

SOLUTION

IDENTIFY and SET UP: This problem involves the properties of the Carnot cycle and those of an ideal gas. We are given the number of moles n and the pressure and temperature at point a (which is at the higher of the two reservoir temperatures); we can find the volume at a using the ideal-gas equation $pV = nRT$. We then find the pressure and volume at points b , c , and d from the known doubling of volume in step $a \rightarrow b$, from equations given in this section, and from $pV = nRT$. In each step we use Eqs. (20.10) and (20.11) to find the heat flow and work done and Eq. (19.13) to find the internal energy change.

EXECUTE: The volume at point a is

$$V_a = \frac{nRT_a}{p_a} = \frac{(0.200 \text{ mol})(8.31 \text{ J/mol}\cdot\text{K})(500 \text{ K})}{(1.00 \times 10^5 \text{ Pa})} = 8.31 \times 10^{-3} \text{ m}^3$$

The volume at point b is twice that at point a , so

$$V_b = 2V_a = 1.66 \times 10^{-2} \text{ m}^3$$

The pressure at point b is

$$p_b = \frac{nRT_b}{V_b} = \frac{(0.200 \text{ mol})(8.31 \text{ J/mol}\cdot\text{K})(500 \text{ K})}{1.66 \times 10^{-2} \text{ m}^3} = 5.00 \times 10^4 \text{ Pa}$$

The volume at point c is

$$V_c = 2V_b = 3.32 \times 10^{-2} \text{ m}^3$$

The pressure at point c is

$$p_c = \frac{nRT_c}{V_c} = \frac{(0.200 \text{ mol})(8.31 \text{ J/mol}\cdot\text{K})(300 \text{ K})}{3.32 \times 10^{-2} \text{ m}^3} = 1.50 \times 10^4 \text{ Pa}$$

The volume at point d is

$$V_d = 2V_c = 6.64 \times 10^{-2} \text{ m}^3$$

The pressure at point d is

$$p_d = \frac{nRT_d}{V_d} = \frac{(0.200 \text{ mol})(8.31 \text{ J/mol}\cdot\text{K})(500 \text{ K})}{6.64 \times 10^{-2} \text{ m}^3} = 1.25 \times 10^4 \text{ Pa}$$

For the adiabatic expansion $b \rightarrow c$, $Q_{bc} = 0$. From the first law of thermodynamics, $\Delta U_{bc} = Q_{bc} - W_{bc} = -W_{bc}$; the work W_{bc} done by the gas in this adiabatic expansion equals the negative of the change in internal energy of the gas. From Eq. (19.13) we have $\Delta U = nC_V\Delta T$, where $\Delta T = T_c - T_b$. Using $C_V = 20.8 \text{ J/mol}\cdot\text{K}$ for an ideal diatomic gas, we find

$$\begin{aligned} W_{bc} &= -\Delta U_{bc} = -nC_V(T_c - T_b) = nC_V(T_b - T_c) \\ &= (0.200 \text{ mol})(20.8 \text{ J/mol}\cdot\text{K})(500 \text{ K} - 300 \text{ K}) = 832 \text{ J} \end{aligned}$$

For the isothermal compression $c \rightarrow d$, $\Delta U_{cd} = 0$; Eq. (20.11)

$$\begin{aligned} W_{cd} &= -nRT_c \ln \frac{V_d}{V_c} \\ &= -(0.200 \text{ mol})(8.31 \text{ J/mol}\cdot\text{K})(300 \text{ K}) \ln \frac{6.64 \times 10^{-2} \text{ m}^3}{3.32 \times 10^{-2} \text{ m}^3} \\ &= -346 \text{ J} \end{aligned}$$

The work done by the gas in the isothermal expansion $a \rightarrow b$ is

$$W_{ab} = nRT_a \ln \frac{V_b}{V_a} = (0.200 \text{ mol})(8.31 \text{ J/mol}\cdot\text{K})(500 \text{ K}) \ln 2 = 582 \text{ J}$$

The work done by the gas in the isothermal compression $d \rightarrow a$ is

$$W_{da} = nRT_d \ln \frac{V_a}{V_d} = (0.200 \text{ mol})(8.31 \text{ J/mol}\cdot\text{K})(500 \text{ K}) \ln \frac{1}{2} = -582 \text{ J}$$

The net work done by the gas in the cycle is

$$W_{\text{net}} = W_{ab} + W_{bc} + W_{cd} + W_{da} = 582 \text{ J} + 832 \text{ J} - 346 \text{ J} - 582 \text{ J} = 486 \text{ J}$$

The heat Q_{ab} added to the gas in the isothermal expansion $a \rightarrow b$ is

$$Q_{ab} = nRT_a \ln \frac{V_b}{V_a} = (0.200 \text{ mol})(8.31 \text{ J/mol}\cdot\text{K})(500 \text{ K}) \ln 2 = 582 \text{ J}$$

The heat Q_{bc} added to the gas in the adiabatic expansion $b \rightarrow c$ is

$$Q_{bc} = 0$$

The heat Q_{cd} added to the gas in the isothermal compression $c \rightarrow d$ is

$$Q_{cd} = nRT_c \ln \frac{V_d}{V_c} = (0.200 \text{ mol})(8.31 \text{ J/mol}\cdot\text{K})(300 \text{ K}) \ln 2 = 346 \text{ J}$$

The heat Q_{da} added to the gas in the isothermal expansion $d \rightarrow a$ is

$$Q_{da} = nRT_d \ln \frac{V_a}{V_d} = (0.200 \text{ mol})(8.31 \text{ J/mol}\cdot\text{K})(500 \text{ K}) \ln \frac{1}{2} = -582 \text{ J}$$

Masteringphysics Solution Chapter

M Carnoy



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