F4

Chapter Six

MOMENTUM AND ITS CONSERVATION

KEY IDEAS

Momentum is the product of mass and velocity. It is a vector quantity that measures the tendency of an object to remain in motion. An *impulse* is the product of force and time and is responsible for changing the momentum of an object. It is also a vector quantity.

If two objects interact (and are not subject to external forces) the momentum of the system (i.e., the two objects) is conserved. This basic law of physics can be used to describe collision and explosion phenomena.

KEY OBJECTIVES

At the conclusion of this chapter you will be able to:

- Define the term *momentum*, and state its SI unit.
- Solve problems involving mass, velocity, and momentum.
- Define the term *impulse*, and state its SI unit.
- Relate impulse to change in momentum.
- Solve impulse-momentum problems.
- State the law of conservation of momentum, and solve problems based on this law.
- Relate the law of conservation of momentum to Newton's third law of motion.

6.1 MOMENTUM

Suppose we wanted to measure the "tendency" of an object to remain in motion. We would find that two factors are necessary to describe this tendency: the mass and the velocity of the object. The more mass an object has, the more force is required to bring it to rest. Similarly, the greater the velocity of the object, the more force is necessary to bring it to rest. These two factors, mass and velocity, are combined into a single quantity that we call **momentum**. We define momentum, symbolized as **p**, as the product of mass and velocity:

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

Momentum is a vector quantity and its direction is the direction of the velocity of the object. Its unit is the *kilogram · meter per second* (kg · m/s).

PROBLEM

An object whose mass is 3.5 kilograms is traveling at 20. meters per second [east]. Calculate the momentum of the object.

SOLUTION

6.2 NEWTON'S SECOND LAW AND MOMENTUM

When Newton developed his second law of motion, he recognized that the unbalanced force on an object caused a change in the object's momentum:

$$\mathbf{F}_{net} = \frac{\Delta \mathbf{p}}{t} = \frac{\Delta(m\mathbf{v})}{t}$$

Since mass is usually constant:

$$\mathbf{F}_{net} = \frac{m\Delta\mathbf{v}}{t} = m\mathbf{a}$$

We can rewrite Newton's second law in the following form:

$$\mathbf{F}_{net}\, t = \Delta \mathbf{p}$$

We call the quantity $F\ t$, the **impulse** delivered to the object. Impulse is symbolized by the letter **J**, and its unit is the *newton · second* (N · s). Impulse is a vector quantity, and its direction is the direction of the net force.

From Newton's second law it follows that the impulse delivered to the object changes its momentum, and the unit newton · second is equivalent to the unit kilogram · meter per second.

PROBLEM

A 5.0-kilogram object traveling at 3.0 meters per second [east] is subjected to a force that increases its velocity to 7.0 meters per second [east]. Calculate: (a)

the *initial* momentum of the object, (b) the final momentum of the object, (c) the change in momentum of the object, and (d) the impulse delivered to the object. (e) If the force acts for 0.20 second, what are its magnitude and its direction?

SOLUTION

6.3 CONSERVATION OF MOMENTUM

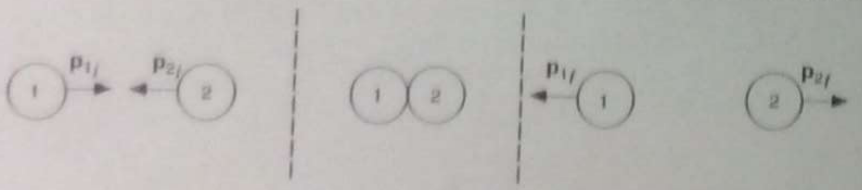
If two objects that are not subjected to any external forces interact (e.g., they collide), the total momentum of the objects before the interaction is equal to their total momentum after the interaction:

PHYSICS CONCEPTS

$$p_{before} = p_{after}$$

$$p_{1i} + p_{2i} = p_{1f} + p_{2f}$$

This relationship, known as *conservation of momentum*, is a fundamental law of physics. The diagram below illustrates the conservation of momentum.



PROBLEM

A 0.50-kilogram object traveling at 2.0 meters per second [east] collides with a 0.30-kilogram object traveling at 4.0 meters per second [west]. After the collision, the 0.30-kilogram object is traveling at 2.0 meters per second [east]. What are the magnitude and the direction of the velocity of the first object?

SOLUTION

$m_1 v_{1_i}$

3 kg)(2 m/s)

Consider a gun about to fire a bullet. The initial momentum of the gun-bullet system is zero. Since the bullet moves in one direction, the gun recoils in the opposite direction, so that the momentum after the "explosion" is also zero.

PROBLEM

A 5.0-kilogram gun fires a 0.0020-kilogram bullet. If the bullet exits the gun at 800. meters per second [east], calculate the recoil velocity of the gun.

SOLUTION