Chapter 19

1 The First Law of Thermodynamics

In a thermodynamic process, Q is positive when heat flows **into** a system, and negative when heat flows **out** of the system.

Work W is **positive** when work is done by the system against its surroundings, and hence corresponds to energy leaving the system. W is negative when work is done on the system.

1.1 Work Done During Volume Changes

- Isobaric: p is constant

$$\begin{aligned} dW &= (F)dx \\ dW &= (pA)dx, \quad \text{Pressure} = \frac{\text{Force}}{\text{Area}} \\ dW &= (p)dV \\ \int_0^W (1)dW &= p\int_{V_0}^{V_1}(1)dV \\ W &= p\left[V_1 - V_0\right] \end{aligned}$$

$$W = p\left[V_1 - V_0\right] \tag{1}$$

- Isochoric: V is constant, $\Delta U = Q - 0$

$$W = \int (p)dV = p(0) = 0$$

- Isothermal: T is constant, $0 = Q - nRT \ln \frac{V_1}{V_0}$

$$W = \int (p) dV$$
$$W = \int \left(\frac{nRT}{V} \right) dV$$
$$W = nRT \int_{V_0}^{V_1} \left(\frac{1}{V} \right) dV$$
$$W = nRT \ln \left[\frac{V_1}{V_0} \right]$$

- Adiabatic: No heat enters or exits, $Q = 0$, $\Delta U = 0 - W$

1.1.1 Question

$$dW = \int \left(\frac{nRT}{P} \right) dp$$
$$\int_0^W (1) dW = nRT \int_{p_0}^{p_1} \left(\frac{1}{P} \right) dp$$

1.1.2 19.7

(a)

$$W_{1,3} = p_1(V_2 - V_1)$$
$$W_{3,2} = 0$$
$$W_{2,4} = p_2(V_1 - V_2)$$
$$W_{4,1} = 0$$

$$W_{total} = p_1(V_2 - V_1) + p_2(V_1 - V_2)$$
$$W_{total} = p_1(V_2 - V_1) - p_2(-V_1 + V_2)$$
$$W_{total} = (p_1 - p_2)(V_2 - V_1)$$

1.1.3 19.1

$$n = 2\,\mathrm{mol}$$
$$T_0 = 27\,^\circ\mathrm{C} = 300\,\mathrm{K}$$
$$T_1 = 107\,^\circ\mathrm{C} = 380\,\mathrm{K}$$
$$W = ?$$

$$W = p \int_{V_1}^{V_2} (1) dV$$
$$W = p(V_2 - V_1)$$

$$pV = nRT$$
$$p(V_2 - V_1) = nR(T_2 - T_1)$$

$$W = nR(T_2 - T_1)$$
$$W = (2\,\mathrm{mol})(8.314\,\mathrm{J\,mol^{-1}\,K^{-1}})(380\,\mathrm{K} - 300\,\mathrm{K})$$
$$W = 1330.24\,\mathrm{J}$$

1.1.4 19.2

$$n = 6\,\mathrm{mol}$$
$$T_0 = 27.0\,^\circ\mathrm{C} = 300\,\mathrm{K}$$
$$p = \text{constant}$$
$$T_1 = ?$$
$$W = 2.40 \times 10^3\,\mathrm{J}$$

$$W = p\left[V_1 - V_0\right]$$
$$p\left[V_1 - V_0\right] = nR\left[T_1 - T_0\right]$$
$$W = nR\left[T_1 - T_0\right]$$
$$T_1 = \frac{W}{nR} + T_0$$
$$T_1 = \frac{2.40 \times 10^3\,\mathrm{J}}{(6\,\mathrm{mol})(8.314\,\mathrm{J\,mol^{-1}\,K^{-1}})} + 300\,\mathrm{K}$$
$$T_1 = 348.112\,\mathrm{K}$$