EXAMPLE 15–5 **First law in isobaric and isovolumetric processes.** An ideal gas is slowly compressed at a constant pressure of 2.0 atm from 10.0 L to 2.0 L. This process is represented in Fig. 15–8 as the path B to D. (In this process, some heat flows out of the gas and the temperature drops.) Heat is then added to the gas, holding the volume constant, and the pressure and temperature are allowed to rise (line DA) until the temperature reaches its original value $(T_A = T_B)$. Calculate (*a*) the total work done by the gas in the process BDA, and (*b*) the total heat flow into the gas.

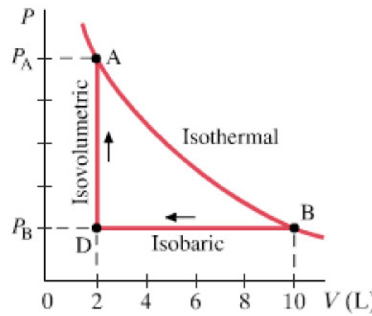

FIGURE 15–8 Example 15–5.

APPROACH (*a*) Work is done only in the compression process BD. In process DA, the volume is constant so $\Delta V = 0$ and no work is done (Eq. 15–3). (*b*) We use the first law of thermodynamics, Eq. 15–1.

SOLUTION (*a*) During the compression BD, the pressure is $2.0\,\text{atm} = 2(1.01 \times 10^5\,\text{N/m}^2)$ and the change in volume is

$$\Delta V = (2.0 \times 10^{-3}\,\text{m}^3) - (10.0 \times 10^{-3}\,\text{m}^3) = -8.0 \times 10^{-3}\,\text{m}^3.$$

Then the work done is

$$W = P\,\Delta V = (2.02 \times 10^5\,\text{N/m}^2)(-8.0 \times 10^{-3}\,\text{m}^3) = -1.6 \times 10^3\,\text{J}.$$

The total work done by the gas is $-1.6 \times 10^3\,\text{J}$, where the minus sign means that $+1.6 \times 10^3\,\text{J}$ of work is done *on* the gas.

(*b*) Because the temperature at the beginning and at the end of process BDA is the same, there is no change in internal energy: $\Delta U = 0$. From the first law of thermodynamics we have

$$0 = \Delta U = Q - W,$$

so

$$Q = W = -1.6 \times 10^3\,\text{J}.$$

Since Q is negative, 1600 J of heat flows out of the gas for the whole process, BDA.

EXERCISE C In Example 15–5, if the heat lost from the gas in the process BD is $8.4 \times 10^3\,\text{J}$, what is the change in internal energy of the gas during process BD?

Additional Examples

EXAMPLE 15–6 **Work done in an engine.** In an engine, 0.25 moles of an ideal monatomic gas in the cylinder expands rapidly and adiabatically against the piston. In the process, the temperature of the gas drops from 1150 K to 400 K. How much work does the gas do?

APPROACH We take the gas as our system (the piston is part of the surroundings). The pressure is not constant, so we can't use Eq. 15–3. Instead, we can use the first law of thermodynamics because we can determine ΔU given $Q = 0$ (the process is adiabatic).

SOLUTION We determine ΔU from Eq. 14–1 for the internal energy of an ideal monatomic gas:

$$\begin{aligned}\Delta U = U_f - U_i &= \tfrac{3}{2}nR(T_f - T_i)\\ &= \tfrac{3}{2}(0.25\,\text{mol})(8.314\,\text{J/mol}\cdot\text{K})(400\,\text{K} - 1150\,\text{K})\\ &= -2300\,\text{J}.\end{aligned}$$

Then, from the first law of thermodynamics, Eq. 15–1,

$$W = Q - \Delta U = 0 - (-2300\,\text{J}) = 2300\,\text{J}.$$