3 Conservation of Momentum and Energy

Prerequisites: Chapters 1 and 2

Conservation laws are an important part of the way the physicist views nature. Two of the most important are the laws of conservation of momentum and of conservation of energy. The former follows directly from Newton's laws of motion, while the latter is much deeper.

OBJECTIVES

After completing this chapter, you will be able to

- define momentum and state its metric units;
- relate momentum to impulse;
- given a change in momentum and the time involved, calculate the average force used;
- explain how momentum is conserved in an isolated system;
- apply the principle of conservation of momentum to analysis of simple collisions;
- calculate velocity after a collision between two objects, given initial velocities and masses of the objects;
- recognize the part played by the earth in conservation of momentum;
- define work and power;
- given force, distance, and time, calculate work and power;
- state correct units for work and power in the metric system;
- define and differentiate between gravitational potential energy and kinetic energy;
- calculate gravitational potential energy, given weight (or mass) and height;
- explain how gravitational potential energy, kinetic energy, and work are related in a system;
- use the principle of conservation of energy to calculate the speed of an object that has fallen from a given height (optional).

12 FRICTION AND THE EARTH

We have thus far neglected to mention the effect of friction. We spoke of the momentum of cars and trucks immediately before and after collisions, for example, but said nothing of the fact that after a wreck the wreckage would slide to a stop. What happens to the momentum of the wreckage? The answer is that the momentum is transferred to the earth. The earth spins a little faster (or slower, depending upon whether the motion was eastward or not). It may at first glance seem hard to believe that an object as small as a truck can affect the speed of the earth, but one must remember that we are not saying that the effect would be great enough to measure. Since the mass of the earth is so tremendous, its change in speed would be very, very small. Undetectable—but not nonexistent.

Consider the recoiling ice-skater from frame 10. Now suppose the skater is standing against a wall when the bowling ball is tossed forward. In this case, the system of the skater and the ball is not isolated, because it now includes the entire earth. Is the change in momentum of the skater detectable? __________

Answer: No, because the skater braces against the wall and the momentum is transferred to the earth.

13 WORK

In physics, work is defined as the product of the net force and the displacement through which that force is exerted, or $W = \vec{F}_{net}\vec{d}$. This corresponds to our everyday meaning of the word in that when you lift a brick 6 feet from the floor you do twice as much work as when you lift it 3 feet. Or suppose you lift 50 bricks to a height of 3 feet. You do 50 times as much work as lifting one brick that high.

But here comes a conclusion that may seem odd. After you lift a dozen bricks up to your waist, you are told by your boss to hold them there for 5 minutes. Do you do work in holding them there? To answer this we must go back to our definition. The force you exert is simply the weight of the 50 bricks.

(a) In holding them waist-high, does that force move the bricks through a distance? ____________________

(b) Using the formula, calculate the total work done in holding the bricks. ____________________

Answers: (a) no; (b) zero (In holding the bricks, there is motion within the muscles, so work is done inside your body, but no external work is done on the bricks. It is this external work with which we are concerned.)

15. Lifting a 5-kg object 3 m requires how much energy? ____________________

16. If the object in question 15 is lifted in 2 seconds, what is the power of the lifter? ____________________

17. *Optional*. An object is going 10 m/s when it hits the ground. From how high did it fall? (Hint: Since the object's mass does not matter, you may choose any mass you want.) ____________________

ANSWERS

1. The impulse applied to an object is equal to the change in momentum of the object. (frames 1, 2)

2. The two momenta are equal (but opposite in direction). (frames 3–5)

3. It will be less. (The momentum of the stuck-together objects must be equal to the momentum of the original moving object. Since the two objects have a mass greater than the mass of the single object, the speed of the two objects must be less.) (frames 6, 7)

4. vector (frames 8, 9)

5. 6.67 m/s. Solution: The total momentum before the explosion is zero, so the momentum of one piece of ice after the explosion plus the momentum of the other piece must equal zero.

$$(12\ \text{kg}\cdot 10\ \text{m/s}) + (18\ \text{kg}\cdot \text{v}) = 0$$
$$v = -6.67\ \text{m/s}$$

(The minus sign tells us that the speed of this block is in the opposite direction from the other block.) (frame 10)

6. 20 m/s. Solution:

$$(2000\ \text{kg}\cdot 50\ \text{m/s}) + (3{,}000\ \text{kg}\cdot 0) = 5{,}000\ \text{kg}\cdot \text{v}$$
$$100{,}000\ \text{kg}\cdot\text{m/s} = 5{,}000\ \text{kg}\cdot \text{v}$$
$$v = 20\ \text{m/s}$$

(frame 11)

7. No. Since the pitcher is fixed to the earth, the entire earth recoils. (frame 12)

8. Work is the product of the force exerted and the distance through which it is exerted. (frame 13)