Summary

The **momentum**, $\vec{\mathbf{p}}$, of an object is defined as the product of its mass times its velocity,

$$\vec{\mathbf{p}} = m\vec{\mathbf{v}}. \tag{7–1}$$

In terms of momentum, **Newton's second law** can be written as

$$\Sigma\vec{\mathbf{F}} = \frac{\Delta\vec{\mathbf{p}}}{\Delta t}. \tag{7–2}$$

That is, the rate of change of momentum equals the net applied force.

The **law of conservation of momentum** states that the total momentum of an isolated system of objects remains constant. An **isolated system** is one on which the net external force is zero.

The law of conservation of momentum is very useful in dealing with **collisions**. In a collision, two (or more) objects interact with each other over a very short time interval, and the forces between them during this time interval are very large.

The **impulse** of a force on an object is defined as $\vec{\mathbf{F}}\,\Delta t$, where $\vec{\mathbf{F}}$ is the average force acting during the (usually short) time interval Δt. The impulse is equal to the change in momentum of the object:

$$\text{Impulse} = \vec{\mathbf{F}}\,\Delta t = \Delta\vec{\mathbf{p}}. \tag{7–5}$$

Total momentum is conserved in *any* collision as long as any net external force is zero or negligible. If $m_A\vec{\mathbf{v}}_A$ and $m_B\vec{\mathbf{v}}_B$ are the momenta of two objects before the collision and $m_A\vec{\mathbf{v}}'_A$ and $m_B\vec{\mathbf{v}}'_B$ are their momenta after, then momentum conservation tell us that

$$m_A\vec{\mathbf{v}}_A + m_B\vec{\mathbf{v}}_B = m_A\vec{\mathbf{v}}'_A + m_B\vec{\mathbf{v}}'_B \tag{7–3}$$

for this two-object system.

Total energy is also conserved, but this may not be helpful in problem solving unless the only type of energy transformation involves kinetic energy. In that case kinetic energy is conserved and the collision is called an **elastic collision**, and we can write

$$\tfrac{1}{2}m_A v_A^2 + \tfrac{1}{2}m_B v_B^2 = \tfrac{1}{2}m_A v_A'^2 + \tfrac{1}{2}m_B v_B'^2. \tag{7–6}$$

If kinetic energy is not conserved, the collision is called **inelastic**. A **completely inelastic** collision is one in which the colliding objects stick together after the collision.

The **center of mass** (CM) of an extended object (or group of objects) is that point at which the net force can be considered to act, for purposes of determining the translational motion of the object as a whole. The x component of the CM for objects with mass $m_A, m_B, \ldots,$ is given by

$$x_{CM} = \frac{m_A x_A + m_B x_B + \cdots}{m_A + m_B + \cdots}. \tag{7–9a}$$

[*The complete motion of an object can be described as the translational motion of its center of mass plus rotation (or other internal motion) about its center of mass.]

Questions

1. We claim that momentum is conserved, yet most moving objects eventually slow down and stop. Explain.

2. When a person jumps from a tree to the ground, what happens to the momentum of the person upon striking the ground?

3. When you release an inflated but untied balloon, why does it fly across the room?

4. It is said that in ancient times a rich man with a bag of gold coins froze to death while stranded on a frozen lake. Because the ice was frictionless, he could not push himself to shore. What could he have done to save himself had he not been so miserly?

5. How can a rocket change direction when it is far out in space and is essentially in a vacuum?

6. According to Eq. 7–5, the longer the impact time of an impulse, the smaller the force can be for the same momentum change, and hence the smaller the deformation of the object on which the force acts. On this basis, explain the value of air bags, which are intended to inflate during an automobile collision and reduce the possibility of fracture or death.

7. Cars used to be built as rigid as possible to withstand collisions. Today, though, cars are designed to have "crumple zones" that collapse upon impact. What is the advantage of this new design?

8. Why can a batter hit a pitched baseball further than a ball tossed in the air by the batter?

9. Is it possible for an object to receive a larger impulse from a small force than from a large force? Explain.

10. A light object and a heavy object have the same kinetic energy. Which has the greater momentum? Explain.

11. Describe a collision in which all kinetic energy is lost.

12. At a hydroelectric power plant, water is directed at high speed against turbine blades on an axle that turns an electric generator. For maximum power generation, should the turbine blades be designed so that the water is brought to a dead stop, or so that the water rebounds?

13. A squash ball hits a wall at a 45° angle as shown in Fig. 7–30. What is the direction (*a*) of the change in momentum of the ball, (*b*) of the force on the wall?

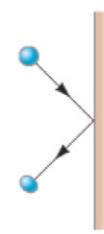

FIGURE 7–30 Question 13.

14. A Superball is dropped from a height h onto a hard steel plate (fixed to the Earth), from which it rebounds at very nearly its original speed. (*a*) Is the momentum of the ball conserved during any part of this process? (*b*) If we consider the ball and Earth as our system, during what parts of the process is momentum conserved? (*c*) Answer part (*b*) for a piece of putty that falls and sticks to the steel plate.

15. Why do you tend to lean backward when carrying a heavy load in your arms?

16. Why is the CM of a 1-m length of pipe at its mid-point, whereas this is not true for your arm or leg?

* **17.** Show on a diagram how your CM shifts when you change from a lying position to a sitting position.

* **18.** If only an external force can change the momentum of the center of mass of an object, how can the internal force of an engine accelerate a car?

* **19.** A rocket following a parabolic path through the air suddenly explodes into many pieces. What can you say about the motion of this system of pieces?