CHAPTER 12

Quick Quizzes

1.

Situation		System	Q	W	ΔU
(a)	Rapidly pumping up a bicycle tire	Air in the pump	near 0	+	+
(b)	Pan of room-temperature water sitting on a hot stove	Water in the pan	+	near 0	+
(c)	Air quickly leaking out of a balloon	Air originally in balloon	near 0	–	–

(a) Because the pumping is rapid, no energy enters or leaves the system by heat. Because $W > 0$ when work is done on the system, it is positive here. Thus, $\Delta U = Q + W$ must be positive. The air in the pump is warmer.

(b) No work is done either by or on the system, but energy flows into the water by heat from the hot burner, making both Q and ΔU positive.

(c) Again no energy flows into or out of the system by heat, but the air molecules escaping from the balloon do work on the surrounding air molecules as they push them out of the way. Thus W is negative and ΔU is negative. The decrease in internal energy is evidenced by the fact that the escaping air becomes cooler.

2. *A* is isovolumetric, *B* is adiabatic, *C* is isothermal, *D* is isobaric.

3. C, B, A. $e_A = 1 - \frac{700\text{ K}}{1000\text{ K}} = 0.300$, $e_B = 1 - \frac{500\text{ K}}{800\text{ K}} = 0.375$,

$$e_C = 1 - \frac{300\text{ K}}{600\text{ K}} = 0.500\text{, so } e_C > e_B > e_A .$$

4. (b). $\Delta S = 0$ because $Q = 0$ in any adiabatic process.

5. The number 7 is the most probable outcome because there are six ways this could occur: 1-6, 2-5, 3-4, 4-3, 5-2, and 6-1. The numbers 2 and 12 are the least probable because they could only occur one way each: either 1-1, or 6-6. Thus, you are six times more likely to throw a 7 than a 2 or 12.

Problem Solutions

12.1 From kinetic theory, the average kinetic energy per molecule is

$$\overline{KE}_{molecule} = \frac{3}{2}k_B T = \frac{3}{2}\left(\frac{R}{N_A}\right)T$$

For a monatomic ideal gas containing N molecules, the total energy associated with random molecular motions is

$$U = N \cdot \overline{KE}_{molecule} = \frac{3}{2}\left(\frac{N}{N_A}\right)RT = \frac{3}{2}nRT$$

Since $PV = nRT$ for an ideal gas, the internal energy of a monatomic ideal gas is found to be given by $\boxed{U = \frac{3}{2}PV}$.

12.2 The work done *by* the gas is $W_{\text{by gas}} = +P(\Delta V)$, so

$$W_{\text{by gas}} = PV_f - PV_i = nRT_f - nRT_i = nR(\Delta T),$$

Thus, $n = \dfrac{W_{\text{by gas}}}{R(\Delta T)} = \dfrac{20.0\text{ J}}{(8.31\text{ J/mol}\cdot\text{K})(100\text{ K})} = 0.0241\text{ mol}$,

and $m = nM = (0.0241\text{ mol})(4.00\text{ g/mol}) = 0.0963\text{ g} = \boxed{96.3\text{ mg}}$

12.3 The number of molecules in the gas is $N = nN_A$ and the total internal energy is

$$U = N\left(\overline{KE}\right) = nN_A\left(\frac{3}{2}k_B T\right) = \frac{3}{2}nRT$$

$$= \frac{3}{2}(3.0\text{ mol})\left(8.31\ \frac{\text{J}}{\text{mol}\cdot\text{K}}\right)(303\text{ K}) = \boxed{1.1\times 10^4\text{ J}}$$

Alternatively, use the result of Problem 12.1,

$U = \frac{3}{2}PV = \frac{3}{2}nRT$, just as found above.

12.4 (a) The work done *by* the gas on the projectile is given by the area under the curve in the PV diagram. This is

$$W_{\text{by gas}} = (\text{triangular area}) + (\text{rectangular area})$$
$$= \frac{1}{2}(P_0 - P_f)(V_f - V_0) + P_f(V_f - V_0) = \frac{1}{2}(P_0 + P_f)(V_f - V_0)$$
$$= \frac{1}{2}\left[(11 + 1.0)\times 10^5\ \text{Pa}\right]\left[(40.0 - 8.0)\ \text{cm}^3\right]\left(\frac{1\ \text{m}^3}{10^6\ \text{cm}^3}\right) = 19\ \text{J}$$

From the work-kinetic energy theorem, $W = \Delta KE = \frac{1}{2}mv^2 - 0$ where W is the work done on the projectile by the gas. Thus, the speed of the emerging projectile is

$$v = \sqrt{\frac{2W_{net}}{m}} = \sqrt{\frac{2(19\ \text{J})}{40.0\times 10^{-3}\ \text{kg}}} = \boxed{31\ \text{m/s}}$$

(b) The air in front of the projectile would exert a retarding force of

$$F_r = P_{air}A = (1.0\times 10^5\ \text{Pa})\left[(1.0\ \text{cm}^2)(1\ \text{m}^2/10^4\ \text{cm}^2)\right] = 10\ \text{N}$$

on the projectile as it moves down the launch tube. The energy spent overcoming this retarding force would be

$$W_{spent} = F_r \cdot s = (10\ \text{N})(0.32\ \text{m}) = 3.2\ \text{J},$$

and the needed fraction is $\frac{W_{spent}}{W} = \frac{3.2\ \text{J}}{19\ \text{J}} = \boxed{0.17}$.

12.5 In each case, the work done *on* the gas is given by the negative of the area under the path on the PV diagram. Along those parts of the path where volume is constant, no work is done. Note that $1\ \text{atm} = 1.013\times 10^5\ \text{Pa}$ and $1\ \text{Liter} = 10^{-3}\ \text{m}^3$.

(a) $W_{IAF} = W_{IA} + W_{AF} = -P_I(V_A - V_I) + 0$

$$= -\left[4.00(1.013\times 10^5\ \text{Pa})\right]\left[(4.00 - 2.00)\times 10^{-3}\ \text{m}^3\right] = \boxed{-810\ \text{J}}$$

(b) $W_{IF} = -(\text{triangular area}) - (\text{rectangular area})$

$$= -\frac{1}{2}(P_I - P_B)(V_F - V_B) - P_B(V_F - V_B) = -\frac{1}{2}(P_I + P_B)(V_F - V_B)$$

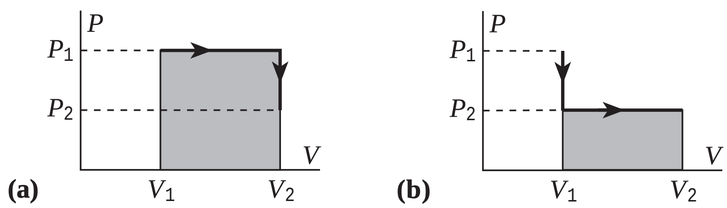
$$= -\frac{1}{2}\left[(4.00 + 1.00)(1.013 \times 10^5 \text{ Pa})\right](4.00 - 2.00) \times 10^{-3} \text{ m}^3$$

$$= \boxed{-507 \text{ J}}$$

(c) $W_{IBF} = W_{IB} + W_{BF} = 0 - P_B(V_F - V_I)$

$$= -\left[1.00(1.013 \times 10^5 \text{ Pa})\right]\left[(4.00 - 2.00) \times 10^{-3} \text{ m}^3\right] = \boxed{-203 \text{ J}}$$

12.6 The sketches for (a) and (b) are shown below:



(c) As seen from the areas under the paths in the *PV* diagrams above, the higher pressure during the expansion phase of the process results in more work done *by* the gas in (a) than in (b).

12.7 The constant pressure is $P = (1.5 \text{ atm})(1.013 \times 10^5 \text{ Pa/atm}) = 1.52 \times 10^5 \text{ Pa}$ and the work done on the gas is $W = -P(\Delta V)$.

(a) $\Delta V = +4.0 \text{ m}^3$ and

$$W = -P(\Delta V) = -(1.52 \times 10^5 \text{ Pa})(+4.0 \text{ m}^3) = \boxed{-6.1 \times 10^5 \text{ J}}$$

(b) $\Delta V = -3.0 \text{ m}^3$, so

$$W = -P(\Delta V) = -(1.52 \times 10^5 \text{ Pa})(-3.0 \text{ m}^3) = \boxed{+4.6 \times 10^5 \text{ J}}$$

12.8 As the temperature increases, while pressure is held constant, the volume increases by

$$\Delta V = V_f - V_i = \frac{nRT_f}{P} - \frac{nRT_i}{P} = \frac{nR(\Delta T)}{P},$$

where the change in absolute temperature is $\Delta T = \Delta T_C = 280\text{ K}$. The work done on the gas is

$$W = -P(\Delta V) = -nR(\Delta T) = -(0.200\text{ mol})(8.31\text{ J/mol}\cdot\text{K})(280\text{ K}) = \boxed{-465\text{ J}}$$

12.9 (a) From the ideal gas law, $nR = PV_f/T_f = PV_i/T_i$. With pressure constant this gives

$$T_f = T_i\left(\frac{V_f}{V_i}\right) = (273\text{ K})(4) = \boxed{1.09\times10^3\text{ K}}$$

(b) The work done on the gas is

$$W = -P(\Delta V) = -(PV_f - PV_i) = -nR(T_f - T_i)$$
$$= -(1.00\text{ mol})(8.31\text{ J/mol}\cdot\text{K})(1092\text{ J} - 273\text{ K})$$
$$= -6.81\times10^3\text{ J} = \boxed{-6.81\text{ kJ}}$$

12.10 (a) The work done on the fluid is the negative of the area under the curve on the PV diagram. Thus,

$$W_{if} = -\Big\{(6.00\times10^6\text{ Pa})(2.00-1.00)\text{ m}^3 + \frac{1}{2}\left[(6.00-2.00)\times10^6\text{ Pa}\right](2.00-1.00)\text{ m}^3 + (2.00\times10^6\text{ Pa})(4.00-2.00)\text{ m}^3\Big\}$$

$$W_{if} = -1.20\times10^7\text{ J} = \boxed{-12.0\text{ MJ}}$$

(b) When the system follows the process curve in the reverse direction, the work done on the fluid is the negative of that computed in (a), or

$$W_{fi} = -W_{if} = \boxed{+12.0\text{ MJ}}$$

12.11 (a) Because the volume is held constant, $\boxed{W = 0}$. Energy is transferred by heat *from* the burning mixture, so $\boxed{Q < 0}$. The first law then gives $\Delta U = Q + W = Q$, so $\boxed{\Delta U < 0}$.

(b) Again, since volume is constant, $\boxed{W = 0}$. Energy is transferred by heat from the burning mixture to the water, so $\boxed{Q > 0}$. Then, $\Delta U = Q + W = Q$ gives $\boxed{\Delta U > 0}$.

12.12 The work done on the gas is the negative of the area under the curve on the PV diagram, or

$$W = -\left[P_0\left(2V_0 - V_0\right) + \frac{1}{2}\left(2P_0 - P_0\right)\left(2V_0 - V_0\right)\right] = -\frac{3}{2}P_0V_0.$$

From the result of Problem 1,

$$\Delta U = \frac{3}{2}P_fV_f - \frac{3}{2}P_iV_i = \frac{3}{2}\left(2P_0\right)\left(2V_0\right) - \frac{3}{2}P_0V_0 = \frac{9}{2}P_0V_0$$

Thus, from the first law, $Q = \frac{9}{2}P_0V_0 - \left(-\frac{3}{2}P_0V_0\right) = \boxed{6P_0V_0}$

12.13 (a) $W = -P\left(\Delta V\right) = -\left(0.800 \text{ atm}\right)\left(-7.00 \text{ L}\right)\left(\frac{1.013\times 10^5 \text{ Pa}}{1 \text{ atm}}\right)\left(\frac{10^{-3} \text{ m}^3}{1 \text{ L}}\right) = \boxed{567 \text{ J}}$

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

12.14 The work done on the gas is the negative of the area under the curve on the PV diagram,

so $$W = -\left[P_0\left(V_0 - 2V_0\right) + \frac{1}{2}\left(2P_0 - P_0\right)\left(V_0 - 2V_0\right)\right] = +\frac{3}{2}P_0V_0\text{, or } W > 0$$

From the result of Problem 1,

$$\Delta U = \frac{3}{2}P_fV_f - \frac{3}{2}P_iV_i = \frac{3}{2}\left(2P_0\right)\left(V_0\right) - \frac{3}{2}\left(P_0\right)\left(2V_0\right) = 0 .$$

Then, from the first law, $Q = \Delta U - W = 0 - \frac{3}{2}P_0V_0 = -\frac{3}{2}P_0V_0$, or $\boxed{Q < 0}$

12.15 (a) Along the direct path *IF*, the work done on the gas is

$$W = -(\text{area under curve})$$
$$= -\left[(1.00 \text{ atm})(4.00 \text{ L} - 2.00 \text{ L}) + \frac{1}{2}(4.00 \text{ atm} - 1.00 \text{ atm})(4.00 \text{ L} - 2.00 \text{ L})\right]$$
$$W = -(5.00 \text{ atm} \cdot \text{L})\left(\frac{1.013 \times 10^5 \text{ Pa}}{1 \text{ atm}}\right)\left(\frac{10^{-3} \text{ m}^3}{1 \text{ L}}\right) = -506.5 \text{ J}$$

Thus, $\Delta U = Q + W = 418 \text{ J} - 506.5 \text{ J} = \boxed{-88.5 \text{ J}}$

(b) Along path *IAF*, the work done on the gas is

$$W = -(4.00 \text{ atm})(4.00 \text{ L} - 2.00 \text{ L})\left(\frac{1.013 \times 10^5 \text{ Pa}}{1 \text{ atm}}\right)\left(\frac{10^{-3} \text{ m}^3}{1 \text{ L}}\right) = -810 \text{ J}$$

From the first law, $Q = \Delta U - W = -88.5 \text{ J} - (-810 \text{ J}) = \boxed{722 \text{ J}}$.

12.16 (a) In a cyclic process, $\Delta U = 0$ and the first law gives

$\Delta U = Q + W = 0$, or $Q = -W$

The total work done on the gas is $W_{ABC} = W_{AB} + W_{BC} + W_{CA}$, and on each step the work is the negative of the area under the curve on the *PV* diagram, or

$$W_{AB} = -\left[(2.0 \text{ kPa})(10 \text{ m}^3 - 6.0 \text{ m}^3) + \frac{1}{2}(8.00 \text{ kPa} - 2.0 \text{ kPa})\right] = -20 \text{ kJ},$$

$W_{BC} = 0$, and $W_{cA} - (2.0 \text{ kPa})(6.0 \text{ m}^3 - 10 \text{ m}^3) = +8.0 \text{ kJ}$

Thus, $W_{ABC} = -20 \text{ kJ} + 0 + 8.0 \text{ kJ} = -12 \text{ kJ}$, and $Q = -W = \boxed{12 \text{ kJ}}$

(b) If the cycle is reversed,

$W_{CBA} = -W_{ABC} = -(-12 \text{ kJ}) = 12 \text{ kJ}$ and $Q = -W = \boxed{-12 \text{ kJ}}$

12.17 From the first law, $Q = \Delta U - W = -500 \text{ J} - 220 \text{ J} = \boxed{-720 \text{ J}}$

The negative sign in the result means that energy is transferred *from* the system by heat.

12.18 Volume is constant in process *BC*, so $\boxed{W_{BC} = 0}$. Given that $\boxed{Q_{BC} < 0}$, the first law shows that $\Delta U_{BC} = Q_{BC} + W_{BC} = Q_{BC} + 0$. Thus, $\boxed{\Delta U_{BC} < 0}$.

For process *CA*, $\Delta V_{CA} = V_A - V_C < 0$, so $W = -P(\Delta V)$ shows that $\boxed{W_{CA} > 0}$. Then, given that $\boxed{\Delta U_{CA} < 0}$, the first law gives $Q_{CA} = \Delta U_{CA} - W_{CA}$ and $\boxed{Q_{CA} < 0}$.

In process *AB*, the work done on the system is $W = -(\text{area under curve } AB)$ where

$$(\text{area under curve } AB) = P_A\left(V_B - V_A\right) + \frac{1}{2}\left(P_B - P_A\right)\left(V_B - V_A\right) > 0$$

Hence, $\boxed{W_{AB} < 0}$. For the cyclic process, $\Delta U = \Delta U_{AB} + \Delta U_{BC} + \Delta U_{CA} = 0$, so, $\Delta U_{AB} = -\left(\Delta U_{BC} + \Delta U_{CA}\right)$. This gives $\boxed{\Delta U_{AB} > 0}$, since both ΔU_{BC} and ΔU_{CA} are negative. Finally, from the first law, $Q = \Delta U - W$ shows that $\boxed{Q_{AB} > 0}$ since both ΔU_{AB} and $-W_{AB}$ are positive.

12.19 (a) $W = -P(\Delta V)$

$$= -\left(1.013 \times 10^5 \text{ Pa}\right)\left[\left(1.09 \text{ cm}^3 - 1.00 \text{ cm}^3\right)\left(\frac{1 \text{ m}^3}{10^6 \text{ cm}^3}\right)\right] = \boxed{-9.12 \times 10^{-3} \text{ J}}$$

(b) To freeze the water, the required energy transfer by heat is

$$Q = -mL_f = -\left(1.00 \times 10^{-3} \text{ kg}\right)\left(3.33 \times 10^5 \text{ J/kg}\right) = -333 \text{ J}.$$

The first law then gives

$$\Delta U = Q + W = -333 \text{ J} - 9.12 \times 10^{-3} \text{ J} = \boxed{-333 \text{ J}}$$

12.20 Treating the air as an ideal gas at constant pressure, the final volume is

$V_f = V_i\left(T_f / T_i\right)$, or the change in volume is

$$\Delta V = V_f - V_i = V_i\left(\frac{T_f - T_i}{T_i}\right)$$

$$= \left[(0.600 \text{ L})\left(\frac{10^{-3} \text{ m}^3}{1 \text{ L}}\right)\right]\left(\frac{310 \text{ K} - 273 \text{ K}}{273 \text{ K}}\right) = 8.13 \times 10^{-5} \text{ m}^3$$

(a) The work done on the lungs *by* the air is

$$W_{\text{by gas}} = +P(\Delta V) = \left(1.013\times 10^5\ \text{Pa}\right)\left(8.13\times 10^{-5}\ \text{m}^3\right) = \boxed{8.24\ \text{J}}$$

(b) Using the result of Problem 1, the change in the internal energy of the air is

$$\Delta U = \frac{3}{2}P(\Delta V) = \frac{3}{2}\left(1.013\times 10^5\ \text{Pa}\right)\left(8.13\times 10^{-5}\ \text{m}^3\right) = \boxed{12.4\ \text{J}}$$

(c) The energy added to the air by heat is

$$Q = \Delta U - W = \frac{3}{2}P(\Delta V) - \left[-P(\Delta V)\right] = \frac{5}{2}P(\Delta V),$$

or, $Q = \frac{5}{2}\left(1.013\times 10^5\ \text{Pa}\right)\left(8.13\times 10^{-5}\ \text{m}^3\right) = \boxed{20.6\ \text{J}}$

12.21 (a) The original volume of the aluminum is

$$V_0 = \frac{m}{\rho} = \frac{5.0\ \text{kg}}{2.70\times 10^3\ \text{kg/m}^3} = 1.85\times 10^{-3}\ \text{m}^3,$$

and the change in volume is $\Delta V = \beta V_0(\Delta T) = (3\alpha)V_0(\Delta T)$, or

$$\Delta V = 3\left[24\times 10^{-6}\ (^\circ\text{C})^{-1}\right]\left(1.85\times 10^{-3}\right)(70^\circ\text{C}) = 9.3\times 10^{-6}\ \text{m}^3$$

The work done *by* the aluminum is then

$$W_{\text{by system}} = +P(\Delta V) = \left(1.013\times 10^5\ \text{Pa}\right)\left(9.3\times 10^{-6}\ \text{m}^3\right) = \boxed{0.95\ \text{J}}$$

(b) The energy transferred by heat to the aluminum is

$$Q = mc_{\text{Al}}(\Delta T) = (5.0\ \text{kg})(900\ \text{J/kg}\cdot{}^\circ\text{C})(70^\circ\text{C}) = \boxed{3.2\times 10^5\ \text{J}}$$

(c) The work done on the aluminum is $W = -W_{\text{by system}} = -0.95\ \text{J}$, so the first law gives

$$\Delta U = Q + W = 3.2\times 10^5\ \text{J} - 0.95\ \text{J} = \boxed{3.2\times 10^5\ \text{J}}$$

12.22 (a) The work done on the gas in each process is the negative of the area under the process curve on the *PV* diagram.

For path *IAF*, $W_{IAF} = W_{IA} + W_{AF} = 0 + W_{AF}$, or

$$W_{IAF} = -\left[(1.50\text{ atm})\left(1.013\times 10^{5}\ \frac{\text{Pa}}{\text{atm}}\right)\right]\left[(0.500\text{ L})\left(\frac{10^{-3}\text{ m}^{3}}{1\text{ L}}\right)\right]$$

$$= \boxed{-76.0\text{ J}}$$

For path *IBF*, $W_{IBF} = W_{IB} + W_{BF} = W_{IB} + 0$, or

$$W_{IBF} = -\left[(2.00\text{ atm})\left(1.013\times 10^{5}\ \frac{\text{Pa}}{\text{atm}}\right)\right]\left[(0.500\text{ L})\left(\frac{10^{-3}\text{ m}^{3}}{1\text{ L}}\right)\right]$$

$$= \boxed{-101\text{ J}}$$

For path *IF*, $W_{IF} = W_{AF} - (\textit{triangular area})$, or

$$W_{IF} = -76.0\text{ J} - \frac{1}{2}\left[(0.500\text{ atm})\left(1.013\times 10^{5}\ \frac{\text{Pa}}{\text{atm}}\right)\right]\left[(0.500\text{ L})\left(\frac{10^{-3}\text{ m}^{3}}{1\text{ L}}\right)\right]$$

$$= \boxed{-88.7\text{ J}}$$

(b) Using the first law, with $\Delta U = U_F - U_A = (180 - 91.0)\text{ J} = 89.0\text{ J}$, for each process gives

$$Q_{IAF} = \Delta U - W_{IAF} = 89.0\text{ J} - (-76.0\text{ J}) = \boxed{165\text{ J}}$$

$$Q_{IBF} = \Delta U - W_{IBF} = 89.0\text{ J} - (-101\text{ J}) = \boxed{190\text{ J}}$$

$$Q_{IF} = \Delta U - W_{IF} = 89.0\text{ J} - (-88.7\text{ J}) = \boxed{178\text{ J}}$$

12.23 The maximum efficiency possible is that of a Carnot engine operating between the given reservoirs.

$$e_c = \frac{T_h - T_c}{T_h} = 1 - \frac{T_c}{T_h} = 1 - \frac{293\text{ K}}{573\text{ K}} = \boxed{0.489\ \ (\text{or } 48.9\%)}$$

12.24 (a) From $e = \dfrac{|Q_h| - |Q_c|}{|Q_h|} = 1 - \dfrac{|Q_c|}{|Q_h|}$, the energy expelled is

$$|Q_c| = |Q_h|(1-e) = (800\text{ J})(1-0.300) = \boxed{560\text{ J}}$$

(b) From $e_c = \dfrac{T_h - T_c}{T_h} = 1 - \dfrac{T_c}{T_h}$, the temperature of the cold reservoir is

$$T_c = T_h(1-e_c) = (500\text{ K})(1-0.300) = \boxed{350\text{ K}}$$

12.25 (a) $e \equiv \dfrac{W_{\text{eng}}}{|Q_h|} = \dfrac{W_{\text{eng}}}{3W_{\text{eng}}} = \dfrac{1}{3} = \boxed{0.333 \text{ or } 33.3\%}$

(b) $e \equiv \dfrac{W_{\text{eng}}}{|Q_h|} = 1 - \dfrac{|Q_c|}{|Q_h|}$, so $\dfrac{|Q_c|}{|Q_h|} = 1 - e = 1 - \dfrac{1}{3} = \boxed{\dfrac{2}{3}}$

12.26 (a) From $e \equiv \dfrac{W_{\text{eng}}}{|Q_h|} = 1 - \dfrac{|Q_c|}{|Q_h|}$, the energy intake each cycle is

$$|Q_h| = \frac{|Q_c|}{1-e} = \frac{8000\text{ J}}{1\text{-}0.250} = 10\,667\text{ J} = \boxed{10.7\text{ kJ}}$$

(b) From $\wp = \dfrac{W_{\text{eng}}}{t} = \dfrac{e|Q_c|}{t}$, the time for one cycle is

$$t = \frac{e|Q_c|}{\wp} = \frac{(0.250)(10\,667\text{ J})}{5.00\times 10^3\text{ W}} = \boxed{0.533\text{ s}}$$

12.27 (a) The maximum efficiency possible is that of a Carnot engine operating between the specified reservoirs.

$$e_c = \frac{T_h - T_c}{T_h} = 1 - \frac{T_c}{T_h} = 1 - \frac{703\text{ K}}{2143\text{ K}} = \boxed{0.672 \ \ (\text{or } 67.2\%)}$$

(b) From $e = \dfrac{W_{\text{eng}}}{|Q_h|}$, we find $W_{\text{eng}} = e|Q_h| = 0.420\left(1.40\times 10^5\text{ J}\right) = 5.88\times 10^4\text{ J}$,

so $\wp = \dfrac{W_{\text{eng}}}{t} = \dfrac{5.88\times 10^4\text{ J}}{1.00\text{ s}} = 5.88\times 10^4\text{ W} = \boxed{58.8\text{ kW}}$

12.28 (a) Using $e = W_{\text{eng}} / |Q_h|$, the energy absorbed by heat each cycle is

$$|Q_h| = \frac{W_{\text{eng}}}{e} = \frac{200\text{ J}}{0.30} = \boxed{6.7 \times 10^2\text{ J}}$$

(b) From $W_{\text{eng}} = |Q_h| - |Q_c|$, the energy expelled by heat each cycle is

$$|Q_c| = |Q_h| - W_{\text{eng}} = 6.7 \times 10^2\text{ J} - 200\text{ J} = \boxed{4.7 \times 10^2\text{ J}}$$

12.29 (a) $e \equiv \dfrac{W_{\text{eng}}}{|Q_h|} = 1 - \dfrac{|Q_c|}{|Q_h|} = 1 - \dfrac{1200\text{ J}}{1700\text{ J}} = \boxed{0.294\ \ (\text{or } 29.4\%)}$

(b) $W_{\text{eng}} = |Q_h| - |Q_c| = 1700\text{ J} - 1200\text{ J} = \boxed{500\text{ J}}$

(c) $\wp = \dfrac{W_{\text{eng}}}{t} = \dfrac{500\text{ J}}{0.300\text{ s}} = 1.67 \times 10^3\text{ W} = \boxed{1.67\text{ kW}}$

12.30 (a) The maximum possible efficiency is

$$e_c = \frac{T_h - T_c}{T_h} = 1 - \frac{T_c}{T_h} = 1 - \frac{278\text{ K}}{293\text{ K}} = \boxed{0.0512\ \ (\text{or } 5.12\%)}$$

(b) The work done in one hour is

$$W_{\text{eng}} = \wp \cdot t = (75.0 \times 10^6\text{ W})(3600\text{ s}) = 2.70 \times 10^{11}\text{ J},$$

so the energy absorbed in one hour is

$$|Q_h| = \frac{W_{\text{eng}}}{e} = \frac{2.70 \times 10^{11}\text{ J}}{0.0512} = \boxed{5.27 \times 10^{12}\text{ J}}$$

(c) As fossil-fuel prices rise, this could be an attractive way to use solar energy. However, the potential environmental impact of such an engine would require serious study. The energy output, $|Q_c| = |Q_h| - W_{\text{eng}}$, to the low temperature reservoir (cool water deep in the ocean) could raise the temperature of over a million cubic meters of water by 1 °C every hour.

12.31 The actual efficiency of the engine is $e = 1 - \frac{|Q_c|}{|Q_h|} = 1 - \frac{300\text{ J}}{500\text{ J}} = 0.400$.

If this is 60.0% of the Carnot efficiency, then $e_c = \frac{e}{0.600} = \frac{0.400}{0.600} = \frac{2}{3}$

Thus, from $e_c = 1 - \frac{T_c}{T_h}$, we find $\frac{T_c}{T_h} = 1 - e_c = 1 - \frac{2}{3} = \boxed{\frac{1}{3}}$

12.32 (a) The Carnot efficiency is $e_c = 1 - \frac{T_c}{T_h} = 1 - \frac{353\text{ K}}{623\text{ K}} = 0.433$, so the maximum power output is

$$\wp_{max} = \frac{(W_{\text{eng}})_{max}}{t} = \frac{e_c|Q_h|}{t} = \frac{0.433(21.0\text{ kJ})}{1.00\text{ s}} = \boxed{9.10\text{ kW}}$$

(b) From $e = 1 - \frac{|Q_c|}{|Q_h|}$, the energy expelled by heat each cycle is

$$|Q_c| = |Q_h|(1-e) = (21.0\text{ kJ})(1-0.433) = \boxed{11.9\text{ kJ}}$$

12.33 From $\wp = \frac{W_{\text{eng}}}{t} = \frac{e|Q_h|}{t}$, the energy input by heat in time *t* is $|Q_h| = \frac{\wp \cdot t}{e}$

Thus, from $e = \frac{|Q_h| - |Q_c|}{|Q_h|}$, the energy expelled in time *t* is

$$|Q_c| = |Q_h|(1-e) = \left(\frac{\wp \cdot t}{e}\right)(1-e) = \wp \cdot t\left(\frac{1}{e} - 1\right)$$

In time *t*, the mass of cooling water used is $m = (1.0 \times 10^6\ \text{kg/s}) \cdot t$, and its rise in temperature is

$$\Delta T = \frac{|Q_c|}{mc} = \frac{\wp \cdot t}{(1.0 \times 10^6\ \text{kg/s}) \cdot t \cdot c}\left(\frac{1}{e} - 1\right)$$

$$= \frac{(1000 \times 10^6\ \text{J/s})}{(1.0 \times 10^6\ \text{kg/s})(4186\ \text{J/kg} \cdot °\text{C})}\left(\frac{1}{0.33} - 1\right)$$

or $\Delta T = \boxed{0.49°\text{C}}$

12.34 The actual efficiency is $e = W_{actual}/|Q_h|$, and the maximum theoretical efficiency is $e_c = W_{max}/|Q_h|$. Thus, $e_c/e = W_{max}/W_{actual}$, or the Carnot efficiency for this pair of reservoirs is given by

$$e_c = e\left(\frac{W_{max}}{W_{actual}}\right) = e\left(\frac{\frac{1}{2}m_{train}v_{max}^2}{\frac{1}{2}m_{train}v_{actual}^2}\right) = (0.200)\left[\frac{(6.50\ \text{m/s})^2}{(5.00\ \text{m/s})^2}\right] = 0.338$$

From $e_c = 1 - T_c/T_h$, the temperature of the hot reservoir is

$$T_h = \frac{T_c}{1-e_c} = \frac{300\ \text{K}}{1-0.338} = \boxed{453\ \text{K}}$$

12.35 The energy transferred from the water by heat, and absorbed by the freezer, is

$$Q = mL_f = (\rho V)L_f = \left[(10^3\ \text{kg/m}^3)(1.0\times10^{-3}\ \text{m}^3)\right]\left(3.33\times10^5\ \frac{\text{J}}{\text{kg}}\right) = 3.3\times10^5\ \text{J}$$

Thus, the change in entropy of the water is

(a) $$\Delta S_{water} = \frac{(\Delta Q_r)_{water}}{T} = \frac{-3.3\times10^5\ \text{J}}{273\ \text{K}} = -1.2\times10^3\ \frac{\text{J}}{\text{K}} = \boxed{-1.2\ \text{kJ/K}},$$

and that of the freezer is

(b) $$\Delta S_{freezer} = \frac{(\Delta Q_r)_{freezer}}{T} = \frac{+3.3\times10^5\ \text{J}}{273\ \text{K}} = \boxed{+1.2\ \text{kJ/K}}$$

12.36 The energy added to the water by heat is

$$\Delta Q_r = mL_v = (1.00\ \text{kg})(2.26\times10^6\ \text{J/kg}) = 2.26\times10^6\ \text{J},$$

so the change in entropy is

$$\Delta S = \frac{\Delta Q_r}{T} = \frac{2.26\times10^6\ \text{J}}{373\ \text{K}} = 6.06\times10^3\ \frac{\text{J}}{\text{K}} = \boxed{6.06\ \text{kJ/K}}$$

12.37 The potential energy lost by the log is carried away by heat, so

$$Q = mgh = (70\text{ kg})(9.80\text{ m/s}^2)(25\text{ m}) = 1.7\times10^4\text{ J},$$

and the change in entropy is $\Delta S = \dfrac{\Delta Q_r}{T} = \dfrac{1.7\times10^4\text{ J}}{300\text{ K}} = \boxed{57\text{ J/K}}$

12.38 The total momentum before collision is zero, so the combined mass must be at rest after the collision. The energy dissipated by heat equals the total initial kinetic energy, of

$$Q = 2\left(\frac{1}{2}mv^2\right) = (2000\text{ kg})(20\text{ m/s})^2 = 8.0\times10^5\text{ J} = 800\text{ kJ}$$

The change in entropy is then $\Delta S = \dfrac{\Delta Q_r}{T} = \dfrac{800\text{ kJ}}{296\text{ K}} = \boxed{2.7\text{ kJ/K}}$

12.39 A quantity of energy, of magnitude Q, is transferred from the Sun and added to the Earth. Thus, $\Delta S_{Sun} = \dfrac{-Q}{T_{Sun}}$ and $\Delta S_{Earth} = \dfrac{+Q}{T_{Earth}}$, so the total change in entropy is

$$\Delta S_{total} = \Delta S_{Earth} + \Delta S_{Sun} = \frac{Q}{T_{Earth}} - \frac{Q}{T_{Sun}}$$

$$= (1000\text{ J})\left(\frac{1}{290\text{ K}} - \frac{1}{5700\text{ K}}\right) = \boxed{3.27\text{ J/K}}$$

12.40 (a)

End Result	Possible Draws	Total Number of Same Result
All R	RRR	1
1G, 2R	RRG, RGR, GRR	3
2G, 1R	GGR, GRG, RGG	3
All G	GGG	1

(b)

End Result	Possible Draws	Total Number of Same Result
All R	RRRRR	1
1G, 4R	RRRRG, RRRGR, RRGRR, RGRRR, GRRRR	5
2G, 3R	RRRGG, RRGRG, RGRRG, GRRRG, RRGGR, RGRGR, GRRGR, RGGRR, GRGRR, GGRRR	10
3G, 2R	GGGRR, GGRGR, GRGGR, RGGGR, GGRRG, GRGRG, RGGRG, GRRGG, RGRGG, RRGGG	10
4G, 1R	GGGGR, GGGRG, GGRGG, GRGGG, RGGGG	5
All G	GGGGG	1

12.41 (a) The table is shown below. On the basis of the table, the most probable result of a toss is $\boxed{\text{2 H and 2 T}}$.

End Result	Possible Tosses	Total Number of Same Result
All H	HHHH	1
1T, 3H	HHHT, HHTH, HTHH, THHH	4
2T, 2H	HHTT, HTHT, THHT, HTTH, THTH, TTHH	6
3T, 1H	TTTH, TTHT, THTT, HTTT	4
All T	TTTT	1

(b) The most ordered state is the least likely. This is seen to be $\boxed{\text{all H or all T}}$.

(c) The least ordered state is the most likely. This is seen to be $\boxed{\text{2H and 2T}}$.

12.42 (a) There is only one ace of spades out of 52 cards, so the probability is $\boxed{\dfrac{1}{52}}$

(b) There are four aces out of 52 cards, so the probability is $\dfrac{4}{52} = \boxed{\dfrac{1}{13}}$

(c) There are 13 spades out of 52 cards, so the probability is $\dfrac{13}{52} = \boxed{\dfrac{1}{4}}$

12.43 The maximum efficiency is that of a Carnot engine and is given by

$$e_c = 1 - \frac{T_c}{T_h} = 1 - \frac{100\text{ K}}{200\text{ K}} = 0.50\text{, or } e_{max} = \boxed{50\%}\text{. The } \boxed{\text{claim is invalid}}.$$

12.44 The efficiency of the engine is $e_c = 1 - \frac{T_c}{T_h} = 1 - \frac{|Q_c|}{|Q_h|}$. Thus, $|Q_h| = \left(\frac{T_h}{T_c}\right)|Q_c|$.

(a) From $\wp = \frac{W_{\text{eng}}}{t} = \frac{|Q_h| - |Q_c|}{t}$,

we find $\wp = \left(\frac{T_h}{T_c} - 1\right)\frac{|Q_c|}{t}$ for a Carnot engine. For the given engine,

this yields $\wp = \left(\frac{373\text{ K}}{293\text{ K}} - 1\right)(15.4\text{ W}) = \boxed{4.20\text{ W}}$

(b) In one hour, the heat transferred from the high-temperature reservoir by heat is

$$|Q_h| = \left(\frac{|Q_h|}{t}\right)\cdot t = \left[\left(\frac{T_h}{T_c}\right)\cdot\frac{|Q_c|}{t}\right]\cdot t = \left(\frac{373\text{ K}}{293\text{ K}}\right)\left(15.4\ \frac{\text{J}}{\text{s}}\right)(3600\text{ s}) = 7.06\times 10^4\text{ J},$$

and the mass of steam condensed is

$$m = \frac{|Q_h|}{L_v} = \frac{7.06\times 10^4\text{ J}}{2.26\times 10^6\text{ J/kg}} = 3.12\times 10^{-2}\text{ kg} = \boxed{31.2\text{ g}}$$

12.45 (a) The entropy change of the hot reservoir, with an energy output of magnitude $|Q_h|$, is

$$\Delta S_h = \frac{\Delta Q_r}{T_h} = \boxed{\frac{-|Q_h|}{T_h}}$$

(b) For the cold reservoir, with an energy input of magnitude $|Q_c|$, the change in entropy is

$$\Delta S_c = \frac{\Delta Q_r}{T_c} = \boxed{\frac{+|Q_c|}{T_c}}$$

(c) The engine has an energy input of magnitude $|Q_h|$ from a reservoir at temperature T_h and an energy output of magnitude $|Q_c|$ to a reservoir at temperature T_c. The net change in entropy for the engine is

$$\Delta S_{\text{eng}} = \sum\left(\frac{\Delta Q_r}{T}\right) = \boxed{\frac{|Q_h|}{T_h} - \frac{|Q_c|}{T_c}}$$

(d) For the isolated system consisting of the engine and the two reservoirs, the change in entropy is

$$\Delta S_{\substack{\text{isolated}\\\text{system}}} = \Delta S_h + \Delta S_{\text{eng}} + \Delta S_c = -\frac{|Q_h|}{T_h} + \left(\frac{|Q_h|}{T_h} - \frac{|Q_c|}{T_c}\right) + \frac{|Q_c|}{T_c} = \boxed{0}$$

12.46 In this case, $|Q_h| = |Q_c| = 8000\ \text{J}$. The change in entropy of the hot reservoir is

$$\Delta S_h = \frac{-|Q_h|}{T_h} = \frac{-8000\ \text{J}}{500\ \text{K}} = \boxed{-16.0\ \text{J/K}}$$

For the cold reservoir, $\Delta S_c = \dfrac{+|Q_c|}{T_c} = \dfrac{8000\ \text{J}}{300\ \text{K}} = \boxed{26.7\ \text{J/K}}$

The net entropy change for this irreversible process is

$$\Delta S_{universe} = \Delta S_h + \Delta S_c = (-16.0+26.7)\ \text{J/K} = \boxed{10.7\ \text{J/K}} > 0$$

12.47 The energy output to the river each minute has magnitude

$$|Q_c| = (1-e)|Q_h| = (1-e)\left(\frac{|Q_h|}{t}\right)\cdot t = (1-0.30)\left(25\times10^8\ \frac{\text{J}}{\text{s}}\right)(60\ \text{s}) = 1.05\times10^{11}\ \text{J}$$

so the rise in temperature of the $9.0\times10^6\ \text{kg}$ of cooling water used in one minute is

$$\Delta T = \frac{|Q_c|}{mc} = \frac{1.05\times10^{11}\ \text{J}}{(9.0\times10^6\ \text{kg})(4186\ \text{J/kg}\cdot{}^\circ\text{C})} = \boxed{2.8^\circ\text{C}}$$

12.48 The rate of energy input by heat to the environment equals the rate of potential energy loss by the water, or $\Delta Q/t = (\Delta m/t)gh$, and the rate of change of entropy is

$$\frac{\Delta S}{t} = \frac{(\Delta Q/t)}{T} = \frac{(\Delta m/t)gh}{T} = \frac{[\rho(\Delta V/t)]gh}{T}$$

Thus, $$\frac{\Delta S}{t} = \frac{[(10^3 \text{ kg/m}^3)(5000 \text{ m}^3\text{/s})](9.80 \text{ m/s}^2)(50 \text{ m})}{293 \text{ K}} = \boxed{8.4\times 10^6 \text{ J/K}\cdot\text{s}}$$

12.49 Assume that a quantity of energy, of magnitude $|Q|$, flows *out* of a reservoir at absolute temperature T_1 and *into* a reservoir at absolute temperature T_2. Thus, $\Delta Q_1 = -|Q|$ and $\Delta Q_2 = +|Q|$, so the total change in entropy is

$$\Delta S_{universe} = \Delta S_1 + \Delta S_2 = \frac{-|Q|}{T_1} + \frac{+|Q|}{T_2} = |Q|\left(\frac{T_1 - T_2}{T_1 T_2}\right)$$

The second law of thermodynamics requires that $\Delta S_{universe} \geq 0$. Since the quantity $\frac{|Q|}{T_1 T_2}$ is positive, the second law requires that $T_1 - T_2 \geq 0$, or $T_1 \geq T_2$. Thus, we see that the second law requires that, in a spontaneous energy transfer by heat, the energy must flow *out* of a reservoir that is at a higher temperature $(T_1 = T_h)$ than the reservoir it flows *into* $(T_2 = T_c)$.

12.50 (a) From the first law, $\Delta U_{1\to 3} = Q_{123} + W_{123} = +418 \text{ J} + (-167 \text{ J}) = \boxed{251 \text{ J}}$

(b) The difference in internal energy between states 1 and 3 is independent of the path used to get from state 1 to state 3.

Thus, $\Delta U_{1\to 3} = Q_{143} + W_{143} = 251 \text{ J}$,

and $Q_{143} = 251 \text{ J} - W_{143} = 251 \text{ J} - (-63.0 \text{ J}) = \boxed{314 \text{ J}}$

(c) $W_{12341} = W_{123} + W_{341} = W_{123} + (-W_{143}) = -167 \text{ J} - (-63.0 \text{ J}) = -104 \text{ J}$,

or $\boxed{\text{104 J of work is done } \textit{by} \text{ the gas}}$ in the cyclic process 12341.

(d) $W_{14321} = W_{143} + W_{321} = W_{143} + (-W_{123}) = -63.0 \text{ J} - (-167 \text{ J}) = +104 \text{ J}$,

or $\boxed{\text{104 J of work is done } \textit{on} \text{ the gas}}$ in the cyclic process 14321.

(e) The change in internal energy is $\boxed{\text{zero}}$ for both parts (c) and (d) since both are cyclic processes.

12.51 (a) The work done *by* the system in process *AB* equals the area under this curve on the *PV* diagram. Thus,

$$W_{\text{by system}} = (\text{triangular area}) + (\text{rectangular area}), \text{ or}$$

$$W_{\substack{\text{by}\\\text{system}}} = \left[\frac{1}{2}(4.00\text{ atm})(40.0\text{ L}) + (1.00\text{ atm})(40.0\text{ L})\right]\left(1.013\times10^{5}\ \frac{\text{Pa}}{\text{atm}}\right)\left(\frac{10^{-3}\text{ m}^3}{\text{L}}\right)$$

$$= 1.22\times10^{4}\text{ J} = \boxed{12.2\text{ kJ}}$$

Note that the work done on the system is $W_{AB} = -W_{\substack{\text{by}\\\text{system}}} = -12.2\text{ kJ}$ for this process.

(b) The work done on the system (i.e., the work input) for process *BC* is the negative of the area under the curve on the *PV* diagram, or

$$W_{BC} = -\left[(1.00\text{ atm})(10.0\text{ L} - 50.0\text{ L})\right]\left(1.013\times10^{5}\ \frac{\text{Pa}}{\text{atm}}\right)\left(\frac{10^{-3}\text{ m}^3}{1\text{ L}}\right)$$

$$= \boxed{4.05\text{ kJ}}$$

(c) The change in internal energy is zero for any full cycle, so the first law gives

$$Q_{cycle} = \Delta U_{cycle} - W_{cycle} = 0 - (W_{AB} + W_{BC} + W_{CA})$$

$$= 0 - (-12.2\text{ kJ} + 4.05\text{ kJ} + 0) = \boxed{8.15\text{ kJ}}$$

12.52 The efficiency of the plant is $e = e_c = 1 - \dfrac{T_c}{T_h} = 1 - \dfrac{300\text{ K}}{500\text{ K}} = 0.400$

Also, $e = 1 - \dfrac{|Q_c|}{|Q_h|}$, so $|Q_h| = \dfrac{|Q_c|}{1-e} = \dfrac{|Q_c|}{0.600}$

From $\wp = \frac{W_{\text{eng}}}{t} = \frac{e|Q_h|}{t} = \left(\frac{0.400}{0.600}\right)\frac{|Q_c|}{t}$,

the rate of energy transfer to the river by heat is

$$|Q_c|/t = 1.50\,\wp = 1.50(1000 \text{ MW}) = 1.50 \times 10^9 \text{ J/s}$$

The flow rate in the river is then

$$\frac{m}{t} = \frac{(|Q_c|/t)}{c_{water}(\Delta T)_{river}} = \frac{1.50 \times 10^9 \text{ J/s}}{(4186 \text{ J/kg}\cdot°\text{C})(6.00°\text{C})} = \boxed{5.97 \times 10^4 \text{ kg/s}}$$

12.53 (a) The change in length, due to linear expansion, of the rod is

$$\Delta L = \alpha L_i(\Delta T) = \left[11 \times 10^{-6} \ (°\text{C})^{-1}\right](2.0 \text{ m})(40°\text{C} - 20°\text{C}) = 4.4 \times 10^{-4} \text{ m}$$

The load exerts a force $F = mg = (6000 \text{ kg})(9.80 \text{ m/s}^2) = 5.88 \times 10^4 \text{ N}$ on the end of the rod in the direction of movement of that end. Thus, the work done on the rod is

$$W = F \cdot \Delta L = (5.88 \times 10^4 \text{ N})(4.4 \times 10^{-4} \text{ m}) = \boxed{26 \text{ J}}$$

(b) The energy added by heat is

$$Q = mc(\Delta T) = (100 \text{ kg})\left(448 \ \frac{\text{J}}{\text{kg}\cdot°\text{C}}\right)(20°\text{C}) = \boxed{9.0 \times 10^5 \text{ J}}$$

(c) From the first law, $\Delta U = Q + W = 9.0 \times 10^5 \text{ J} + 26 \text{ J} = \boxed{9.0 \times 10^5 \text{ J}}$

12.54 (a) The work done *by* the gas during each full cycle equals the area enclosed by the cycle on the PV diagram. Thus

$$W_{\text{by gas}} = (3P_0 - P_0)(3V_0 - V_0) = \boxed{4P_0V_0}$$

(b) Since the work done on the gas is $W = -W_{\text{by gas}} = -4P_0V_0$ and $\Delta U = 0$ for any cyclic process, the first law gives

$$Q = \Delta U - W = 0 - (-4P_0V_0) = \boxed{4P_0V_0}$$

(c) From the ideal gas law, $P_0V_0 = nRT_0$, so the work done by the gas each cycle is

$$W_{\text{by gas}} = 4nRT_0 = 4(1.00\text{ mol})\left(8.31\ \frac{\text{J}}{\text{mol}\cdot\text{K}}\right)(273\text{ K})$$

$$= 9.07\times10^3\text{ J} = \boxed{9.07\text{ kJ}}.$$

12.55 (a) The energy transferred to the gas by heat is

$$Q = mc(\Delta T) = (1.00\text{ mol})\left(20.79\ \frac{\text{J}}{\text{mol}\cdot\text{K}}\right)(120\text{ K})$$

$$= 2.49\times10^3\text{ J} = \boxed{2.49\text{ kJ}}$$

(b) Treating the neon as an ideal gas, the result of Problem 1 gives the change in internal energy as

$$\Delta U = \frac{3}{2}\left(P_fV_f - P_iV_i\right) = \frac{3}{2}\left(nRT_f - nRT_i\right) = \frac{3}{2}nR(\Delta T)\text{, or}$$

$$\Delta U = \frac{3}{2}(1.00\text{ mol})\left(8.31\ \frac{\text{J}}{\text{mol}\cdot\text{K}}\right)(120\text{ K}) = 1.50\times10^3\text{ J} = \boxed{1.50\text{ kJ}}$$

(c) From the first law, the work done *on* the gas is

$$W = \Delta U - Q = 1.50\times10^3\text{ J} - 2.49\times10^3\text{ J} = \boxed{-990\text{ J}}$$

12.56 (a) The change in volume of the aluminum is

$$\Delta V = \beta V_i(\Delta T) = (3\alpha)(m/\rho)(\Delta T)\text{, or}$$

$$\Delta V = 3\left[24\times10^{-6}\ (^\circ\text{C})^{-1}\right]\left(\frac{1.0\text{ kg}}{2.70\times10^3\ \text{kg/m}^3}\right)(18^\circ\text{C}) = 4.8\times10^{-7}\text{ m}^3,$$

so the work done on the aluminum is

$$W = -P(\Delta V) = -\left(1.013\times10^5\text{ Pa}\right)\left(4.8\times10^{-7}\text{ m}^3\right) = \boxed{-4.9\times10^{-2}\text{ J}}$$

(b) The energy added by heat is

$$Q = mc(\Delta T) = (1.0\text{ kg})(900\ \text{J/kg}\cdot{}^\circ\text{C})(18^\circ\text{C}) = 1.6\times10^4\text{ J} = \boxed{16\text{ kJ}}$$

(c) The first law gives the change in internal energy as

$$\Delta U = Q + W = 1.6\times10^{4}\ \text{J} - 4.9\times10^{-2}\ \text{J} = 1.6\times10^{4}\ \text{J} = \boxed{16\ \text{kJ}}.$$

12.57 (a) The energy input by heat from the molten aluminum is

$$|Q_h| = m_{\text{Al}}L_f = \left(1.00\times10^{-3}\ \text{kg}\right)\left(3.97\times10^{5}\ \text{J/kg}\right) = 397\ \text{J},$$

and the energy output to the frozen mercury is

$$|Q_c| = m_{\text{Hg}}L_f = \left(15.0\times10^{-3}\ \text{kg}\right)\left(1.18\times10^{4}\ \text{J/kg}\right) = 177\ \text{J}$$

The efficiency of the heat engine is given by

$$e = \frac{W_{\text{eng}}}{|Q_h|} = \frac{|Q_h| - |Q_c|}{|Q_h|} = 1 - \frac{|Q_c|}{|Q_h|} = 1 - \frac{177\ \text{J}}{397\ \text{J}} = \boxed{0.554\ \text{or}\ 55.4\%}$$

(b) $T_h = 660\,°\text{C} = 933\ \text{K}$ and $T_c = -38.9\,°\text{C} = 234\ \text{K}$. The Carnot efficiency for a heat engine operating between these two reservoirs is

$$e_c = 1 - \frac{T_c}{T_h} = 1 - \frac{234\ \text{K}}{933\ \text{K}} = \boxed{0.749\ \text{or}\ 74.9\%}$$

12.58 (a) From the result of Problem 1,

$$\Delta U_{A\to C} = \frac{3}{2}\left(P_C V_C - P_A V_A\right) = \frac{3}{2}\left[\left(3P_0\right)\left(2V_0\right) - P_0 V_0\right] = \frac{15}{2}P_0 V_0 = \frac{15}{2}nRT_0$$

The work done on the gas in process ABC equals the negative of the area under the process curve on the PV diagram, or

$$W_{ABC} = -\left[\left(3P_0\right)\left(2V_0 - V_0\right)\right] = -3P_0V_0 = -3nRT_0$$

The total energy input by heat, $Q_{ABC} = Q_1 + Q_2$, is found from the first law as

$$Q_{ABC} = \Delta U_{A\to C} - W_{ABC} = \frac{15}{2}nRT_0 - \left(-3nRT_0\right) = \boxed{\frac{21}{2}nRT_0}$$

(b) For process *CDA*, the work done on the gas is the negative of the area under curve *CDA*, or $W_{CDA} = -\left[(P_0)(V_0 - 2V_0)\right] = +P_0V_0 = +nRT_0$. The change in internal energy is $\Delta U_{C\to A} = -\Delta U_{A\to C} = -\frac{15}{2}nRT_0$. Thus, the energy *input* by heat for this process is

$$Q_{CDA} = \Delta U_{C\to A} - W_{CDA} = -\frac{15}{2}nRT_0 - nRT_0 = -\frac{17}{2}nRT_0$$

The total energy *output* by heat for the cycle is

$$Q_3 + Q_4 = -Q_{CDA} = -\left(-\frac{17}{2}nRT_0\right) = \boxed{\frac{17}{2}nRT_0}$$

(c) The efficiency of a heat engine using this cycle is

$$e = 1 - \frac{|Q_{output}|}{|Q_{input}|} = 1 - \frac{(17nRT_0/2)}{(21nRT_0/2)} = 1 - \frac{17}{21} = \boxed{0.190 \text{ or } 19.0\%}$$

(d) $$e_c = 1 - \frac{T_A}{T_C} = 1 - \frac{(P_AV_A/nR)}{(P_CV_C/nR)} = 1 - \frac{P_0V_0}{(3P_0)(2V_0)} = \frac{5}{6} = \boxed{0.833 \text{ or } 83.3\%}$$

12.59 The mass of coal consumed in time *t* is given by $\Delta M = |Q_h|/Q_{coal}$ where $|Q_h|$ is the required energy input and Q_{coal} is the heat of combustion of coal. Thus, if $\wp$ is the power output and *e* is the efficiency of the plant,

$$\Delta M = \frac{|Q_h|}{Q_{coal}} = \frac{(W_{eng}/e)}{Q_{coal}} = \frac{\wp \cdot t}{e \cdot Q_{coal}}$$

(a) The coal used each day is

$$\Delta M = \frac{\wp \cdot t}{e \cdot Q_{coal}} = \frac{(150 \times 10^6 \text{ J/s})(86\,400 \text{ s/d})}{(0.15)\left[\left(7.8 \times 10^3 \ \frac{\text{cal}}{\text{g}}\right)\left(\frac{10^3 \text{ g}}{1 \text{ kg}}\right)\left(\frac{4.186 \text{ J}}{1 \text{ cal}}\right)\right]}$$

$$= 2.6 \times 10^6 \text{ kg/d} = \boxed{2.6 \times 10^3 \text{ metric ton/d}}$$

(b) The annual fuel cost is: $cost = (coal\ used\ yearly)\cdot(rate)$, or

$$cost = \left(\frac{\wp \cdot t}{e \cdot Q_{coal}}\right)\cdot(\$8.0/\text{ton})$$

$$= \frac{(150\times10^{6}\ \text{J/s})(3.156\times10^{7}\ \text{s/yr})}{(0.15)\left[\left(7.8\times10^{3}\ \frac{\text{cal}}{\text{g}}\right)\left(\frac{10^{3}\ \text{g}}{1\ \text{kg}}\right)\left(\frac{4.186\ \text{J}}{1\ \text{cal}}\right)\right]}\left(\frac{1\ \text{ton}}{10^{3}\ \text{kg}}\right)\left(\frac{\$8.0}{\text{ton}}\right) = \boxed{\$7.7\times10^{6}/\text{yr}}$$

(c) The rate of energy transfer to the river by heat is

$$\frac{|Q_c|}{t} = \frac{|Q_h| - W_{\text{eng}}}{t} = \frac{(W_{\text{eng}}/e) - W_{\text{eng}}}{t} = \wp\cdot\left(\frac{1}{e}-1\right)$$

Thus, the flow required is

$$\frac{m}{t} = \frac{|Q_c|/t}{c_{water}(\Delta T)} = \frac{\wp}{c_{water}(\Delta T)}\left(\frac{1}{e}-1\right)$$

$$= \frac{150\times10^{6}\ \text{J/s}}{(4186\ \text{J/kg}\cdot{}^\circ\text{C})(5.0^\circ\text{C})}\left(\frac{1}{0.15}-1\right) = \boxed{4.1\times10^{4}\ \text{kg/s}}$$

Answers to Even Numbered Conceptual Questions

2. Yes, a reversible adiabatic process is always isentropic.

4. Shaking opens up spaces between the jelly beans. The smaller ones have a chance of falling down into spaces below them. The accumulation of larger ones on top and smaller ones on the bottom implies an increase in order and a decrease in one contribution to the total entropy. However, the second law is not violated and the total entropy of the system increases. The increase in the internal energy of the system comes from the work required to shake the jar of beans (that is, work your muscles must do, with an increase in entropy accompanying the biological process) and also from the small loss of gravitational potential energy as the beans settle together more compactly.

6. Temperature = A measure of molecular motion. Heat = the process through which energy is transferred between objects by means of random collisions of molecules. Internal energy = energy associated with random molecular motions plus chemical energy, strain potential energy, and an object's other energy not associated with center of mass motion or location.

8. A higher steam temperature means that more energy can be extracted from the steam. For a constant temperature heat sink at T_c and steam at T_h, the maximum efficiency of the power plant goes as $\frac{T_h - T_c}{T_h} = 1 - \frac{T_c}{T_h}$ and is maximized for high T_h.

10. $e_{max} = \frac{\Delta T}{T_h} = \frac{80\text{ K}}{373\text{ K}} \approx 22\%$ (Assumes atmospheric temperature of 20°C.)

12. If the work done on the system exceeds the energy transferred from the system by heat, the internal energy will increase and the temperature of the system will rise. A good example of this is the rapid compression of a gas. Energy is input as work faster than it can be transferred out by heat and the temperature of the gas increases.

14. An analogy due to Carnot is instructive: A waterfall continuously converts mechanical energy into internal energy. It continuously creates entropy as the organized motion of the falling water turns into disorganized molecular motion. We humans put turbines into the waterfall, diverting some of the energy stream to our use. Water flows spontaneously from high to low elevation and energy is transferred spontaneously from high to low temperature by heat. Into the great flow of solar radiation from Sun to Earth, living things put themselves. They live on energy flow. A basking snake diverts high-temperature energy through itself temporarily, before it is inevitably lost as low-temperature energy radiated into outer space. A tree builds organized cellulose molecules and we build libraries and babies who look like their grandmothers, all out of a thin diverted stream in the universal flow of energy crashing down to disorder. We do not violate the second law, for we build local reductions in the entropy of one thing within the inexorable increase in the total entropy of the Universe. Your roommate's exercise increases random molecular motions within the room.

16. Even at essentially constant temperature, energy must be transferred by heat out of the solidifying sugar into the surroundings. This action will increase the entropy of the environment. The water molecules become less ordered as they leave the liquid in the container to mix with the entire atmosphere.

18. A slice of hot pizza cools off. Road friction brings a skidding car to a stop. A cup falls to the floor and shatters. Any process is irreversible if it looks funny or frightening when shown in a videotape running backward. At fairly low speeds, air resistance is small and the flight of a projectile is nearly reversible.

Answers to Even Numbered Problems

2. 96.3 mg

4. (a) 31 m/s (b) 0.17

6. (c) More work is done in (a) because of higher pressure during the expansion.

8. -465 J

10. (a) –12.0 MJ (b) 12.0 MJ

12. $6P_0V_0$

14. $\Delta U = 0,\ Q<0,\ W>0$

16. (a) 12 kJ (b) –12 kJ

18. $Q_{AB}>0,\ W_{AB}<0,\ \Delta U_{AB} > 0$
$Q_{BC}<0,\ W_{BC}=0,\ \Delta U_{BC} < 0$
$Q_{CA}<0,\ W_{CA}>0,\ \Delta U_{CA} < 0$

20. (a) 8.24 J (b) 12.4 J (c) 20.6 J

22. (a) $W_{IAF} = -76.0$ J, $W_{IBF} = -101$ J, $W_{IF} = -88.7$ J
(b) $Q_{IAF} = 165$ J, $Q_{IBF} = 190$ J, $Q_{IF} = 178$ J

24. (a) 560 J (b) 350 K

26. (a) 10.7 kJ (b) 0.533 s

28. (a) 6.7×10^2 J (b) 4.7×10^2 J

30. (a) 0.0512 (or 5.12%) (b) 5.27×10^{12} J
(c) Such engines would be one way to harness solar energy as conventional energy sources become more expensive. However, this engine could produce unacceptable thermal pollution in the deep ocean waters.

32. (a) 9.10 kW (b) 11.9 kJ

34. 453 K

36. 6.06 kJ/K

38. 2.7 kJ/K

40. (a)

End Result	Possible Draws	Total Number of Same Result
All R	RRR	1
1G, 2R	RRG, RGR, GRR	3
2G, 1R	GGR, GRG, RGG	3
All G	GGG	1

(b)

End Result	Possible Draws	Total Number of Same Result
All R	RRRRR	1
1G, 4R	RRRRG, RRRGR, RRGRR, RGRRR, GRRRR	5
2G, 3R	RRRGG, RRGRG, RGRRG, GRRRG, RRGGR, RGRGR, GRRGR, RGGRR, GRGRR, GGRRR	10
3G, 2R	GGGRR, GGRGR, GRGGR, RGGGR, GGRRG, GRGRG, RGGRG, GRRGG, RGRGG, RRGGG	10
4G, 1R	GGGGR, GGGRG, GGRGG, GRGGG, RGGGG	5
All G	GGGGG	1

42. (a) $1/52$ (b) $1/13$ (c) $1/4$

44. (a) 4.20 W (b) 31.2 g

46. $\Delta S_h = -16.0\ \text{J/K}$, $\Delta S_c = 26.7\ \text{J/K}$, $\Delta S_{Universe} = 10.7\ \text{J/K}$

48. $8.4 \times 10^6\ \text{J/K}\cdot\text{s}$

50. (a) 251 J (b) 314 J (c) 104 J by the gas
(d) 104 J on the gas (e) zero in both cases

52. $5.97 \times 10^4\ \text{kg/s}$

54. (a) $4P_0V_0$ (b) $4P_0V_0$ (c) 9.07 kJ

56. (a) $-4.9 \times 10^{-2}\ \text{J}$ (b) 16 kJ (c) 16 kJ

58. (a) $\frac{21}{2}nRT_0$ (b) $\frac{17}{2}nRT_0$
(c) 0.190 (or 19.0%) (d) 0.833 (or 83.3%)