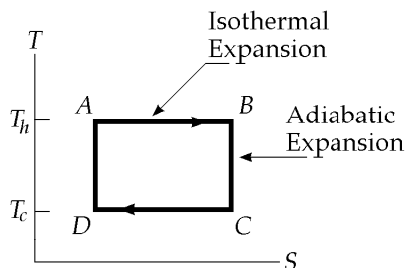


CHAPTER 18

ANSWERS TO QUESTIONS

- Q18.1** First, the efficiency of the automobile engine cannot exceed the Carnot efficiency. Second, the engine block cannot exceed a certain temperature. Third, any practical engine has friction, incomplete burning of fuel, and there are limits on timing and energy transfer by heat.
- Q18.2** 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 efficiency of the power plant goes as $(T_h - T_c)/T_h = 1 - (T_c/T_h)$ and is maximized for a high T_h .
- Q18.3** No. Any heat engine takes in energy by heat and must also put out energy by heat. The energy that is dumped as exhaust into the low-temperature sink will always be thermal pollution in the outside environment.
- Q18.4** (a) For an expanding ideal gas at constant temperature, $\Delta S = \frac{\Delta Q}{T} = nR \ln\left(\frac{V_2}{V_1}\right)$.
 (b) For a reversible adiabatic expansion $\Delta Q = 0$, $\Delta S = 0$.
- Q18.5** Suppose the ambient temperature is 20°C . A gas can be heated to the temperature of the bottom of the pond, and allowed to cool as it blows through a turbine. The Carnot efficiency of such an engine is about $e_c = \Delta T / T_h = 80 / 373 = 22\%$.
- Q18.6** Loss of energy to heating the gasoline and the air in which it burns.
- Q18.7** No, because the work done to run the heat pump represents energy transferred into the house by heat.

Q18.8



- Q18.9** A slice of hot pizza cools off. Road friction brings a skidding car to a stop. A cup falls to the floor and shatters. Your cat dies. Any process is irreversible if it looks funny or frightening when shown in a videotape running backwards. The free flight of a projectile is nearly reversible.
- Q18.10** The rest of the Universe must have an entropy change of $+8.0 \text{ J/K}$, or more.
- Q18.11** Even at essentially constant temperature, energy must flow by heat out of the solidifying sugar into the surroundings, to raise the entropy of the environment. The water molecules become less ordered as they leave the liquid in the container to mix into the whole atmosphere and hydrosphere.
- Q18.12** To increase its entropy, raise its temperature. To decrease its entropy, lower its temperature. "Remove energy from it by heat" is not such a good answer, for if you hammer on it or rub it with a blunt file and at the same time remove energy from it by heat into a constant temperature bath, its entropy can stay constant.
- Q18.13** Below the frost line, the winter temperature is much higher than the air or surface temperature. The earth is a huge reservoir of internal energy, but digging a lot of deep trenches is much more expensive than setting a heat-exchanger out on a concrete pad. A heat pump can have a much higher coefficient of performance when it is transferring energy by heat between reservoirs at close to the same temperature.

Chapter 18

- Q18.14** An analogy used by 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 spontaneously flows by heat from high to low temperature. Into the great flow of solar radiation from Sun to Earth, living things put themselves. They live on energy flow. A basking snake diverts energy from a high-temperature source (the Sun) through itself temporarily, before the energy inevitably is radiated from the body of the snake to a low-temperature sink (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 puts energy into the room by heat.
- Q18.15** (a) Entropy increases as the yeast dies and as energy is transferred from the hot oven into the originally cooler dough and then from the hot bread into the surrounding air.
(b) Entropy increases some more as you metabolize the starches, converting chemical energy into internal energy.
- Q18.16** An internal-combustion engine takes in fuel and air at the environmental temperature and then compresses it. During the rapid (adiabatic) compression, work is done on the gas. The time interval for this compression is so short that no appreciable energy leaves the gas by heat, so the internal energy and temperature rise. The temperature-increase factor depends only on the nature of the molecules and on the volume-decrease factor, called the compression ratio. With a larger compression ratio, a diesel engine will have its fuel and air hotter both before and after combustion, compared to a gasoline engine with spark plugs. Its Carnot efficiency limit is set by the higher temperature of the fuel-air mixture after combustion occurs, so the diesel engine can have higher efficiency.
- Q18.17** Shaking opens up spaces between jellybeans. The smaller ones more often can fall down into spaces below them. The accumulation of larger candies on top and smaller ones on the bottom implies a small increase in order, a small decrease in one contribution to the total entropy, but the second law is not violated. The total entropy increases as the system warms up, its increase in internal energy coming from the work put into shaking the box and also from a bit of gravitational energy loss as the beans settle compactly together.
- Q18.18** (a) When the two sides of the semiconductor are at different temperatures, an electric potential (voltage) is generated across the material, which can drive electric current through an external circuit. The two cups at 50°C contain the same amount of internal energy as the pair of hot and cold cups. But no energy flows by heat through the converter bridging between them and no voltage is generated across the semiconductors.
(b) A heat engine must put out exhaust energy by heat. The cold cup provides a sink to absorb output or wasted energy by heat, which has nowhere to go between two cups of equally warm water.

PROBLEM SOLUTIONS

$$18.1 \quad (a) \quad e = \frac{W_{\text{eng}}}{|Q_h|} = \frac{25.0 \text{ J}}{360 \text{ J}} = \boxed{0.0694} \quad \text{or} \quad \boxed{6.94\%}$$

$$(b) \quad |Q_c| = |Q_h| - W_{\text{eng}} = 360 \text{ J} - 25.0 \text{ J} = \boxed{335 \text{ J}}$$

$$18.2 \quad W_{\text{eng}} = |Q_h| - |Q_c| = 200 \text{ J} \quad (1)$$

$$e = \frac{W_{\text{eng}}}{|Q_h|} = 1 - \frac{|Q_c|}{|Q_h|} = 0.300 \quad (2)$$

$$\text{From (2),} \quad |Q_c| = 0.700|Q_h| \quad (3)$$

Solving (3) and (1) simultaneously,

$$\text{we have} \quad \boxed{|Q_h| = 667 \text{ J}} \quad \text{and} \quad \boxed{|Q_c| = 467 \text{ J}}$$

$$18.3 \quad (a) \quad \text{We have} \quad e = \frac{W_{\text{eng}}}{|Q_h|} = \frac{|Q_h| - |Q_c|}{|Q_h|} = 1 - \frac{|Q_c|}{|Q_h|} = 0.250$$

$$\text{with } |Q_c| = 8000 \text{ J, we have} \quad \boxed{|Q_h| = 10.7 \text{ kJ}}$$

$$(b) \quad W_{\text{eng}} = |Q_h| - |Q_c| = 2667 \text{ J}$$

$$\text{and from } \mathcal{P} = \frac{W_{\text{eng}}}{\Delta t}, \text{ we have} \quad \Delta t = \frac{W_{\text{eng}}}{\mathcal{P}} = \frac{2667 \text{ J}}{5000 \text{ J/s}} = \boxed{0.533 \text{ s}}$$

$$18.4 \quad \text{The heat to melt } 15.0 \text{ g of Hg is} \quad |Q_c| = mL_f = (15 \times 10^{-3} \text{ kg})(1.18 \times 10^4 \text{ J/kg}) = 177 \text{ J}$$

The energy absorbed to freeze 1.00 g of aluminum is

$$|Q_h| = mL_f = (10^{-3} \text{ kg})(3.97 \times 10^5 \text{ J/kg}) = 397 \text{ J}$$

and the work output is

$$W_{\text{eng}} = |Q_h| - |Q_c| = 220 \text{ J}$$

$$e = \frac{W_{\text{eng}}}{|Q_h|} = \frac{220 \text{ J}}{397 \text{ J}} = 0.554, \text{ or } \boxed{55.4\%}$$

$$\text{The theoretical (Carnot) efficiency is} \quad \frac{T_h}{T_h - T_c} = \frac{933 \text{ K} - 243.1 \text{ K}}{933 \text{ K}} = 0.749 = 74.9\%$$

Chapter 18

18.5 $T_c = 703 \text{ K}$ $T_h = 2143 \text{ K}$

(a) $e_c = \frac{\Delta T}{T_h} = \frac{1440}{2143} = \boxed{67.2\%}$

(b) $|Q_h| = 1.40 \times 10^5 \text{ J}$, $W_{\text{eng}} = 0.420|Q_h|$

$$\mathcal{P} = \frac{W_{\text{eng}}}{\Delta t} = \frac{5.88 \times 10^4 \text{ J}}{1 \text{ s}} = \boxed{58.8 \text{ kW}}$$

18.6 The Carnot efficiency of the engine is

$$e_c = \frac{\Delta T}{T_h} = \frac{120 \text{ K}}{473 \text{ K}} = 0.253$$

At 20.0% of this maximum efficiency,

$$e = 0.200(0.253) = 0.0506$$

From Equation 18.2,

$$W_{\text{eng}} = |Q_h|e$$

and

$$|Q_h| = \frac{W_{\text{eng}}}{e} = \frac{10.0 \text{ kJ}}{0.0506} = \boxed{197 \text{ kJ}}$$

18.7

When $e = e_c$, $1 - \frac{T_c}{T_h} = \frac{W_{\text{eng}}}{|Q_h|}$ and $\frac{(W_{\text{eng}} / \Delta t)}{(|Q_h| / \Delta t)} = 1 - \frac{T_c}{T_h}$

(a) $|Q_h| = \frac{(W_{\text{eng}} / \Delta t)\Delta t}{1 - (T_c / T_h)} = \frac{(1.50 \times 10^5 \text{ W})(3600 \text{ s})}{1 - (293 / 773)}$

$$|Q_h| = 8.69 \times 10^8 \text{ J} = \boxed{869 \text{ MJ}}$$

(c) $|Q_c| = |Q_h| - \left(\frac{W_{\text{eng}}}{\Delta t}\right)\Delta t = 8.69 \times 10^8 - (1.50 \times 10^5)(3600) = 3.30 \times 10^8 \text{ J} = \boxed{330 \text{ MJ}}$

18.8

We use $e_c = 1 - \frac{T_c}{T_h}$

as $0.300 = 1 - \frac{573 \text{ K}}{T_h}$

From which, $T_h = 819 \text{ K} = \boxed{546^\circ\text{C}}$

Chapter 18

18.9 Isothermal expansion at $T_h = 523 \text{ K}$

Isothermal compression at $T_c = 323 \text{ K}$

Gas absorbs 1200 J during expansion.

$$(a) \quad |Q_c| = |Q_h| \left(\frac{T_c}{T_h} \right) = 1200 \text{ J} \left(\frac{323}{523} \right) = \boxed{741 \text{ J}}$$

$$(b) \quad W_{\text{eng}} = |Q_h| - |Q_c| = (1200 - 741) \text{ J} = \boxed{459 \text{ J}}$$

***18.10** The efficiency is

$$e_c = 1 - \frac{T_c}{T_h} = 1 - \frac{|Q_c|}{|Q_h|}$$

Then

$$\frac{T_c}{T_h} = \frac{|Q_c| / \Delta t}{|Q_h| / \Delta t}$$

$$\frac{|Q_h|}{\Delta t} = \frac{|Q_c|}{\Delta t} \frac{T_h}{T_c} = 15.4 \text{ W} \frac{(273 + 100) \text{ K}}{(273 + 20) \text{ K}} = 19.6 \text{ W}$$

$$(a) \quad |Q_h| = W_{\text{eng}} + |Q_c|$$

The useful power output is

$$\frac{W_{\text{eng}}}{\Delta t} = \frac{|Q_h|}{\Delta t} - \frac{|Q_c|}{\Delta t} = 19.6 \text{ W} - 15.4 \text{ W} = \boxed{4.20 \text{ W}}$$

$$(b) \quad |Q_h| = \left(\frac{|Q_h|}{\Delta t} \right) \Delta t = mL_V \quad m = \frac{|Q_h|}{\Delta t} \frac{\Delta t}{L_V} = (19.6 \text{ J/s}) \left(\frac{3600 \text{ s}}{2.26 \times 10^6 \text{ J/kg}} \right) = \boxed{3.12 \times 10^{-2} \text{ kg}}$$

18.11 The Carnot summer efficiency is

$$e_{c,s} = 1 - \frac{T_c}{T_h} = 1 - \frac{(273 + 20) \text{ K}}{(273 + 350) \text{ K}} = 0.530$$

And in winter,

$$e_{c,w} = 1 - \frac{283}{623} = 0.546$$

Then the actual winter efficiency is

$$0.320 \left(\frac{0.546}{0.530} \right) = \boxed{0.330} \quad \text{or} \quad \boxed{33.0\%}$$

Chapter 18

18.12 (a) $e_{\max} = 1 - \frac{T_c}{T_h} = 1 - \frac{278}{293} = 5.12 \times 10^{-2} = \boxed{5.12\%}$

(b) $\mathcal{P} = \frac{W_{\text{eng}}}{\Delta t} = 75.0 \times 10^6 \text{ J/s}$

Therefore,

$$W_{\text{eng}} = (75.0 \times 10^6 \text{ J/s})(3600 \text{ s/h}) = 2.70 \times 10^{11} \text{ J/h}$$

From $e = \frac{W_{\text{eng}}}{|Q_h|}$ we find $|Q_h| = \frac{W_{\text{eng}}}{e} = \frac{2.70 \times 10^{11} \text{ J/h}}{5.12 \times 10^{-2}} = 5.27 \times 10^{12} \text{ J/h} = \boxed{5.27 \text{ TJ/h}}$

(c) As fossil-fuel prices rise, this way to use solar energy will become a good buy.

***18.13** (a) First, consider the adiabatic process $D \rightarrow A$:

$$P_D V_D^\gamma = P_A V_A^\gamma \quad \text{so} \quad P_D = P_A \left(\frac{V_A}{V_D} \right)^\gamma = 1400 \text{ kPa} \left(\frac{10.0 \text{ L}}{15.0 \text{ L}} \right)^{5/3} = \boxed{712 \text{ kPa}}$$

Also

$$\left(\frac{nRT_D}{V_D} \right) V_D^\gamma = \left(\frac{nRT_A}{V_A} \right) V_A^\gamma$$

or

$$T_D = T_A \left(\frac{V_A}{V_D} \right)^{\gamma-1} = 720 \text{ K} \left(\frac{10.0}{15.0} \right)^{2/3} = \boxed{549 \text{ K}}$$

Now, consider the isothermal process $C \rightarrow D$: $T_C = T_D = \boxed{549 \text{ K}}$

$$P_C = P_D \left(\frac{V_D}{V_C} \right) = \left[P_A \left(\frac{V_A}{V_D} \right)^\gamma \right] \left(\frac{V_D}{V_C} \right) = \frac{P_A V_A^\gamma}{V_C V_D^{\gamma-1}}$$

$$P_C = \frac{1400 \text{ kPa} (10.0 \text{ L})^{5/3}}{24.0 \text{ L} (15.0 \text{ L})^{2/3}} = \boxed{445 \text{ kPa}}$$

Next, consider the adiabatic process $B \rightarrow C$: $P_B V_B^\gamma = P_C V_C^\gamma$

But, $P_C = \frac{P_A V_A^\gamma}{V_C V_D^{\gamma-1}}$ from above. Also considering the isothermal process, $P_B = P_A \left(\frac{V_A}{V_B} \right)$

Hence, $P_A \left(\frac{V_A}{V_B} \right) V_B^\gamma = \left(\frac{P_A V_A^\gamma}{V_C V_D^{\gamma-1}} \right) V_C^\gamma$ which reduces to $V_B = \frac{V_A V_C}{V_D} = \frac{10.0 \text{ L} (24.0 \text{ L})}{15.0 \text{ L}} = \boxed{16.0 \text{ L}}$

Finally, $P_B = P_A \left(\frac{V_A}{V_B} \right) = 1400 \text{ kPa} \left(\frac{10.0 \text{ L}}{16.0 \text{ L}} \right) = \boxed{875 \text{ kPa}}$

State	$P(\text{kPa})$	$V(\text{L})$	$T(\text{K})$
A	1400	10.0	720
B	875	16.0	720
C	445	24.0	549
D	712	15.0	549

Chapter 18

(b) For the isothermal process $A \rightarrow B$: $\Delta E_{\text{int}} = nC_V\Delta T = \boxed{0}$

so $Q = -W = nRT \ln\left(\frac{V_B}{V_A}\right) = 2.34 \text{ mol}(8.315 \text{ J/mol}\cdot\text{K})(720 \text{ K}) \ln\left(\frac{16.0}{10.0}\right) = \boxed{+6.58 \text{ kJ}}$

For the adiabatic process $B \rightarrow C$: $Q = \boxed{0}$

$$\Delta E_{\text{int}} = nC_V(T_C - T_B) = 2.34 \text{ mol}\left[\frac{3}{2}(8.315 \text{ J/mol}\cdot\text{K})\right](549 - 720) \text{ K} = \boxed{-4.99 \text{ kJ}}$$

and $W = -Q + \Delta E_{\text{int}} = 0 + (-4.99 \text{ kJ}) = \boxed{-4.99 \text{ kJ}}$

For the isothermal process $C \rightarrow D$: $\Delta E_{\text{int}} = nC_V\Delta T = \boxed{0}$

and $Q = -W = nRT \ln\left(\frac{V_D}{V_C}\right) = 2.34 \text{ mol}(8.315 \text{ J/mol}\cdot\text{K})(549 \text{ K}) \ln\left(\frac{15.0}{24.0}\right) = \boxed{-5.02 \text{ kJ}}$

Finally, for the adiabatic process $D \rightarrow A$: $Q = \boxed{0}$

$$\Delta E_{\text{int}} = nC_V(T_A - T_D) = 2.34 \text{ mol}\left[\frac{3}{2}(8.315 \text{ J/mol}\cdot\text{K})\right](720 - 549) \text{ K} = \boxed{+4.99 \text{ kJ}}$$

and $W = -Q + \Delta E_{\text{int}} = 0 + 4.99 \text{ kJ} = \boxed{+4.99 \text{ kJ}}$

Process	Q(kJ)	W(kJ)	ΔE_{int} (kJ)
$A \rightarrow B$	+6.58	-6.58	0
$B \rightarrow C$	0	-4.99	-4.99
$C \rightarrow D$	-5.02	+5.02	0
$D \rightarrow A$	0	+4.99	+4.99
$ABCD A$	+1.56	-1.56	0

The work done *by* the engine is the negative of the work input. The output work W_{eng} is given by the work column in the table with all signs reversed.

(c) $e = \frac{W_{\text{eng}}}{|Q_h|} = \frac{-W_{ABCD}}{Q_{A \rightarrow B}} = \frac{1.56 \text{ kJ}}{6.58 \text{ kJ}} = 0.237$ or $\boxed{23.7\%}$

$$e_c = 1 - \frac{T_c}{T_h} = 1 - \frac{549}{720} = 0.237$$
 or $\boxed{23.7\%}$

18.14 $(\text{COP})_{\text{refrig}} = \frac{T_c}{\Delta T} = \frac{270}{30.0} = \boxed{9.00}$

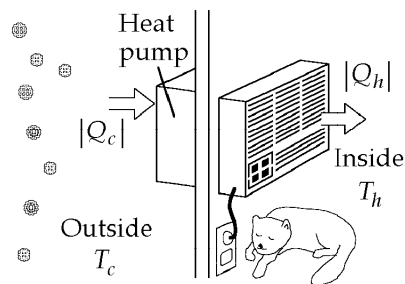
***18.15** $(\text{COP})_{\text{heat pump}} = \frac{|Q_c| + W}{W} = \frac{T_h}{\Delta T} = \frac{295}{25} = \boxed{11.8}$

Chapter 18

18.16 $\text{COP} = 0.100 \text{COP}_{\text{Carnot cycle}}$

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, 1.17 joules of energy enter the room by heat for each joule of work done.

18.17 (a) For a complete cycle, $\Delta E_{\text{int}} = 0$ and $W = |Q_h| - |Q_c| = |Q_c| \left[\frac{|Q_h|}{|Q_c|} - 1 \right]$

We have already shown that for a Carnot cycle (and only for a Carnot cycle) $\frac{|Q_h|}{|Q_c|} = \frac{T_h}{T_c}$

Therefore,

$$W = |Q_c| \left[\frac{T_h - T_c}{T_c} \right]$$

(b) We have from Equation 18.6,

$$\text{COP} = \frac{|Q_c|}{W}$$

Using the result from part (a), this becomes

$$\text{COP} = \frac{T_c}{T_h - T_c}$$

18.18 $|Q_c| = mc\Delta T + mL + mc\Delta T =$

$$|Q_c| = 0.500 \text{ kg}(4186 \text{ J/kg} \cdot ^\circ\text{C})(10^\circ\text{C}) + 0.500 \text{ kg}(3.33 \times 10^5 \text{ J/kg}) + 0.500 \text{ kg}(2090 \text{ J/kg} \cdot ^\circ\text{C})(20^\circ\text{C})$$

$$|Q_c| = 2.08 \times 10^5 \text{ J}$$

$$\frac{|Q_c|}{W} = \text{COP}_c \text{ (refrigerator)} = \frac{T_c}{T_h - T_c}$$

$$W = \frac{|Q_c|(T_h - T_c)}{T_c} = \frac{(2.08 \times 10^5 \text{ J})[20.0^\circ\text{C} - (-20.0^\circ\text{C})]}{(273 - 20.0) \text{ K}} = \boxed{32.9 \text{ kJ}}$$

18.19 $(\text{COP})_{\text{Carnot refriger}} = \frac{T_c}{\Delta T} = \frac{4.00}{289} = 0.0138 = \frac{|Q_c|}{W}$

$\therefore W = \boxed{72.2 \text{ J}}$ per 1 J energy removed by heat.

Chapter 18

18.20 For a freezing process,

$$\Delta S = \frac{\Delta Q}{T} = \frac{-(0.500 \text{ kg})(3.33 \times 10^5 \text{ J/kg})}{273 \text{ K}} = \boxed{-610 \text{ J/K}}$$

18.21
$$\Delta S = \int_i^f \frac{dQ}{T} = \int_{T_i}^{T_f} \frac{mc dT}{T} = mc \ln\left(\frac{T_f}{T_i}\right)$$

$$\Delta S = 250 \text{ g}(1.00 \text{ cal/g} \cdot ^\circ\text{C}) \ln\left(\frac{353}{293}\right) = 46.6 \text{ cal/K} = \boxed{195 \text{ J/K}}$$

***18.22** For any infinitesimal step in a process on an ideal gas,

$$dE_{\text{int}} = dQ + dW$$

$$dQ = dE_{\text{int}} - dW = nC_V dT + PdV$$

and

$$\frac{dQ}{T} = nC_V \frac{dT}{T} + \frac{P}{T} dV = nC_V \frac{dT}{T} + nR \frac{dV}{V}$$

If the whole process is reversible, $\Delta S = \int_i^f \frac{dQ_r}{T}$:

$$\Delta S = \int_i^f \left(nC_V \frac{dT}{T} + nR \frac{dV}{V} \right)$$

$$\Delta S = nC_V \ln\left(\frac{T_f}{T_i}\right) + nR \ln\left(\frac{V_f}{V_i}\right)$$

(a)
$$\Delta S = n\left(\frac{5}{2}\right)R \ln\left(\frac{255 \text{ K}}{298 \text{ K}}\right) + 0$$

$$\Delta S = -0.390(2.50 \text{ mol})(8.315 \text{ J/mol} \cdot \text{K}) = \boxed{-8.10 \text{ J/K}}$$

(b) The volume now decreases according to $V_f / V_i = T_f / T_i$

$$\Delta S = n\left(\frac{5}{2}\right)R \ln(0.856) + nR \ln(0.856) = n\left(\frac{7}{2}\right)R \ln(0.856) = nC_P \ln\left(\frac{T_f}{T_i}\right)$$

$$\Delta S = -0.545(2.50 \text{ mol})(8.315 \text{ J/mol} \cdot \text{K}) = \boxed{-11.3 \text{ J/K}}$$

Chapter 18

- *18.23** We take data from the description of Figure 17.3 in section 17.3, and we assume a constant specific heat for each phase. As the ice is warmed from -12°C to 0°C , its entropy increases by

$$\Delta S = \int_i^f \frac{dQ}{T} = \int_{261\text{ K}}^{273\text{ K}} \frac{mc_{\text{ice}}dT}{T} = mc_{\text{ice}} \int_{261\text{ K}}^{273\text{ K}} T^{-1}dT = mc_{\text{ice}} \ln T \Big|_{261\text{ K}}^{273\text{ K}}$$

$$\Delta S = 0.0270\text{ kg}(2090\text{ J/kg}\cdot^{\circ}\text{C})(\ln 273\text{ K} - \ln 261\text{ K}) = 0.0270\text{ kg}(2090\text{ J/kg}\cdot^{\circ}\text{C})\left(\ln\left(\frac{273}{261}\right)\right)$$

$$\Delta S = 2.54\text{ J/K}$$

As the ice melts its entropy change is

$$\Delta S = \frac{Q}{T} = \frac{mL_f}{T} = \frac{0.0270\text{ kg}(3.33 \times 10^5\text{ J/kg})}{273\text{ K}} = 32.9\text{ J/K}$$

As liquid water warms from 273 K to 373 K,

$$\Delta S = \int_i^f \frac{mc_{\text{liquid}}dT}{T} = mc_{\text{liquid}} \ln\left(\frac{T_f}{T_i}\right) = 0.0270\text{ kg}(4186\text{ J/kg}\cdot^{\circ}\text{C})\ln\left(\frac{373}{273}\right) = 35.3\text{ J/K}$$

As the water boils and the steam warms,

$$\Delta S = \frac{mL_v}{T} + mc_{\text{steam}} \ln\left(\frac{T_f}{T_i}\right)$$

$$\Delta S = \frac{0.0270\text{ kg}(2.26 \times 10^6\text{ J/kg})}{373\text{ K}} + 0.0270\text{ kg}(2010\text{ J/kg}\cdot^{\circ}\text{C})\ln\left(\frac{388}{373}\right) = 164\text{ J/K} + 2.14\text{ J/K}$$

The total entropy change is

$$(2.54 + 32.9 + 35.3 + 164 + 2.14)\text{ J/K} = \boxed{236\text{ J/K}}$$

We could equally well have taken the values for specific heats and latent heats from tables 17.1, 17.2, and 17.3. For steam at constant pressure, the molar specific heat in Table 17.3 implies a specific heat of $(35.4\text{ J/mol}\cdot\text{K})(1\text{ mol}/0.018\text{ kg}) = 1970\text{ J/kg}\cdot\text{K}$, nearly agreeing with $2010\text{ J/kg}\cdot\text{K}$.

- 18.24** (a) A 12 can only be obtained one way $6 + 6$
- (b) A 7 can be obtained six ways: $6 + 1, 5 + 2, 4 + 3, 3 + 4, 2 + 5, 1 + 6$

Chapter 18

18.25 (a)

Result	Possible Combinations	Total
All red	RRR	1
2R, 1G	RRG, RGR, GRR	3
1R, 2G	RGG, GRG, GGR	3
All green	GGG	1

(b)

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

18.26 (a) The table is shown below. On the basis of the table, the most probable result of a toss is 2 heads and 2 tails.

(b) The most ordered state is the least likely state. Thus, on the basis of the table this is either all heads or all tails.

(c) The most disordered is the most likely state. Thus, this is 2 heads and 2 tails.

Result	Possible Combinations	Total
All heads	HHHH	1
3H, 1T	THHH, HTHH, HHTH, HHHT	4
2H, 2T	TTHH, THTH, THHT, HTTH, HTHT, HHTT	6
1H, 3T	HTTT, THTT, TTHT, TTTH	4
All tails	TTTT	1

18.27
$$\Delta S = \frac{Q_2}{T_2} - \frac{Q_1}{T_1} = \left(\frac{1000}{290} - \frac{1000}{5700} \right) \text{J/K} = \boxed{3.27 \text{ J/K}}$$

Chapter 18

18.28 $c_{\text{iron}} = 448 \text{ J/kg} \cdot ^\circ\text{C}; c_{\text{water}} = 4186 \text{ J/kg} \cdot ^\circ\text{C}$

$$Q_{\text{cold}} = -Q_{\text{hot}}: \quad 4.00 \text{ kg}(4186 \text{ J/kg} \cdot ^\circ\text{C})(T_f - 10.0^\circ\text{C}) = -(1.00 \text{ kg})(448 \text{ J/kg} \cdot ^\circ\text{C})(T_f - 900^\circ\text{C})$$

which yields $T_f = 33.2^\circ\text{C} = 306.2 \text{ K}$

$$\Delta S = \int_{283 \text{ K}}^{306.2 \text{ K}} \frac{c_{\text{water}} m_{\text{water}} dT}{T} + \int_{1173 \text{ K}}^{306.2 \text{ K}} \frac{c_{\text{iron}} m_{\text{iron}} dT}{T}$$

$$\Delta S = c_{\text{water}} m_{\text{water}} \ln\left(\frac{306.2}{283}\right) + c_{\text{iron}} m_{\text{iron}} \ln\left(\frac{306.2}{1173}\right)$$

$$\Delta S = (4186 \text{ J/kg} \cdot \text{K})(4.00 \text{ kg})(0.0788) + (448 \text{ J/kg} \cdot \text{K})(1.00 \text{ kg})(-1.34)$$

$$\Delta S = \boxed{718 \text{ J/K}}$$

18.29 The car ends up in the same thermodynamic state as it started, so it undergoes zero changes in entropy. The original kinetic energy of the car is transferred by heat to the surrounding air, adding to the internal energy of the air. Its change in entropy is

$$\Delta S = \frac{\frac{1}{2}mv^2}{T} = \frac{750(20.0)^2}{293} \text{ J/K} = \boxed{1.02 \text{ kJ/K}}$$

18.30 The conversion of gravitational potential energy into kinetic energy as the water falls is reversible. But the subsequent conversion into internal energy is not. We imagine arriving at the same final state by adding energy by heat, in amount mgy , to the water from a stove at a temperature infinitesimally above 20.0°C . Then,

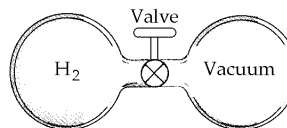
$$\Delta S = \int \frac{dQ}{T} = \frac{Q}{T} = \frac{mgy}{T} = \frac{5000 \text{ m}^3(1000 \text{ kg/m}^3)(9.80 \text{ m/s}^2)(50.0 \text{ m})}{293 \text{ K}} = \boxed{8.36 \times 10^6 \text{ J/K}}$$

***18.31**
$$\Delta S = \int_{T_i=268\text{K}}^{T_f=273\text{K}} \frac{mc_{\text{ice}} dT}{T} + \frac{mL_{\text{ice}}}{273} = mc_{\text{ice}} \ln\left(\frac{273}{268}\right) + \frac{mL_{\text{ice}}}{273}$$

$$\Delta S = 10^5 \text{ kg}(2010 \text{ J/kg} \cdot ^\circ\text{C}) \ln\left(\frac{273}{268}\right) + \frac{10^5(3.33 \times 10^5)}{273} \text{ J/K} = \boxed{1.26 \times 10^8 \text{ J/K}}$$

18.32
$$\Delta S = nR \ln\left(\frac{V_f}{V_i}\right) = R \ln 2 = \boxed{5.76 \text{ J/K}}$$

There is $\boxed{\text{no change in temperature}}$



Chapter 18

***18.33** For any infinitesimal step in a process on an ideal gas,

$$dE_{\text{int}} = dQ + dW: \quad dQ = dE_{\text{int}} - dW = nC_V dT + PdV = nC_V dT + \frac{nRTdV}{V}$$

and
$$\frac{dQ}{T} = nC_V \frac{dT}{T} + nR \frac{dV}{V}$$

If the whole process is reversible,
$$\Delta S = \int_i^f \frac{dQ_r}{T} = \int_i^f \left(nC_V \frac{dT}{T} + nR \frac{dV}{V} \right) = nC_V \ln\left(\frac{T_f}{T_i}\right) + nR \ln\left(\frac{V_f}{V_i}\right)$$

Also, from the ideal gas law,
$$\frac{T_f}{T_i} = \frac{P_f V_f}{P_i V_i}$$

$$\Delta S = (1.00 \text{ mol}) \left[\frac{3}{2} \left(\frac{8.315 \text{ J}}{\text{mol} \cdot \text{K}} \right) \right] \ln\left(\frac{(2.00)(0.0400)}{(1.00)(0.0250)}\right) + (1.00 \text{ mol}) \left(\frac{8.315 \text{ J}}{\text{mol} \cdot \text{K}} \right) \ln\left(\frac{0.0400}{0.0250}\right) = \boxed{18.4 \text{ J/K}}$$

18.34
$$\Delta S = nR \ln\left(\frac{V_f}{V_i}\right) = (0.0440)(2) R \ln 2$$

$$\Delta S = 0.0880(8.315) \ln 2 = \boxed{0.507 \text{ J/K}}$$

0.044 mol H ₂	0.044 mol O ₂
-----------------------------	-----------------------------

***18.35** The Earth presents a circular projected area of $\pi(6.37 \times 10^6 \text{ m})^2$ perpendicular to the direction of energy flow in sunlight. The power incident on the Earth is then

$$\mathcal{P} = IA = (1340 \text{ W/m}^2) \left[\pi(6.37 \times 10^6 \text{ m})^2 \right] = 1.71 \times 10^{17} \text{ W}$$

The power absorbed in the atmosphere is $0.64(1.71 \times 10^{17} \text{ W}) = 1.1 \times 10^{17} \text{ W}$

The mechanical wind power is $0.008(1.1 \times 10^{17} \text{ W}) = \boxed{9 \times 10^{14} \text{ W}}$

***18.36** (a) The volume of the air is $\pi r^2 h$ and its mass is $m = \rho V = \rho \pi r^2 h$.

Then its kinetic energy is
$$K = \frac{1}{2} m v^2 = \frac{1}{2} \rho \pi r^2 h v^2$$

$$K = \frac{1}{2} (1.20 \text{ kg/m}^3) \left[\pi(300000 \text{ m})^2 (11000 \text{ m}) \right] \left(\frac{60000 \text{ m}}{3600 \text{ s}} \right)^2$$

$$K = 5.2 \times 10^{17} \text{ J}$$

(b) We suppose the light shines perpendicularly down onto the hurricane.

Its intensity is $I = \frac{\mathcal{P}}{A} = \frac{E}{A \Delta t}$:
$$\Delta t = \frac{E}{AI} = \frac{5.2 \times 10^{17} \text{ J} \cdot \text{m}^2 \cdot \text{s}}{\pi(3 \times 10^5 \text{ m})^2 (10^3 \text{ J})} = \boxed{1.8 \times 10^3 \text{ s}}$$

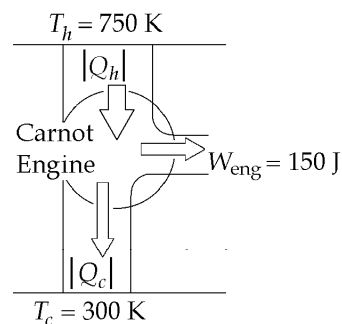
Chapter 18

*18.37 For the Carnot engine, $e_c = 1 - \frac{T_c}{T_h} = 1 - \frac{300 \text{ K}}{750 \text{ K}} = 0.600$

Also, $e_c = \frac{W_{\text{eng}}}{|Q_h|}$

so $|Q_h| = \frac{W_{\text{eng}}}{e_c} = \frac{150 \text{ J}}{0.600} = 250 \text{ J}$

and $|Q_c| = |Q_h| - W_{\text{eng}} = 250 \text{ J} - 150 \text{ J} = 100 \text{ J}$

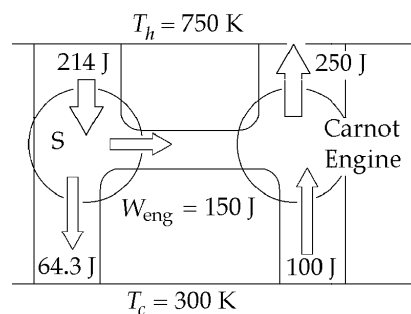


(a) $|Q_h| = \frac{W_{\text{eng}}}{e_s} = \frac{150 \text{ J}}{0.700} = \boxed{214 \text{ J}}$

$|Q_c| = |Q_h| - W_{\text{eng}} = 214 \text{ J} - 150 \text{ J} = \boxed{64.3 \text{ J}}$

(b) $|Q_{h,\text{net}}| = 214 \text{ J} - 250 \text{ J} = \boxed{-35.7 \text{ J}}$

$|Q_{c,\text{net}}| = 64.3 \text{ J} - 100 \text{ J} = \boxed{-35.7 \text{ J}}$



The net flow of energy by heat from the cold to the hot reservoir without work input, is impossible.

(c) For engine S: $|Q_c| = |Q_h| - W_{\text{eng}} = \frac{W_{\text{eng}}}{e_s} - W_{\text{eng}}$

so $W_{\text{eng}} = \frac{|Q_c|}{1/e_s - 1} = \frac{100 \text{ J}}{(1/0.700) - 1} = \boxed{233 \text{ J}}$

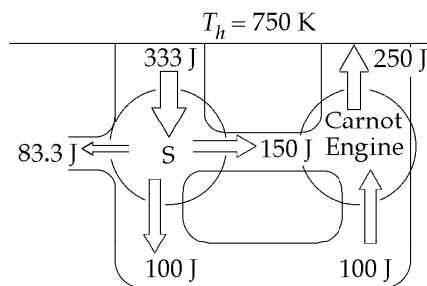
and $|Q_h| = |Q_c| + W_{\text{eng}} = 233 \text{ J} + 100 \text{ J} = \boxed{333 \text{ J}}$

(d) $|Q_{h,\text{net}}| = 333 \text{ J} - 250 \text{ J} = \boxed{83.3 \text{ J}}$

$W_{\text{net}} = 233 \text{ J} - 150 \text{ J} = \boxed{83.3 \text{ J}}$

$|Q_{c,\text{net}}| = \boxed{0}$

The output of 83.3 J of energy from the heat engine by work in a cyclic process without any exhaust by heat is impossible.



(e) Both engines operate in cycles, so $\Delta S_S = \Delta S_{\text{Carnot}} = 0$

For the reservoirs, $\Delta S_h = -\frac{|Q_h|}{T_h}$ and $\Delta S_c = +\frac{|Q_c|}{T_c}$

Thus, $\Delta S_{\text{total}} = \Delta S_S + \Delta S_{\text{Carnot}} + \Delta S_h + \Delta S_c = 0 + 0 - \frac{83.3 \text{ J}}{750 \text{ K}} + \frac{0}{300 \text{ K}} = \boxed{-0.111 \text{ J/K}}$

A decrease in total entropy is impossible.

Chapter 18

- 18.38** Sitting here writing, I convert chemical energy, in ordered molecules in food, into internal energy that leaves my body by heat into the room-temperature surroundings. My rate of energy output is equal to my metabolic rate,

$$2500 \text{ kcal/d} = \frac{2500 \times 10^3 \text{ cal}}{86400 \text{ s}} \left(\frac{4.186 \text{ J}}{1 \text{ cal}} \right) = 120 \text{ W}$$

My body is in steady state, changing little in entropy, as the environment increases in entropy at the rate

$$\frac{\Delta S}{\Delta t} = \frac{Q/T}{\Delta t} = \frac{Q/\Delta t}{T} = \frac{120 \text{ W}}{293 \text{ K}} = 0.4 \text{ W/K} \sim \boxed{1 \text{ W/K}}$$

When using powerful appliances or an automobile, my personal contribution to entropy production is much greater than the above estimate, based only on metabolism.

- 18.39** (a) $\mathcal{P}_{\text{electric}} = \frac{H_{ET}}{\Delta t}$ so if all the electric energy is converted into internal energy, the steady-state condition of the house is described by $H_{ET} = |Q|$

Therefore,
$$\mathcal{P}_{\text{electric}} = \frac{Q}{\Delta t} = \boxed{5000 \text{ W}}$$

- (b) For a heat pump, $(\text{COP})_{\text{Carnot}} = \frac{T_h}{\Delta T} = \frac{295 \text{ K}}{27 \text{ K}} = 10.92$

$$\text{Actual COP} = 0.6(10.92) = 6.55 = \frac{|Q_h|}{W} = \frac{|Q_h|/\Delta t}{W/\Delta t}$$

Therefore, to bring 5000 W of energy into the house only requires input power

$$\mathcal{P}_{\text{heat pump}} = \frac{W}{\Delta t} = \frac{|Q_h|/\Delta t}{\text{COP}} = \frac{5000 \text{ W}}{6.56} = \boxed{763 \text{ W}}$$

- *18.40** We want to evaluate dP/dV for the function implied by $PV = nRT = \text{constant}$, and also for the different function implied by $PV^\gamma = \text{constant}$. We can use implicit differentiation:

From $PV = \text{constant}$
$$P \frac{dV}{dV} + V \frac{dP}{dV} = 0 \quad \left(\frac{dP}{dV} \right)_{\text{isotherm}} = -\frac{P}{V}$$

From $PV^\gamma = \text{constant}$
$$P\gamma V^{\gamma-1} + V^\gamma \frac{dP}{dV} = 0 \quad \left(\frac{dP}{dV} \right)_{\text{adiabat}} = -\frac{\gamma P}{V}$$

Therefore,
$$\left(\frac{dP}{dV} \right)_{\text{adiabat}} = \gamma \left(\frac{dP}{dV} \right)_{\text{isotherm}}$$

The theorem is proved.

Chapter 18

- 18.41 (a) For an isothermal process,

$$Q = nRT \ln\left(\frac{V_2}{V_1}\right)$$

Therefore,

$$Q_1 = nR(3T_i) \ln 2$$

and

$$Q_3 = nR(T_i) \ln(1/2)$$

For the constant volume processes,

$$Q_2 = \Delta E_{\text{int},2} = \frac{3}{2} nR(T_i - 3T_i)$$

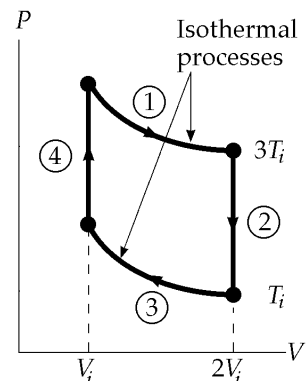
and

$$Q_4 = \Delta E_{\text{int},4} = \frac{3}{2} nR(3T_i - T_i)$$

The net energy by heat transferred is then $Q = Q_1 + Q_2 + Q_3 + Q_4$

or

$$Q = \boxed{2nRT_i \ln 2}$$



- (b) A positive value for heat represents energy transferred into the system.

Therefore,

$$|Q_h| = Q_1 + Q_4 = 3nRT_i(1 + \ln 2)$$

Since the change in temperature for the complete cycle is zero,

$$\Delta E_{\text{int}} = 0 \quad \text{and} \quad W_{\text{eng}} = Q$$

Therefore, the efficiency is

$$e_c = \frac{W_{\text{eng}}}{|Q_h|} = \frac{Q}{|Q_h|} = \frac{2 \ln 2}{3(1 + \ln 2)} = \boxed{0.273}$$

18.42 $\Delta S_{\text{hot}} = \frac{-1000 \text{ J}}{600 \text{ K}}$

$$\Delta S_{\text{cold}} = \frac{+750 \text{ J}}{350 \text{ K}}$$

(a) $\Delta S_U = \Delta S_{\text{hot}} + \Delta S_{\text{cold}} = \boxed{0.476 \text{ J/K}}$

(b) $e_c = 1 - \frac{T_1}{T_2} = 0.417$

$$W_{\text{eng}} = e_c |Q_h| = 0.417(1000 \text{ J}) = \boxed{417 \text{ J}}$$

(c) $W_{\text{net}} = 417 \text{ J} - 250 \text{ J} = 167 \text{ J}$

$$T_1 \Delta S_U = 350 \text{ K}(0.476 \text{ J/K}) = \boxed{167 \text{ J}}$$

18.43

$$e_c = 1 - \frac{T_c}{T_h} = \frac{W_{\text{eng}}}{|Q_h|} = \frac{(W_{\text{eng}} / \Delta t)}{(|Q_h| / \Delta t)}; \quad \frac{|Q_h|}{\Delta t} = \frac{\mathcal{P}}{\left(1 - \frac{T_c}{T_h}\right)} = \frac{\mathcal{P}T_h}{T_h - T_c}$$

$$|Q_h| = W_{\text{eng}} + |Q_c|; \quad \frac{|Q_c|}{\Delta t} = \frac{|Q_h|}{\Delta t} - \frac{W_{\text{eng}}}{\Delta t}$$

$$\frac{|Q_c|}{\Delta t} = \frac{\mathcal{P}T_h}{T_h - T_c} - \mathcal{P} = \frac{\mathcal{P}T_c}{T_h - T_c}$$

$$|Q_c| = mc\Delta T; \quad \frac{|Q_c|}{\Delta t} = \left(\frac{\Delta m}{\Delta t}\right)c\Delta T = \frac{\mathcal{P}T_c}{T_h - T_c}$$

$$\frac{\Delta m}{\Delta t} = \frac{\mathcal{P}T_c}{(T_h - T_c)c\Delta T}$$

$$\frac{\Delta m}{\Delta t} = \frac{(1.00 \times 10^9 \text{ W})(300 \text{ K})}{200 \text{ K}(4186 \text{ J/kg} \cdot ^\circ\text{C})(6.00 \text{ } ^\circ\text{C})} = \boxed{5.97 \times 10^4 \text{ kg/s}}$$

18.44

$$e_c = 1 - \frac{T_c}{T_h} = \frac{W_{\text{eng}}}{|Q_h|} = \frac{(W_{\text{eng}} / \Delta t)}{(|Q_h| / \Delta t)}; \quad \frac{|Q_h|}{\Delta t} = \frac{\mathcal{P}}{\left(1 - \frac{T_c}{T_h}\right)} = \frac{\mathcal{P}T_h}{T_h - T_c}$$

$$\frac{|Q_c|}{\Delta t} = \left(\frac{|Q_h|}{\Delta t}\right) - \mathcal{P} = \frac{\mathcal{P}T_c}{T_h - T_c}$$

$|Q_c| = mc\Delta T$, where c is the specific heat of water.

Therefore,

$$\frac{|Q_c|}{\Delta t} = \left(\frac{\Delta m}{\Delta t}\right)c\Delta T = \frac{\mathcal{P}T_c}{T_h - T_c}$$

and

$$\frac{\Delta m}{\Delta t} = \boxed{\frac{\mathcal{P}T_c}{(T_h - T_c)c\Delta T}}$$

18.45

$$\frac{|Q_c|}{W} = \text{COP}_C (\text{refrigerator}) = \frac{T_c}{T_h - T_c} = \frac{|Q_c| / \Delta t}{W / \Delta t}$$

$$\frac{0.150 \text{ W}}{W / \Delta t} = \frac{260 \text{ K}}{40.0 \text{ K}}$$

$$\mathcal{P} = \frac{W}{\Delta t} = 0.150 \text{ W} \left(\frac{40.0 \text{ K}}{260 \text{ K}}\right) = \boxed{23.1 \text{ mW}}$$

Chapter 18

- *18.46 (a) For the isothermal process AB , the work on the gas is

$$W_{AB} = -P_A V_A \ln\left(\frac{V_B}{V_A}\right)$$

$$W_{AB} = -5(1.013 \times 10^5 \text{ Pa})(10.0 \times 10^{-3} \text{ m}^3) \ln\left(\frac{50.0}{10.0}\right)$$

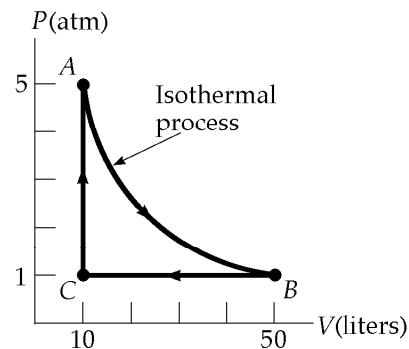
$$W_{AB} = -8.15 \times 10^3 \text{ J}$$

where we have used $1.00 \text{ atm} = 1.013 \times 10^5 \text{ Pa}$

and $1.00 \text{ L} = 1.00 \times 10^{-3} \text{ m}^3$

$$W_{BC} = -P_B \Delta V = -(1.013 \times 10^5 \text{ Pa})[(10.0 - 50.0) \times 10^{-3}] \text{ m}^3 = +4.05 \times 10^3 \text{ J}$$

$$W_{CA} = 0 \quad \text{and} \quad W_{\text{eng}} = -W_{AB} - W_{BC} = 4.11 \times 10^3 \text{ J} = \boxed{4.11 \text{ kJ}}$$



- (b) Since AB is an isothermal process, $\Delta E_{\text{int},AB} = 0$

and $Q_{AB} = -W_{AB} = 8.15 \times 10^3 \text{ J}$

For an ideal monatomic gas, $C_V = 3R/2$ and $C_P = 5R/2$.

$$T_B = T_A = \frac{P_B V_B}{nR} = \frac{(1.013 \times 10^5)(50.0 \times 10^{-3})}{R} = \frac{5.05 \times 10^3}{R}$$

Also, $T_C = \frac{P_C V_C}{nR} = \frac{(1.013 \times 10^5)(10.0 \times 10^{-3})}{R} = \frac{1.01 \times 10^3}{R}$

$$Q_{CA} = nC_V \Delta T = 1.00 \left(\frac{3}{2}R\right) \left(\frac{5.05 \times 10^3 - 1.01 \times 10^3}{R}\right) = 6.08 \text{ kJ}$$

so the total energy absorbed by heat is $Q_{AB} + Q_{CA} = 8.15 \text{ kJ} + 6.08 \text{ kJ} = \boxed{14.2 \text{ kJ}}$

- (c) $Q_{BC} = nC_P \Delta T = \frac{5}{2}(nR \Delta T) = \frac{5}{2}P_B \Delta V_{BC}$

$$Q_{BC} = \frac{5}{2}(1.013 \times 10^5) [(10.0 - 50.0) \times 10^{-3}] = -1.01 \times 10^4 \text{ J} = \boxed{-10.1 \text{ kJ}}$$

- (d) $e = \frac{W_{\text{eng}}}{|Q_h|} = \frac{W_{\text{eng}}}{Q_{AB} + Q_{CA}} = \frac{4.11 \times 10^3 \text{ J}}{1.42 \times 10^4 \text{ J}} = 0.289 \quad \text{or} \quad \boxed{28.9\%}$

Chapter 18

***18.47** Define $T_1 = \text{Temp Cream} = 5.00\text{ }^\circ\text{C} = 278\text{ K}$
 Define $T_2 = \text{Temp Coffee} = 60.0\text{ }^\circ\text{C} = 333\text{ K}$
 The final temperature of the mixture is: $T_f = \frac{(20.0\text{ g})T_1 + (200\text{ g})T_2}{220\text{ g}} = 55.0\text{ }^\circ\text{C} = 328\text{ K}$
 The entropy change due to this mixing is $\Delta S = (20.0\text{ g}) \int_{T_1}^{T_f} \frac{c_V dT}{T} + (200\text{ g}) \int_{T_2}^{T_f} \frac{c_V dT}{T}$

$$\Delta S = (84.0\text{ J/K}) \ln\left(\frac{T_f}{T_1}\right) + (840\text{ J/K}) \ln\left(\frac{T_f}{T_2}\right) = (84.0\text{ J/K}) \ln\left(\frac{328}{278}\right) + (840\text{ J/K}) \ln\left(\frac{328}{333}\right)$$

$$\Delta S = \boxed{+1.18\text{ J/K}}$$

***18.48** Like a refrigerator, an air conditioner has as its purpose the removal of energy by heat from the cold reservoir.

Its ideal COP is $\text{COP}_{\text{Carnot}} = \frac{T_c}{T_h - T_c} = \frac{280\text{ K}}{20\text{ K}} = 14.0$

(a) Its actual COP is $0.400(14.0) = 5.60 = \frac{|Q_c|}{|Q_h| - |Q_c|} = \frac{|Q_c / \Delta t|}{|Q_h / \Delta t| - |Q_c / \Delta t|}$

$$5.60 \left| \frac{Q_h}{\Delta t} \right| - 5.60 \left| \frac{Q_c}{\Delta t} \right| = \left| \frac{Q_c}{\Delta t} \right|$$

$$5.60(10.0\text{ kW}) = 6.60 \left| \frac{Q_c}{\Delta t} \right| \quad \text{and} \quad \left| \frac{Q_c}{\Delta t} \right| = \boxed{8.48\text{ kW}}$$

(b) $|Q_h| = W_{\text{eng}} + |Q_c|$: $\frac{W_{\text{eng}}}{\Delta t} = \left| \frac{Q_h}{\Delta t} \right| - \left| \frac{Q_c}{\Delta t} \right| = 10.0\text{ kW} - 8.48\text{ kW} = \boxed{1.52\text{ kW}}$

(c) The air conditioner operates in a cycle, so the entropy of the working fluid does not change. The hot reservoir increases in entropy by

$$\frac{|Q_h|}{T_h} = \frac{(10.0 \times 10^3\text{ J/s})(3600\text{ s})}{300\text{ K}} = 1.20 \times 10^5\text{ J/K}$$

The cold room decreases in entropy by $\Delta S = -\frac{|Q_c|}{T_c} = -\frac{(8.48 \times 10^3\text{ J/s})(3600\text{ s})}{280\text{ K}} = -1.09 \times 10^5\text{ J/K}$

The net entropy change is positive, as it must be:

$$+1.20 \times 10^5\text{ J/K} - 1.09 \times 10^5\text{ J/K} = \boxed{1.09 \times 10^4\text{ J/K}}$$

(d) The new ideal COP is $\text{COP}_{\text{Carnot}} = \frac{T_c}{T_h - T_c} = \frac{280\text{ K}}{25\text{ K}} = 11.2$

We suppose the actual COP is $0.400(11.2) = 4.48$

As a fraction of the original 5.60, this is $4.48/5.60 = 0.800$, so the fractional change is to $\boxed{\text{drop by } 20.0\%}$.

Chapter 18

***18.49** At point A, $P_i V_i = nRT_i$ and $n = 1.00$ mol

At point B, $3P_i V_i = nRT_B$ so $T_B = 3T_i$

At point C, $(3P_i)(2V_i) = nRT_C$ and $T_C = 6T_i$

At point D, $P_i(2V_i) = nRT_D$ so $T_D = 2T_i$

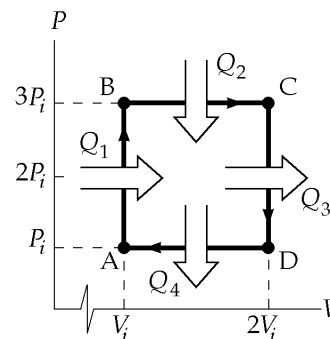
The heat for each step in the cycle is found using $C_V = 3R/2$ and $C_P = 5R/2$:

$$Q_{AB} = nC_V(3T_i - T_i) = 3nRT_i$$

$$Q_{BC} = nC_P(6T_i - 3T_i) = 7.50nRT_i$$

$$Q_{CD} = nC_V(2T_i - 6T_i) = -6nRT_i$$

$$Q_{DA} = nC_P(T_i - 2T_i) = -2.50nRT_i$$



(a) Therefore,

$$Q_{\text{entering}} = |Q_h| = Q_{AB} + Q_{BC} = \boxed{10.5nRT_i}$$

(b)

$$Q_{\text{leaving}} = |Q_c| = |Q_{CD} + Q_{DA}| = \boxed{8.50nRT_i}$$

(c) Actual efficiency,

$$e = \frac{|Q_h| - |Q_c|}{|Q_h|} = \boxed{0.190}$$

(d) Carnot efficiency,

$$e_c = 1 - \frac{T_c}{T_h} = 1 - \frac{T_i}{6T_i} = \boxed{0.833}$$

***18.50** (a) $\left(10.0 \frac{\text{Btu}}{\text{h} \cdot \text{W}}\right) \left(\frac{1055 \text{ J}}{1 \text{ Btu}}\right) \left(\frac{1 \text{ h}}{3600 \text{ s}}\right) \left(\frac{1 \text{ W}}{1 \text{ J/s}}\right) = \boxed{2.93}$

(b) Coefficient of performance for a refrigerator: $\boxed{(\text{COP})_{\text{refrigerator}}}$

(c) With EER 5, $5 \frac{\text{Btu}}{\text{h} \cdot \text{W}} = \frac{10000 \text{ Btu/h}}{\mathcal{P}}$: $\mathcal{P} = \frac{10000 \text{ Btu/h}}{5 \text{ Btu/(h} \cdot \text{W)}} = 2000 \text{ W} = 2.00 \text{ kW}$

Energy purchased is

$$\mathcal{P}\Delta t = (2.00 \text{ kW})(1500 \text{ h}) = 3.00 \times 10^3 \text{ kWh}$$

$$\text{Cost} = (3.00 \times 10^3 \text{ kWh})(0.100 \text{ \$/kWh}) = \$300$$

With EER 10, $10 \frac{\text{Btu}}{\text{h} \cdot \text{W}} = \frac{10000 \text{ Btu/h}}{\mathcal{P}}$:

$$\mathcal{P} = \frac{10000 \text{ Btu/h}}{10 \text{ Btu/(h} \cdot \text{W)}} = 1000 \text{ W} = 1.00 \text{ kW}$$

Energy purchased is

$$\mathcal{P}\Delta t = (1.00 \text{ kW})(1500 \text{ h}) = 1.50 \times 10^3 \text{ kWh}$$

$$\text{Cost} = (1.50 \times 10^3 \text{ kWh})(0.100 \text{ \$/kWh}) = \$150$$

Thus, the cost for air conditioning is

half as much with EER 10

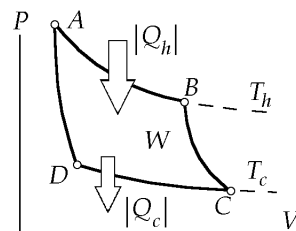
Chapter 18

- *18.51 (a) Use the equation of state for an ideal gas

$$V = \frac{nRT}{P}$$

$$V_A = \frac{1.00(8.315)(600)}{25.0(1.013 \times 10^5)} = \boxed{1.97 \times 10^{-3} \text{ m}^3}$$

$$V_C = \frac{1.00(8.315)(400)}{1.013 \times 10^5} = \boxed{32.8 \times 10^{-3} \text{ m}^3}$$



Since AB is isothermal, $P_A V_A = P_B V_B$

and since BC is adiabatic, $P_B V_B^\gamma = P_C V_C^\gamma$

Combining these expressions,
$$V_B = \left[\left(\frac{P_C}{P_A} \right) \frac{V_C^\gamma}{V_A} \right]^{1/(\gamma-1)} = \left[\left(\frac{1.00}{25.0} \right) \frac{(32.8 \times 10^{-3} \text{ m}^3)^{1.40}}{1.97 \times 10^{-3} \text{ m}^3} \right]^{1/0.400}$$

$$V_B = \boxed{11.9 \times 10^{-3} \text{ m}^3}$$

Similarly,
$$V_D = \left[\left(\frac{P_A}{P_C} \right) \frac{V_A^\gamma}{V_C} \right]^{1/(\gamma-1)} = \left[\left(\frac{25.0}{1.00} \right) \frac{(1.97 \times 10^{-3} \text{ m}^3)^{1.40}}{32.8 \times 10^{-3} \text{ m}^3} \right]^{1/0.400}$$

or
$$V_D = \boxed{5.44 \times 10^{-3} \text{ m}^3}$$

Since AB is isothermal, $P_A V_A = P_B V_B$

and
$$P_B = P_A \left(\frac{V_A}{V_B} \right) = 25.0 \text{ atm} \left(\frac{1.97 \times 10^{-3} \text{ m}^3}{11.9 \times 10^{-3} \text{ m}^3} \right) = \boxed{4.14 \text{ atm}}$$

Also, CD is an isothermal and
$$P_D = P_C \left(\frac{V_C}{V_D} \right) = 1.00 \text{ atm} \left(\frac{32.8 \times 10^{-3} \text{ m}^3}{5.44 \times 10^{-3} \text{ m}^3} \right) = \boxed{6.03 \text{ atm}}$$

Solving part (c) before part (b):

(c) For this Carnot cycle,
$$e_c = 1 - \frac{T_c}{T_h} = 1 - \frac{400 \text{ K}}{600 \text{ K}} = \boxed{0.333}$$

- (b) Energy is added by heat to the gas during the process AB . For the isothermal process, $\Delta E_{\text{int}} = 0$

and the first law gives
$$Q_{AB} = -W_{AB} = nRT_h \ln \left(\frac{V_B}{V_A} \right)$$

or
$$|Q_h| = Q_{AB} = 1.00 \text{ mol} (8.315 \text{ J/mol} \cdot \text{K}) (600 \text{ K}) \ln \left(\frac{11.9}{1.97} \right) = 8.97 \text{ kJ}$$

Then, from
$$e = W_{\text{eng}} / |Q_h|$$

the net work done per cycle is
$$W_{\text{eng}} = e_c |Q_h| = 0.333(8.97 \text{ kJ}) = \boxed{2.99 \text{ kJ}}$$

$$*18.52 \quad \Delta S = \int_i^f \frac{dQ}{T} = \int_i^f \frac{nC_P dT}{T} = nC_P \int_i^f T^{-1} dT = nC_P \ln T \Big|_{T_i}^{T_f} = nC_P (\ln T_f - \ln T_i) = nC_P \ln \left(\frac{T_f}{T_i} \right)$$

$$\Delta S = nC_P \ln \left(\frac{PV_f}{nR} \frac{nR}{PV_i} \right) = \boxed{nC_P \ln 3}$$

- *18.53 (a) The ideal gas at constant temperature keeps constant internal energy. As it puts out energy by work in expanding it must take in an equal amount of energy by heat. Thus its entropy increases. Let P_i, V_i, T_i represent the state of the gas before the isothermal expansion. Let P_C, V_C, T_i represent the state after this process, so that $P_i V_i = P_C V_C$. Let $P_i, 3V_i, T_f$ represent the state after the adiabatic compression.

Then
$$P_C V_C^\gamma = P_i (3V_i)^\gamma$$

Substituting
$$P_C = P_i V_i / V_C$$

gives
$$P_i V_i V_C^{\gamma-1} = P_i (3^\gamma V_i^\gamma)$$

Then
$$V_C^{\gamma-1} = 3^\gamma V_i^{\gamma-1} \quad \text{and} \quad V_C / V_i = 3^{\gamma/(\gamma-1)}$$

The work output in the isothermal expansion is

$$W = \int_i^C P dV = nRT_i \int_i^C V^{-1} dV = nRT_i \ln \left(\frac{V_C}{V_i} \right) = nRT_i \ln \left(3^{\gamma/(\gamma-1)} \right) = nRT_i \left(\frac{\gamma}{\gamma-1} \right) \ln 3$$

This is also the input heat, so the entropy change is

$$\Delta S = \frac{Q}{T} = nR \left(\frac{\gamma}{\gamma-1} \right) \ln 3$$

Since
$$C_P = \gamma C_V = C_V + R$$

we have
$$(\gamma-1)C_V = R, \quad C_V = R/(\gamma-1)$$

and
$$C_P = \gamma R/(\gamma-1)$$

Then the result is
$$\boxed{\Delta S = nC_P \ln 3}$$

- (b) The pair of processes considered here carry the gas from the initial state in Problem 52 to the final state there. Entropy is a function of state. Entropy change does not depend on path. Therefore the entropy change in Problem 52 equals $\Delta S_{\text{isothermal}} + \Delta S_{\text{adiabatic}}$ in this problem. Since $\Delta S_{\text{adiabatic}} = 0$, the answers to Problem 52 and 53 (a) must be the same.

Chapter 18

***18.54** No energy is transferred by heat during the adiabatic processes. Energy Q_h is added by heat during process BC and energy $|Q_c|$ is exhausted during process DA .

We have $Q_h = nC_V(T_C - T_B)$ and $|Q_c| = nC_V(T_D - T_A)$

So
$$e = 1 - \frac{|Q_c|}{Q_h} = 1 - \frac{T_D - T_A}{T_C - T_B}$$

For the adiabatic processes, $P_C V_2^\gamma = P_D V_1^\gamma$ and $P_B V_2^\gamma = P_A V_1^\gamma$

From the gas law $P_C = nRT_C / V_2$ $P_D = nRT_D / V_1$

$P_B = nRT_B / V_2$ $P_A = nRT_A / V_1$

Then $nRT_C V_2^{\gamma-1} = nRT_D V_1^{\gamma-1}$ and $T_B V_2^{\gamma-1} = T_A V_1^{\gamma-1}$

Thus, $\frac{T_C}{T_D} = \left(\frac{V_1}{V_2}\right)^{\gamma-1} = r^{\gamma-1}$ and $\frac{T_B}{T_A} = \left(\frac{V_1}{V_2}\right)^{\gamma-1} = r^{\gamma-1}$

Then
$$e = 1 - \frac{T_D - T_A}{T_D r^{\gamma-1} - T_A r^{\gamma-1}} = 1 - \frac{1}{r^{\gamma-1}} = 1 - r^{1-\gamma}$$

ANSWERS TO EVEN NUMBERED PROBLEMS

2. 667 J, 467 J
4. 55.4%
6. 197 kJ
8. 546 °C
10. (a) 4.20 W (b) 31.2 g
12. (a) 5.12% (b) 5.27 TJ/h
(c) As conventional energy sources become more expensive, or as their true costs are recognized, alternative sources become economically viable.
14. 9.00
16. 1.17 J
18. 3.29×10^4 J
20. -610 J/K
22. (a) -8.10 J/K (b) -11.3 J/K
24. (a) 1 (b) 6
26. (a) 2H and 2T (b) either 4H or 4T (c) 2H and 2T
28. 718 J/K
30. 8.36×10^6 J/K
32. 5.76 J/K; temperature is constant if the gas is ideal
34. 0.507 J/K

Chapter 18

36. 1.8×10^3 s
38. ~ 1 W/K from metabolism; much more if using powerful appliances or an automobile.
40. See the solution
42. (a) 0.476 J/K (b) 417 J (c) $W_{\text{net}} = T_1 \Delta S_U = 167$ J
44.
$$\frac{\Delta m}{\Delta t} = \frac{\mathcal{P}T_c}{(T_h - T_c)c\Delta T}$$
46. (a) 4.11 kJ (b) 14.2 kJ
(c) -10.1 kJ (d) 28.9%
48. (a) 8.48 kW (b) 1.52 kW
(c) 1.09×10^4 J/K (d) COP drops by 20.0%
50. (a) 2.93 (b) $(\text{COP})_{\text{refrigerator}}$
(c) cost is half as much with EER 10
52. $nC_p \ln 3$
54. See the solution.