Chapter Twenty: Heat and the First Law of Thermodynamics

SOLUTIONS TO PROBLEMS

P20.2 The container is thermally insulated, so no energy flows by heat:

$$Q = 0$$
$$\text{and } \Delta E_{\text{int}} = Q + W_{\text{input}} = 0 + W_{\text{input}} = 2mgh$$

The work on the falling weights is equal to the work done on the water in the container by the rotating blades. This work results in an increase in internal energy of the water:

$$2mgh = \Delta E_{\text{int}} = m_{\text{water}} c \Delta T$$

$$\Delta T = \frac{2mgh}{m_{\text{water}} c} = \frac{2 \times 1.50 \text{ kg}\left(9.80 \text{ m/s}^2\right)(3.00 \text{ m})}{0.200 \text{ kg}\left(4\,186 \text{ J/kg}\cdot°\text{C}\right)} = \frac{88.2 \text{ J}}{837 \text{ J/°C}}$$
$$= \boxed{0.105°\text{C}}$$

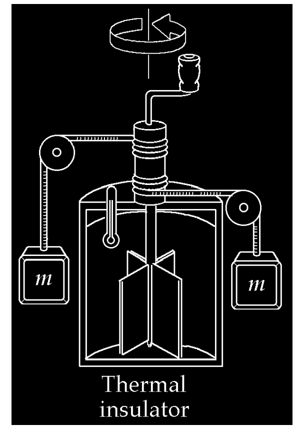

FIG. P20.2

P20.9 (a) $Q_{\text{cold}} = -Q_{\text{hot}}$

$$\left(m_w c_w + m_c c_c\right)\left(T_f - T_c\right) = -m_{\text{Cu}} c_{\text{Cu}}\left(T_f - T_{\text{Cu}}\right) - m_{unk} c_{unk}\left(T_f - T_{unk}\right)$$

where w is for water, c the calorimeter, Cu the copper sample, and unk the unknown.

$$\left[250 \text{ g}\left(1.00 \text{ cal/g}\cdot°\text{C}\right) + 100 \text{ g}\left(0.215 \text{ cal/g}\cdot°\text{C}\right)\right](20.0 - 10.0)°\text{C}$$
$$= -(50.0 \text{ g})\left(0.092\,4 \text{ cal/g}\cdot°\text{C}\right)(20.0 - 80.0)°\text{C} - (70.0 \text{ g})c_{unk}(20.0 - 100)°\text{C}$$
$$2.44 \times 10^3 \text{ cal} = \left(5.60 \times 10^3 \text{ g}\cdot°\text{C}\right)c_{unk}$$

or $c_{unk} = \boxed{0.435 \text{ cal/g}\cdot°\text{C}}$.

(b) The material of the sample is $\boxed{\text{beryllium}}$.

P20.19 $Q = m_{\text{Cu}} c_{\text{Cu}} \Delta T = m_{N_2}\left(L_{\text{vap}}\right)_{N_2}$

$$1.00 \text{ kg}\left(0.092\,0 \text{ cal/g}\cdot°\text{C}\right)(293 - 77.3)°\text{C} = m(48.0 \text{ cal/g})$$
$$m = \boxed{0.414 \text{ kg}}$$

P20.28 (a) $W = -P\Delta V = -(0.800 \text{ atm})(-7.00 \text{ L})\left(1.013 \times 10^5 \text{ Pa/atm}\right)\left(10^{-3} \text{ m}^3\text{/L}\right) = \boxed{+567 \text{ J}}$

(b) $\Delta E_{\text{int}} = Q + W = -400 \text{ J} + 567 \text{ J} = \boxed{167 \text{ J}}$

P20.69 $W = W_{AB} + W_{BC} + W_{CD} + W_{DA}$

$$W = -\int_A^B PdV - \int_B^C PdV - \int_C^D PdV - \int_D^A PdV$$

$$W = -nRT_1\int_A^B \frac{dV}{V} - P_2\int_B^C dV - nRT_2\int_C^D \frac{dV}{V} - P_1\int_D^A dV$$

$$W = -nRT_1 \ln\left(\frac{V_B}{V_1}\right) - P_2\left(V_C - V_B\right) - nRT_2 \ln\left(\frac{V_2}{V_C}\right) - P_1\left(V_A - V_D\right)$$

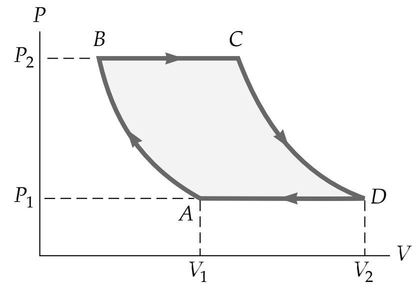

FIG. P20.69

Now $P_1V_A = P_2V_B$ and $P_2V_C = P_1V_D$, so only the logarithmic terms do not cancel out.

Also, $\frac{V_B}{V_1} = \frac{P_1}{P_2}$ and $\frac{V_2}{V_C} = \frac{P_2}{P_1}$

$$\sum W = -nRT_1 \ln\left(\frac{P_1}{P_2}\right) - nRT_2 \ln\left(\frac{P_2}{P_1}\right) = +nRT_1 \ln\left(\frac{P_2}{P_1}\right) - nRT_2 \ln\left(\frac{P_2}{P_1}\right) = -nR\left(T_2 - T_1\right)\ln\left(\frac{P_2}{P_1}\right)$$

Moreover $P_1V_2 = nRT_2$ and $P_1V_1 = nRT_1$

$$\sum W = \boxed{-P_1\left(V_2 - V_1\right)\ln\left(\frac{P_2}{P_1}\right)}$$

P20.32 $W_{BC} = -P_B\left(V_C - V_B\right) = -3.00\text{ atm}\left(0.400 - 0.090\,0\right)\text{ m}^3$
$= -94.2\text{ kJ}$

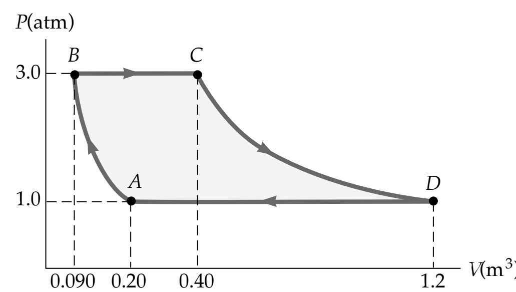

FIG. P20.32

$\Delta E_{int} = Q + W$

$E_{int,\,C} - E_{int,\,B} = \left(100 - 94.2\right)\text{ kJ}$

$E_{int,\,C} - E_{int,\,B} = 5.79\text{ kJ}$

Since T is constant,

$$E_{int,\,D} - E_{int,\,C} = 0$$

$$W_{DA} = -P_D\left(V_A - V_D\right) = -1.00\text{ atm}\left(0.200 - 1.20\right)\text{ m}^3 = +101\text{ kJ}$$

$$E_{int,\,A} - E_{int,\,D} = -150\text{ kJ} + \left(+101\text{ kJ}\right) = -48.7\text{ kJ}$$

Now, $E_{int,\,B} - E_{int,\,A} = -\left[\left(E_{int,\,C} - E_{int,\,B}\right) + \left(E_{int,\,D} - E_{int,\,C}\right) + \left(E_{int,\,A} - E_{int,\,D}\right)\right]$

$$E_{int,\,B} - E_{int,\,A} = -\left[5.79\text{ kJ} + 0 - 48.7\text{ kJ}\right] = \boxed{42.9\text{ kJ}}$$

P20.38 (a) The work done during each step of the cycle equals the negative of the area under that segment of the PV curve.

$$W = W_{DA} + W_{AB} + W_{BC} + W_{CD}$$

$$W = -P_i(V_i - 3V_i) + 0 - 3P_i(3V_i - V_i) + 0 = \boxed{-4P_iV_i}$$

(b) The initial and final values of T for the system are equal. Therefore, $\Delta E_{\text{int}} = 0$ and $Q = -W = \boxed{4P_iV_i}$.

(c) $W = -4P_iV_i = -4nRT_i = -4(1.00)(8.314)(273) = \boxed{-9.08\text{ kJ}}$

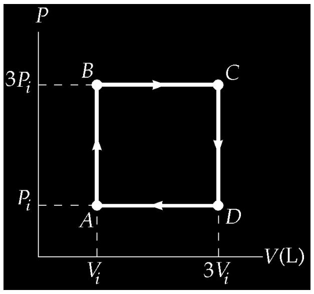

FIG. P20.38

Chapter Twenty-One: The Kinetic Theory of Gases

SOLUTIONS TO PROBLEMS

P21.1 $$\overline{F} = Nm\frac{\Delta v}{\Delta t} = 500\left(5.00\times10^{-3}\text{ kg}\right)\frac{\left[8.00\sin 45.0° - (-8.00\sin 45.0°)\right]\text{ m/s}}{30.0\text{ s}} = \boxed{0.943\text{ N}}$$

$$P = \frac{\overline{F}}{A} = 1.57\text{ N/m}^2 = \boxed{1.57\text{ Pa}}$$

P21.3 We first find the pressure exerted by the gas on the wall of the container.

$$P = \frac{NkT}{V} = \frac{3N_A k_B T}{V} = \frac{3RT}{V} = \frac{3(8.314\text{ N}\cdot\text{m/mol}\cdot\text{K})(293\text{ K})}{8.00\times10^{-3}\text{ m}^3} = 9.13\times10^5\text{ Pa}$$

Thus, the force on one of the walls of the cubical container is

$$F = PA = \left(9.13\times10^5\text{ Pa}\right)\left(4.00\times10^{-2}\text{ m}^2\right) = \boxed{3.65\times10^4\text{ N}}.$$

P21.10 (a) $PV = nRT = \dfrac{Nmv^2}{3}$

The total translational kinetic energy is $\dfrac{Nmv^2}{2} = E_{\text{trans}}$:

$$E_{\text{trans}} = \frac{3}{2}PV = \frac{3}{2}\left(3.00\times1.013\times10^5\right)\left(5.00\times10^{-3}\right) = \boxed{2.28\text{ kJ}}$$

(b) $$\frac{mv^2}{2} = \frac{3k_BT}{2} = \frac{3RT}{2N_A} = \frac{3(8.314)(300)}{2\left(6.02\times10^{23}\right)} = \boxed{6.21\times10^{-21}\text{ J}}$$