SOLUTIONS TO PROBLEMS

P21.15 $n = 1.00 \text{ mol}$, $T_i = 300 \text{ K}$

(b) Since $V =$ constant, $W = \boxed{0}$

(a) $\Delta E_{\text{int}} = Q + W = 209 \text{ J} + 0 = \boxed{209 \text{ J}}$

(c) $\Delta E_{\text{int}} = nC_V \Delta T = n\left(\frac{3}{2}R\right)\Delta T$

so $$\Delta T = \frac{2\Delta E_{\text{int}}}{3nR} = \frac{2(209 \text{ J})}{3(1.00 \text{ mol})(8.314 \text{ J/mol}\cdot\text{K})} = 16.8 \text{ K}$$

$$T = T_i + \Delta T = 300 \text{ K} + 16.8 \text{ K} = \boxed{317 \text{ K}}$$

P21.24 (a) $P_i V_i^\gamma = P_f V_f^\gamma$ so $\frac{V_f}{V_i} = \left(\frac{P_i}{P_f}\right)^{1/\gamma} = \left(\frac{1.00}{20.0}\right)^{5/7} = \boxed{0.118}$

(b) $\frac{T_f}{T_i} = \frac{P_f V_f}{P_i V_i} = \left(\frac{P_f}{P_i}\right)\left(\frac{V_f}{V_i}\right) = (20.0)(0.118)$ $\frac{T_f}{T_i} = \boxed{2.35}$

(c) Since the process is adiabatic, $\boxed{Q = 0}$

Since $\gamma = 1.40 = \frac{C_P}{C_V} = \frac{R + C_V}{C_V}$, $C_V = \frac{5}{2}R$ and $\Delta T = 2.35T_i - T_i = 1.35T_i$

$$\Delta E_{\text{int}} = nC_V \Delta T = (0.016\,0 \text{ mol})\left(\frac{5}{2}\right)(8.314 \text{ J/mol}\cdot\text{K})[1.35(300 \text{ K})] = \boxed{135 \text{ J}}$$

and $W = -Q + \Delta E_{\text{int}} = 0 + 135 \text{ J} = \boxed{+135 \text{ J}}$.

P21.35 Rotational Kinetic Energy $= \frac{1}{2}I\omega^2$

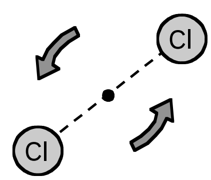

FIG. P21.35

$I = 2mr^2$, $m = 35.0 \times 1.67 \times 10^{-27} \text{ kg}$, $r = 10^{-10} \text{ m}$

$I = 1.17 \times 10^{-45} \text{ kg}\cdot\text{m}^2$ $\omega = 2.00 \times 10^{12} \text{ s}^{-1}$

$$\therefore K_{\text{rot}} = \frac{1}{2}I\omega^2 = \boxed{2.33 \times 10^{-21} \text{ J}}$$

P21.41 (a) From $v_{\text{av}} = \sqrt{\dfrac{8k_BT}{\pi m}}$

we find the temperature as $T = \dfrac{\pi\left(6.64\times10^{-27}\text{ kg}\right)\left(1.12\times10^{4}\text{ m/s}\right)^2}{8\left(1.38\times10^{-23}\text{ J/mol}\cdot\text{K}\right)} = \boxed{2.37\times10^{4}\text{ K}}$

(b) $T = \dfrac{\pi\left(6.64\times10^{-27}\text{ kg}\right)\left(2.37\times10^{3}\text{ m/s}\right)^2}{8\left(1.38\times10^{-23}\text{ J/mol}\cdot\text{K}\right)} = \boxed{1.06\times10^{3}\text{ K}}$

P21.47 From Equation 21.30, $\ell = \dfrac{1}{\sqrt{2}\pi d^2 n_V}$

For an ideal gas, $n_V = \dfrac{N}{V} = \dfrac{P}{k_BT}$

Therefore, $\ell = \dfrac{k_BT}{\sqrt{2}\pi d^2 P}$, as required.

Chapter Twenty-Two: Heat Engines, Entropy, and the
Second Law of Thermodynamics

SOLUTIONS TO PROBLEMS

P22.17 (a) In an adiabatic process, $P_fV_f^{\gamma} = P_iV_i^{\gamma}$. Also, $\left(\dfrac{P_fV_f}{T_f}\right)^{\gamma} = \left(\dfrac{P_iV_i}{T_i}\right)^{\gamma}$.

Dividing the second equation by the first yields $T_f = T_i\left(\dfrac{P_f}{P_i}\right)^{(\gamma-1)/\gamma}$.

Since $\gamma = \dfrac{5}{3}$ for Argon, $\dfrac{\gamma-1}{\gamma} = \dfrac{2}{5} = 0.400$ and we have

$$T_f = \left(1\,073\text{ K}\right)\left(\frac{300\times10^{3}\text{ Pa}}{1.50\times10^{6}\text{ Pa}}\right)^{0.400} = \boxed{564\text{ K}}.$$

(b) $\Delta E_{\text{int}} = nC_V\Delta T = Q - W_{\text{eng}} = 0 - W_{\text{eng}}$, so $W_{\text{eng}} = -nC_V\Delta T$,

and the power output is

$$\mathcal{P} = \frac{W_{\text{eng}}}{t} = \frac{-nC_V\Delta T}{t} \text{ or}$$

$$= \frac{\left(-80.0\text{ kg}\right)\left(\frac{1.00\text{ mol}}{0.039\,9\text{ kg}}\right)\left(\frac{3}{2}\right)\left(8.314\text{ J/mol}\cdot\text{K}\right)\left(564-1\,073\right)\text{K}}{60.0\text{ s}}$$

$$\mathcal{P} = 2.12\times10^{5}\text{ W} = \boxed{212\text{ kW}}$$

(c) $e_C = 1 - \dfrac{T_c}{T_h} = 1 - \dfrac{564\text{ K}}{1\,073\text{ K}} = 0.475$ or $\boxed{47.5\%}$

P22.26 $\text{COP} = 0.100\,\text{COP}_{\text{Carnot cycle}}$

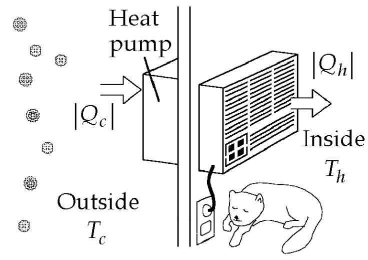

FIG. P22.26

or $$\frac{|Q_h|}{W} = 0.100\left(\frac{|Q_h|}{W}\right)_{\text{Carnot cycle}} = 0.100\left(\frac{1}{\text{Carnot efficiency}}\right)$$

$$\frac{|Q_h|}{W} = 0.100\left(\frac{T_h}{T_h - T_c}\right) = 0.100\left(\frac{293\text{ K}}{293\text{ K} - 268\text{ K}}\right) = 1.17$$

Thus, $\boxed{\text{1.17 joules of energy enter the room by heat for each joule of work done.}}$

P22.32 Compression ratio $= 6.00$, $\gamma = 1.40$

(a) Efficiency of an Otto-engine $e = 1 - \left(\frac{V_2}{V_1}\right)^{\gamma - 1}$

$$e = 1 - \left(\frac{1}{6.00}\right)^{0.400} = \boxed{51.2\%}.$$

(b) If actual efficiency $e' = 15.0\%$ losses in system are $e - e' = \boxed{36.2\%}$.

P22.58 (a) $\frac{W_{\text{eng}}}{t} = 1.50 \times 10^8\ \text{W}_{(\text{electrical})}$, $Q = mL = \left[\frac{\frac{W_{\text{eng}}}{t}}{0.150}\right]\Delta t$,

and $L = 33.0\ \text{kJ/g} = 33.0 \times 10^6\ \text{J/kg}$

$$m = \left[\frac{W_{\text{eng}}/t}{0.150}\right]\frac{\Delta t}{L}$$

$$m = \frac{(1.50 \times 10^8\ \text{W})(86\,400\ \text{s/day})}{0.150(33.0 \times 10^6\ \text{J/kg})(10^3\ \text{kg/metric ton})} = \boxed{2\,620\ \text{metric tons/day}}$$

(b) $\text{Cost} = (\$8.00/\text{metric ton})(2\,618\ \text{metric tons/day})(365\ \text{days/yr})$

$\text{Cost} = \boxed{\$7.65\ \text{million/year}}$

(c) First find the rate at which heat energy is discharged into the water. If the plant is 15.0% efficient in producing electrical energy then the rate of heat production is

$$\frac{|Q_c|}{t} = \left(\frac{W_{\text{eng}}}{t}\right)\left(\frac{1}{e} - 1\right) = (1.50 \times 10^8\ \text{W})\left(\frac{1}{0.150} - 1\right) = 8.50 \times 10^8\ \text{W}.$$

Then, $\frac{|Q_c|}{t} = \frac{mc\Delta T}{t}$ and