angles. The results of Rutherford's experiments were inconsistent with the Thomson model. Rutherford used conservation of momentum and energy to develop a new, and better model of the atom—the nuclear model.

FIGURE 9.22

a) For two-dimensional momentum problems, break the initial momentum vectors into their *x*- and *y*-components.

b) Add the *x*- and *y*-components together separately. This gives you the *x*- and *y*-components of the final momentum, which are shown as red dashed vectors.

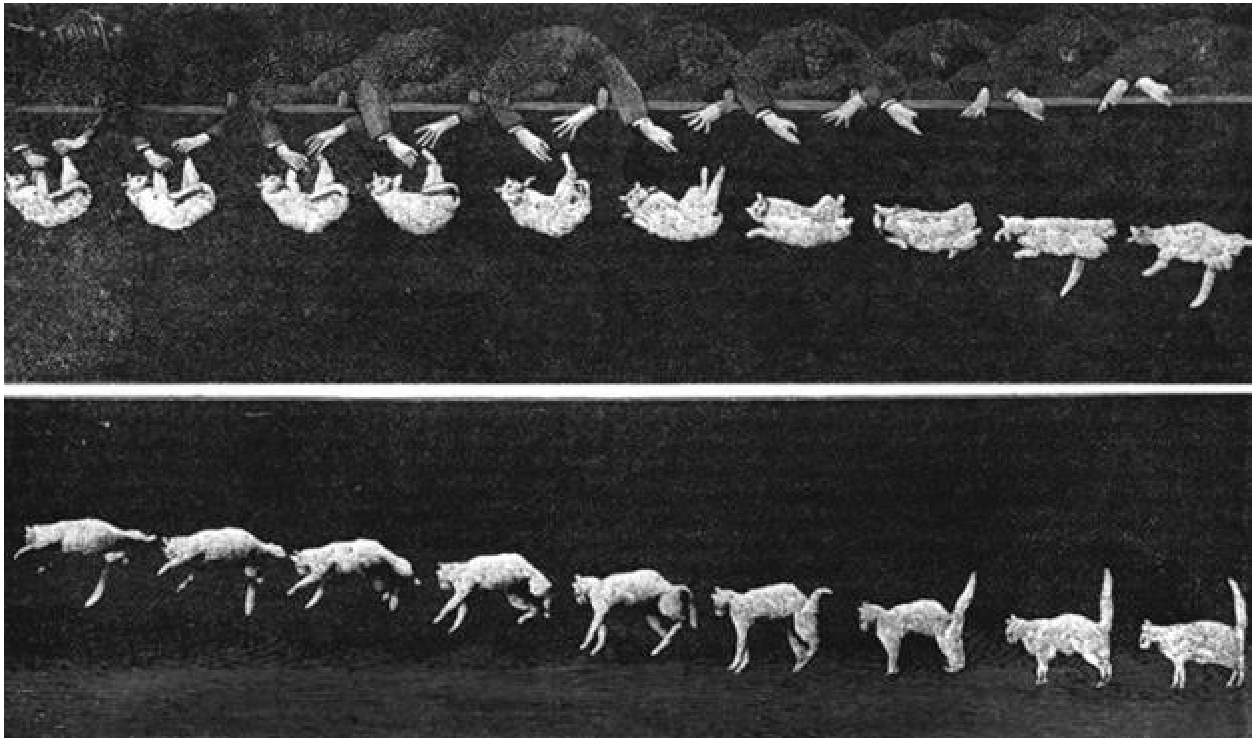
c) Adding these components together gives the final momentum.



Center of mass

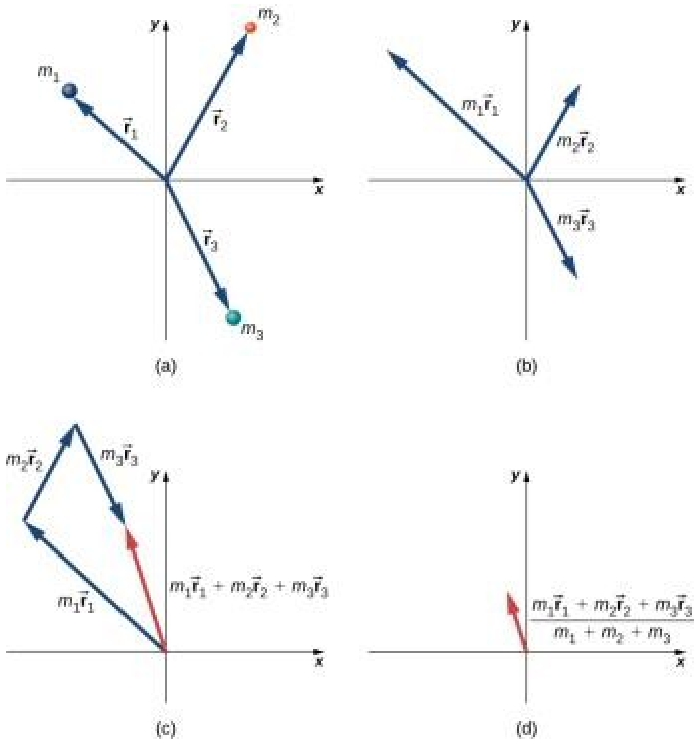
$$\overrightarrow{r_{CM}} = \frac{1}{M}\sum m_i \vec{r}_i = \frac{1}{M}\int \rho\left(\vec{r}\right)\vec{r}\,dV$$

FIGURE 9.26



As the cat falls, its body performs complicated motions so it can land on its feet, but one point in the system moves with the simple uniform acceleration of gravity.

FIGURE 9.27



Finding the center of mass of a system of three different particles.

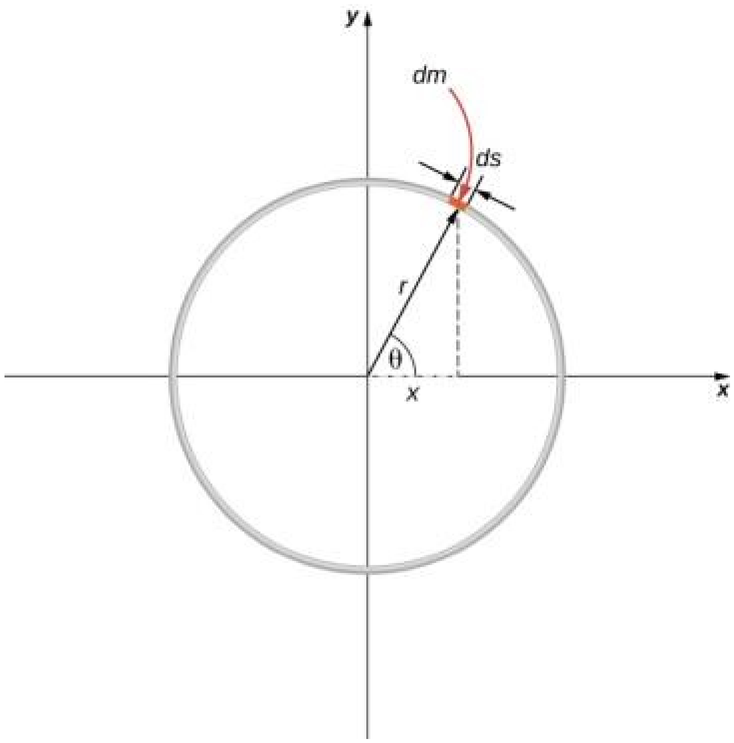
a) Position vectors are created for each object.

b) The position vectors are multiplied by the mass of the corresponding object.

c) The scaled vectors from part (b) are added together.

d) The final vector is divided by the total mass. This vector points to the center of mass of the system. Note that no mass is actually present at the center of mass of this system.

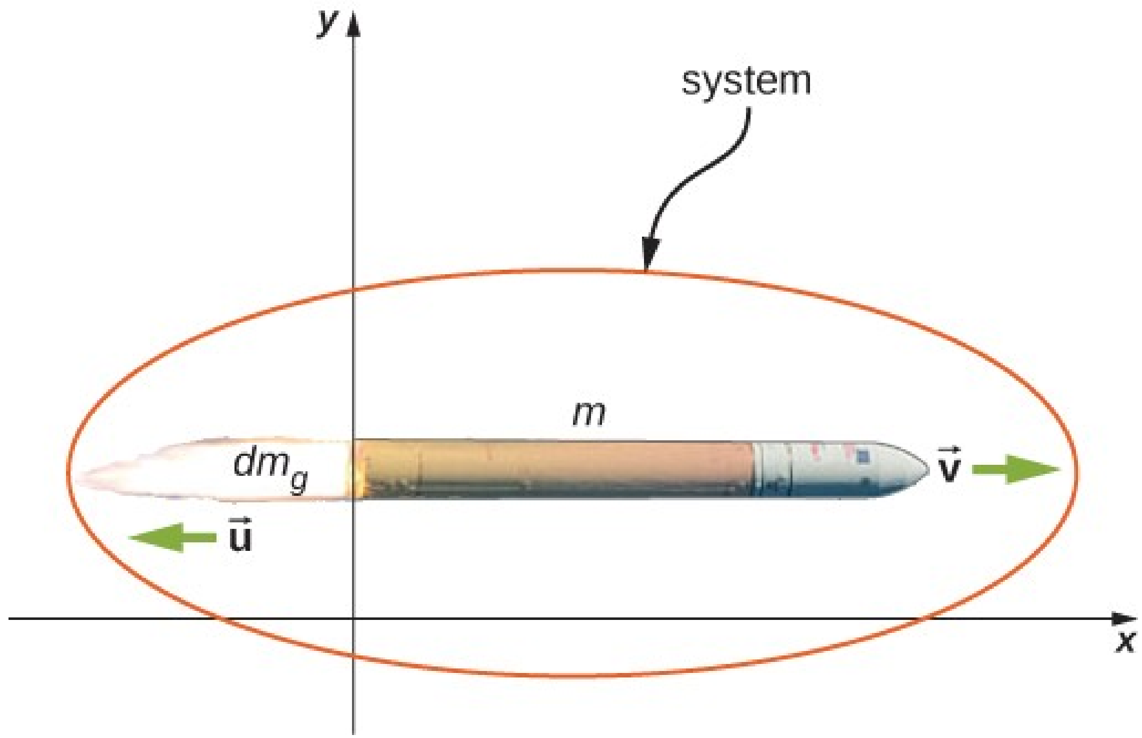
FIGURE 9.30



Finding the center of mass of a uniform hoop. We express the coordinates of a differential piece of the hoop, and then integrate around the hoop.

Rockets

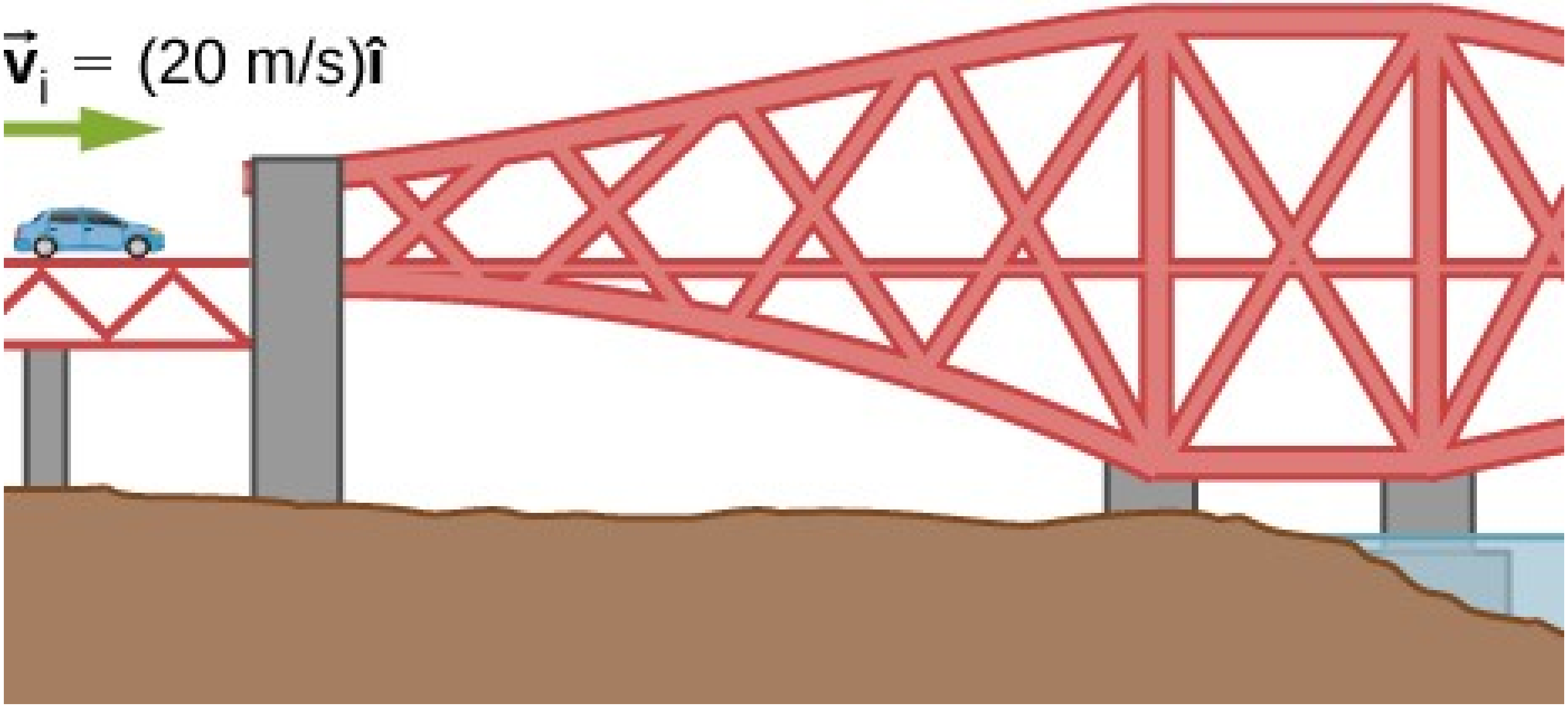
FIGURE 9.33



The rocket accelerates to the right due to the expulsion of some of its fuel mass to the left. Conservation of momentum enables us to determine the resulting change of velocity. The mass *m* is the instantaneous total mass of the rocket (i.e., mass of rocket body plus mass of fuel at that point in time). (credit: modification of work by NASA/Bill Ingalls)

More examples

EXERCISE 25

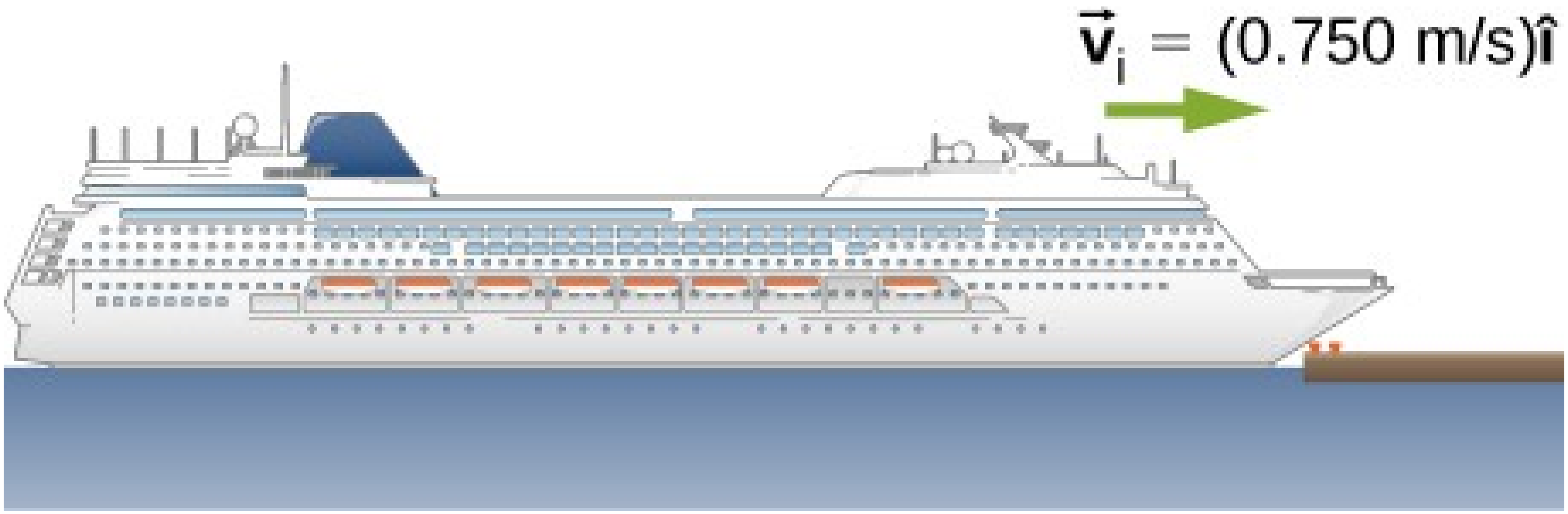


A person (m) is riding in a car moving at v when the car runs into a bridge abutment (see the following figure).

a. Calculate the average force on the person if he is stopped by a padded dashboard that compresses an average of X cm.

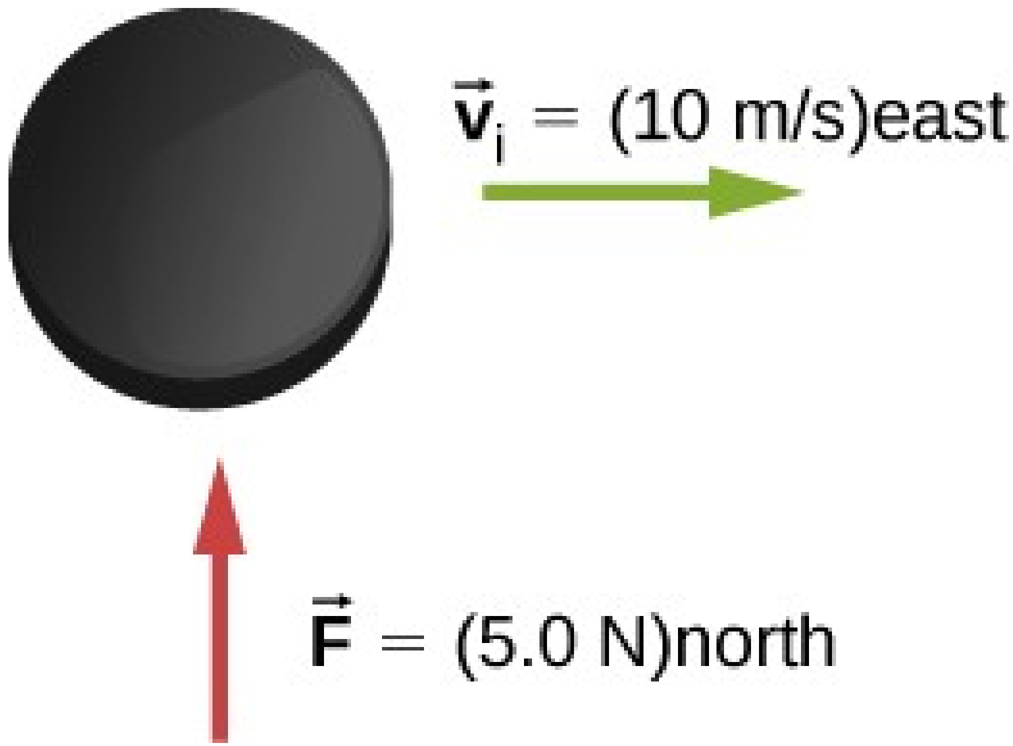
b. Calculate the average force on the person if he is stopped by an air bag that compresses an average of Y cm.

EXERCISE 27



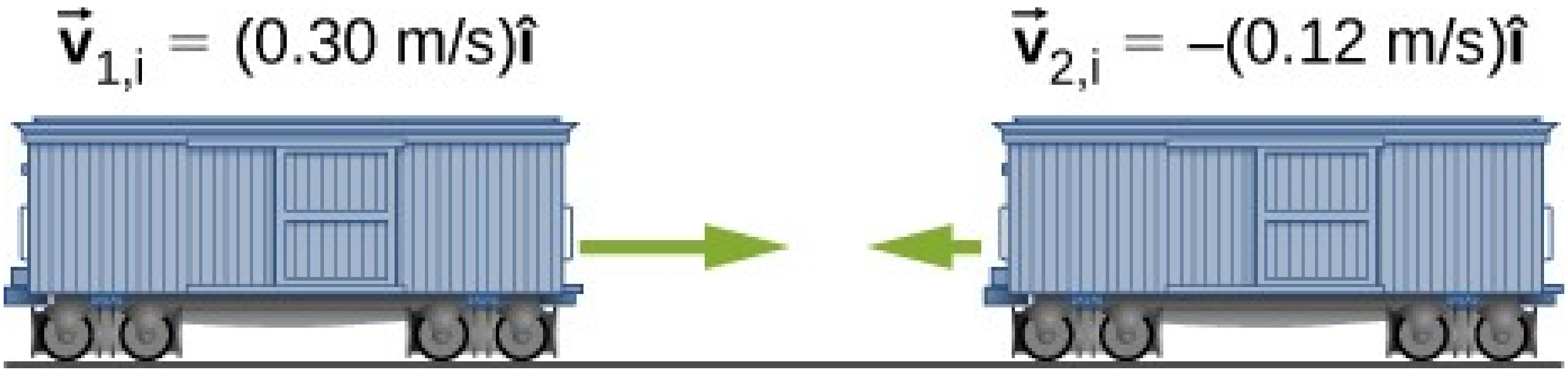
A cruise ship with a mass of M strikes a pier at a speed of v. It comes to rest after traveling X, damaging the ship, the pier, and the tugboat captain's finances. Calculate the average force exerted on the pier using the concept of impulse. (*Hint*: First calculate the time it took to bring the ship to rest, assuming a constant force.)

EXERCISE 33



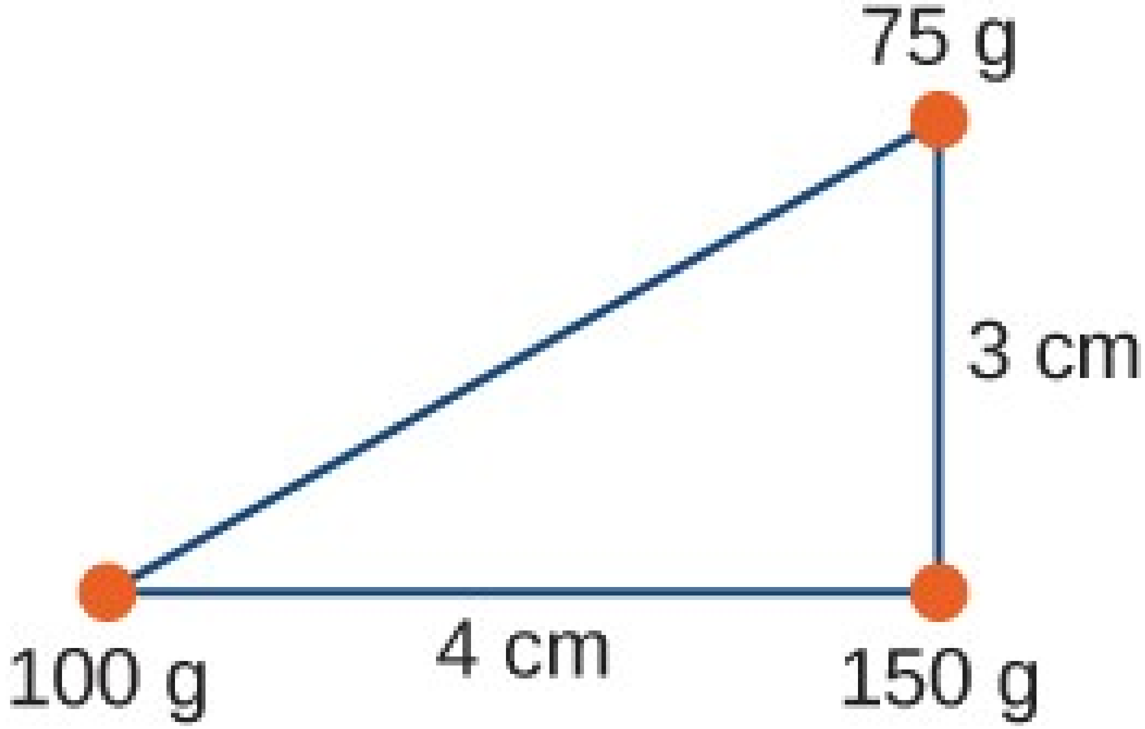
A hockey puck of mass m is sliding due east on a frictionless table with a speed of v. Suddenly, a constant force of magnitude F and direction due north is applied to the puck for t. Find the north and east components of the momentum at the end of the interval.

EXERCISE 35



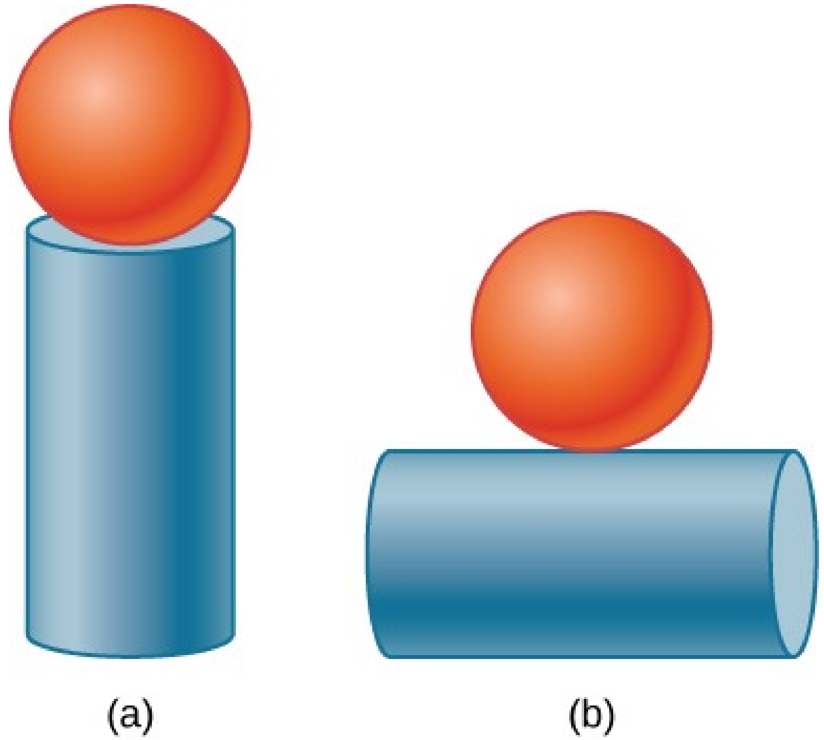
Train cars are coupled together by being bumped into one another. What is their final velocity?

EXERCISE 63



Find the center of mass of the three-mass system.

EXERCISE 76



Find the center of mass of a sphere of mass M and radius R and a cylinder of mass m, radius r, and height h arranged as shown below.