We mentioned in Example 6–15 that only part of the energy output of a car engine reaches the wheels. Not only is some energy wasted in getting from the engine to the wheels, in the engine itself much of the input energy (from the gasoline) does not do useful work. An important characteristic of all engines is their overall *efficiency* e, defined as the ratio of the useful power output of the engine, P_{out}, to the power input, P_{in}:

Efficiency

$$e = \frac{P_{out}}{P_{in}}.$$

The efficiency is always less than 1.0 because no engine can create energy, and no engine can even transform energy from one form to another without some energy going to friction, thermal energy, and other nonuseful forms of energy. For example, an automobile engine converts chemical energy released in the burning of gasoline into mechanical energy that moves the pistons and eventually the wheels. But nearly 85% of the input energy is "wasted" as thermal energy that goes into the cooling system or out the exhaust pipe, plus friction in the moving parts. Thus car engines are roughly only about 15% efficient. We will discuss efficiency in detail in Chapter 15.

Summary

Work is done on an object by a force when the object moves through a distance d. If the direction of a constant force F makes an angle θ with the direction of motion, the work done by this force is

$$W = Fd\cos\theta. \qquad \textbf{(6–1)}$$

Energy can be defined as the ability to do work. In SI units, work and energy are measured in **joules** ($1\text{ J} = 1\text{ N}\cdot\text{m}$).

Kinetic energy (KE) is energy of motion. An object of mass m and speed v has translational kinetic energy

$$\text{KE} = \tfrac{1}{2}mv^2. \qquad \textbf{(6–3)}$$

Potential energy (PE) is energy associated with forces that depend on the position or configuration of objects. Gravitational potential energy is

$$\text{PE}_{grav} = mgy, \qquad \textbf{(6–6)}$$

where y is the height of the object of mass m above an arbitrary reference point. Elastic potential energy is given by

$$\text{elastic PE} = \tfrac{1}{2}kx^2 \qquad \textbf{(6–9)}$$

for a stretched or compressed spring, where x is the displacement from the unstretched position and k is the spring stiffness constant. Other potential energies include chemical, electrical, and nuclear energy. The change in potential energy when an object changes position is equal to the external work needed to take the object from one position to the other.

The **work-energy principle** states that the *net* work done on an object (by the *net* force) equals the change in kinetic energy of that object:

$$W_{net} = \Delta\text{KE} = \tfrac{1}{2}mv_2^2 - \tfrac{1}{2}mv_1^2. \qquad \textbf{(6–2, 6–4)}$$

The **law of conservation of energy** states that energy can be transformed from one type to another, but the total energy remains constant. It is valid even when friction is present, since the heat generated can be considered a form of energy transfer. When only *conservative forces* act, the total mechanical energy is conserved:

$$\text{KE} + \text{PE} = \text{constant}.$$

When nonconservative forces such as friction act, then

$$W_{NC} = \Delta\text{KE} + \Delta\text{PE}, \qquad \textbf{(6–10)}$$

where W_{NC} is the work done by nonconservative forces.

Power is defined as the rate at which work is done, or the rate at which energy is transformed. The SI unit of power is the **watt** ($1\text{ W} = 1\text{ J/s}$).

Questions

1. In what ways is the word "work" as used in everyday language the same as that defined in physics? In what ways is it different? Give examples of both.
2. Can a centripetal force ever do work on an object? Explain.
3. Can the normal force on an object ever do work? Explain.
4. A woman swimming upstream is not moving with respect to the shore. Is she doing any work? If she stops swimming and merely floats, is work done on her?
5. Is the work done by kinetic friction forces always negative? [*Hint*: Consider what happens to the dishes when you pull a tablecloth out from under them.]
6. Why is it tiring to push hard against a solid wall even though you are doing no work?
7. You have two springs that are identical except that spring 1 is stiffer than spring 2 $(k_1 > k_2)$. On which spring is more work done (a) if they are stretched using the same force, (b) if they are stretched the same distance?