* The First Law of Thermodynamics Extended

To be really complete about the first law, consider a system that is moving, so it has kinetic energy KE, and suppose there is also potential energy PE. Then the first law of thermodynamics would have to include these terms and would be written as

$$\Delta \text{KE} + \Delta \text{PE} + \Delta U = Q - W. \qquad \textbf{(15–2)}$$

EXAMPLE 15–2 **Kinetic energy transformed to thermal energy.** A 3.0-g bullet traveling at a speed of 400 m/s enters a tree and exits the other side with a speed of 200 m/s. Where did the bullet's lost KE go, and what was the energy transferred?

APPROACH Take the bullet and tree as our system. No potential energy is involved. No work is done on (or by) the system by outside forces, nor is any heat added because no energy was transferred to or from the system due to a temperature difference. Thus the kinetic energy gets transformed into internal energy of the bullet and tree.

SOLUTION From the first law of thermodynamics as given in Eq. 15–2, we are given $Q = W = \Delta \text{PE} = 0$, so we have

$$\Delta \text{KE} + \Delta U = 0$$

or

$$\Delta U = -\Delta \text{KE} = -(\text{KE}_f - \text{KE}_i) = \tfrac{1}{2}m(v_i^2 - v_f^2)$$
$$= \tfrac{1}{2}(3.0 \times 10^{-3}\,\text{kg})\left[(400\,\text{m/s})^2 - (200\,\text{m/s})^2\right] = 180\,\text{J}.$$

NOTE The internal energy of the bullet and tree both increase, as both experience a rise in temperature. If we had chosen the bullet alone as our system, work would be done on it and heat transfer would occur.

15–2 Thermodynamic Processes and the First Law

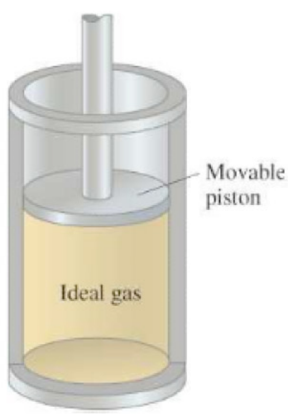


FIGURE 15–1 An ideal gas in a cylinder fitted with a movable piston.

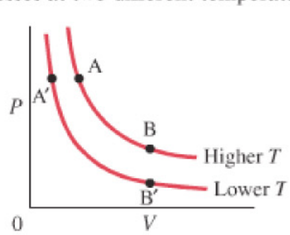
Let us analyze some thermodynamic processes in light of the first law of thermodynamics. To begin, we choose a very simple system: a fixed mass of an ideal gas enclosed in a container fitted with a movable piston as shown in Fig. 15–1.

Isothermal process ($\Delta T = 0$)

First we consider an idealized process that is carried out at constant temperature. Such a process is called an **isothermal** process (from the Greek meaning "same temperature"). If an isothermal process is carried out on our ideal gas, then $PV = nRT$ (Eq. 13–3) becomes $PV = \text{constant}$. Thus the process follows a curve like AB on the PV diagram shown in Fig. 15–2, which is a curve for $PV = \text{constant}$ (as in Fig. 13–12). Each point on the curve, such as point A, represents a state of the system—that is, its pressure P and volume V at a given moment. At a lower temperature, another isothermal process would be represented by a curve like A′ B′ in Fig. 15–2 (the product $PV = nRT = \text{constant}$ is less when T is less). The curves shown in Fig. 15–2 are referred to as *isotherms*.

Heat reservoir

FIGURE 15–2 *PV* diagram for an ideal gas undergoing isothermal processes at two different temperatures.



We assume that the gas is in contact with a **heat reservoir** (a body whose mass is so large that, ideally, its temperature does not change significantly when heat is exchanged with our system). We also assume that the process of compression (volume decrease) or expansion (volume increase) is done very slowly to make certain that all of the gas stays in equilibrium at the same constant temperature. If the gas is initially in a state represented by point A in Fig. 15–2, and an amount of heat Q is added to the system, the pressure and volume will change and the state of the system will be represented by another point, B, on the diagram. If the temperature is to remain constant, the gas must expand and do an amount of work W on the environment (it exerts a force on the piston in Fig. 15–1 and moves it through a distance). The temperature is kept constant so, from Eq. 14–1, the internal energy does not change: $\Delta U = \frac{3}{2}nR\,\Delta T = 0$. Hence, by the first law of thermodynamics (Eq. 15–1), $\Delta U = Q - W = 0$, so $W = Q$: the work done by the gas in an isothermal process equals the heat added to the gas.

Isothermal process (ideal gas): *T = constant, $\Delta U = 0$, $Q = W$*