

19. (a) Work is done only for the ab portion of the process. This portion is at constant pressure, so the work done by the gas is

$$W = \int_{V_0}^{4V_0} p_0 dV = p_0(4V_0 - V_0) = 3p_0V_0 .$$

- (b) We use the first law: $\Delta E_{\text{int}} = Q - W$. Since the process is at constant volume, the work done by the gas is zero and $E_{\text{int}} = Q$. The energy Q absorbed by the gas as heat is $Q = nC_V \Delta T$, where C_V is the molar specific heat at constant volume and ΔT is the change in temperature. Since the gas is a monatomic ideal gas, $C_V = \frac{3}{2}R$. Use the ideal gas law to find that the initial temperature is $T_b = p_b V_b / nR = 4p_0 V_0 / nR$ and that the final temperature is $T_c = p_c V_c / nR = (2p_0)(4V_0) / nR = 8p_0 V_0 / nR$. Thus,

$$Q = \frac{3}{2}nR \left(\frac{8p_0 V_0}{nR} - \frac{4p_0 V_0}{nR} \right) = 6p_0 V_0 .$$

The change in the internal energy is $\Delta E_{\text{int}} = 6p_0 V_0$. Since $n = 1$ mol, this can also be written $Q = 6RT_0$. Since the process is at constant volume, use $dQ = nC_V dT$ to obtain

$$\Delta S = \int \frac{dQ}{T} = nC_V \int_{T_b}^{T_c} \frac{dT}{T} = nC_V \ln \frac{T_c}{T_b} .$$

Substituting $C_V = \frac{3}{2}R$ and using the ideal gas law, we write

$$\frac{T_c}{T_b} = \frac{p_c V_c}{p_b V_b} = \frac{(2p_0)(4V_0)}{p_0(4V_0)} = 2 .$$

Thus, $\Delta S = \frac{3}{2}nR \ln 2$. Since $n = 1$, this is $\Delta S = \frac{3}{2}R \ln 2$.

- (c) For a complete cycle, $\Delta E_{\text{int}} = 0$ and $\Delta S = 0$.