University Physics with Modern Physics - Modern Physics by Young and Freedman Problems

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Contents

17 Temperature and Heat

17.1 Guided Practice

17.1.1

(a)

$$\begin{aligned}\Delta L &= \alpha L_0 \Delta T \\ \alpha &= \frac{\Delta L}{L_0 \Delta T} \\ &= 2.0 \times 10^{-5}\,\mathrm{K}^{-1}\end{aligned}$$

(b)

$$\begin{aligned}\Delta L &= \alpha L_0 \Delta T \\ &= -0.27\,\mathrm{mm}\end{aligned}$$

17.1.2

$$
\begin{aligned}
\Delta V_C &= \beta V_{C0}\Delta T \\
&= (5.1\times 10^{-5})(250)(-70) \\
&= -0.893\,\mathrm{cm}^3 \\
\Delta V_E &= \beta V_{E0}\Delta T \\
&= (75\times 10^{-5}\ )(250)(-70) \\
&= -13.1\,\mathrm{cm}^3 \\
\Delta V_C - \Delta V_E &= 12.2\,\mathrm{cm}^3 \\
&= 12.2\,\mathrm{mL}
\end{aligned}
$$

17.1.3

$$
\begin{aligned}
\frac{\Delta L}{L_0} &= \alpha\Delta T \\
Y &= \frac{F/A}{\Delta L/L_0} \\
\frac{\Delta L}{L_0} &= \frac{F}{AY} \\
\alpha\Delta T + \frac{F}{AY} &= 0 \\
\frac{F}{AY} &= -\alpha\Delta T \\
F &= -\alpha AY\Delta T \\
&= -(2.0\times 10^{-5})(\pi 0.005^2)(9.0\times 10^{10})(-12) \\
&= 1.70\times 10^3\,\mathrm{N}
\end{aligned}
$$

Tensile

17.1.4

$$
\begin{aligned}
\Delta L &= \alpha_A L_A\Delta T + \alpha_B L_B\Delta T \\
\frac{\Delta L}{\Delta T} &= \alpha_A L_A + \alpha_B(L - L_A) \\
&= (\alpha_A - \alpha_B)L_A + \alpha_B L \\
L_A &= \frac{1}{\alpha_A - \alpha_B}\left(\frac{\Delta L}{\Delta T} - \alpha_B L\right)
\end{aligned}
$$

17.1.5

$$\begin{aligned}
0 &= m_{Al}c_{Al}\Delta T_{Al} + m_W c_W \Delta T_W \\
&= m_{Al}c_{Al}(T - T_{Al}) + m_W c_W (T - T_W) \\
m_{Al} &= -\frac{m_W c_W (T - T_W)}{c_{Al}(T - T_{Al})} \\
&= 0.20\,\mathrm{kg}
\end{aligned}$$

17.1.6

$$\begin{aligned}
0 &= m_I L_f + m_C c_C \Delta T \\
&= m_I L_f - m_C c_C T \\
T &= \frac{m_I L_f}{m_C c_C} \\
&= 14.0\,^\circ\mathrm{C}
\end{aligned}$$

17.1.7

$$\begin{aligned}
0 &= m_I L_F + m_I c_I \Delta T_I + m_E c_E \Delta T_E \\
&= m_I (L_F + c_I \Delta T_I) + m_E c_E \Delta T_E \\
m_I &= -\frac{m_E c_E \Delta T_E}{L_F + c_I \Delta T_I} \\
&= 0.176\,\mathrm{kg}
\end{aligned}$$

17.1.8

Cooling the silver to $0\,^\circ\mathrm{C}$ would take

$$Q = mc\Delta T = 92\,137.5\,\mathrm{J}$$

whereas melting all of the ice would take

$$Q = mL_f = 83\,500\,\mathrm{J}$$

so all of the ice will melt.

$$\begin{aligned}
0 &= m_{Ag}c_{Ag}\Delta T_{Ag} + m_I L_f + m_I c_I \Delta T_I + m_I c_W \Delta T_W \\
&= m_{Ag}c_{Ag}(T - T_{Ag}) + m_I L_F - m_I c_I T_I + m_I c_W T \\
&= (m_{Ag}c_{Ag} + m_I c_W)T - m_{Ag}c_{Ag}T_{Ag} + m_I L_F - m_I c_I T_I \\
T &= \frac{m_{Ag}c_{Ag}T_{Ag} + m_I c_I T_I - m_I L_F}{m_{Ag}c_{Ag} + m_I c_W} \\
&= 3.31\,^\circ\mathrm{C}
\end{aligned}$$

17.1.9

(a)

$$
\begin{aligned}
H &= kA\frac{T_H - T_C}{L} \\
k &= \frac{HL}{A(T_H - T_C)} \\
&= 0.754\,\mathrm{W/(m\,K)}
\end{aligned}
$$

(b)

$$
H = kA\frac{T_H - T_C}{L} = 733\,\mathrm{W}
$$

17.1.10

(a)

$$
\begin{aligned}
L &= 0.250\,\mathrm{m} \\
A &= 2.00 \times 10^{-4}\,\mathrm{m}^2 \\
k_B &= 109.0\,\mathrm{W/(m\,K)} \\
k_{Pb} &= 34.7\,\mathrm{W/(m\,K)} \\
T &= 185\,^\circ\mathrm{C} \\
H &= 6.00\,\mathrm{W}
\end{aligned}
$$

$$
\begin{aligned}
H &= k_B A\frac{T_H - T}{L} \\
T_H &= \frac{HL}{k_B A} + T \\
&= 254\,^\circ\mathrm{C}
\end{aligned}
$$

(b)

$$
\begin{aligned}
H &= k_{Pb} A\frac{T - T_C}{L} \\
T_C &= T - \frac{HL}{k_{Pb} A} \\
&= -31.1\,^\circ\mathrm{C}
\end{aligned}
$$

17.1.11

$$
\begin{aligned}
H &= 4\pi(kr_E)^2 e\sigma T^4 \\
(kr_E)^2 &= \frac{H}{4\pi e\sigma T^4} \\
k &= \frac{1}{r_E}\sqrt{\frac{H}{4\pi e\sigma T^4}} \\
&= 1.70
\end{aligned}
$$

17.1.12

(a)

$$
\begin{aligned}
H &= Ae\sigma T^4 \\
&= \pi r^2 \sigma T^4 \\
H &= kA\frac{T_H - T_C}{L} \\
&= k\pi r^2 \frac{T_H - T_C}{L} \\
\pi r^2 \sigma T^4 &= k\pi r^2 \frac{T_H - T_C}{L} \\
T_H &= \frac{L\sigma T^4}{k} + T_C \\
&= 14.26\,\mathrm{K}
\end{aligned}
$$

(b)

$$
\begin{aligned}
H &= mL_f \\
\pi r^2 \sigma T^4 &= mL_f \\
m &= \frac{\pi r^2 \sigma T^4}{L_f} \\
&= 1.19 \times 10^{-4}\,\mathrm{kg/s} \\
&= 0.427\,\mathrm{kg/h}
\end{aligned}
$$

17.2 Exercises and Problems

17.2.15

$$
\begin{aligned}
\Delta V &= \beta V_0 \Delta T \\
\frac{\Delta V}{V_0} &= \beta(T - T_0) \\
T &= T_0 + \frac{\Delta V}{\beta V_0} \\
&= 49\,^\circ\mathrm{C}
\end{aligned}
$$

17.2.25

$$
\begin{aligned}
Q &= (m_{Al}c_{Al} + m_W c_W)\Delta T \\
&= 5.55 \times 10^5\,\mathrm{J}
\end{aligned}
$$

17.2.33

$$
\begin{aligned}
\Delta K &= \frac{1}{2}mv^2 - \frac{1}{2}mv'^2 \\
&= \frac{1}{2}m(v^2 - v'^2) \\
&= 3.47\,\mathrm{kJ} \\
\Delta K &= mc\Delta T \\
\Delta T &= \frac{\Delta K}{mc} \\
&= 6.14 \times 10^{-2}\,{}^\circ\mathrm{C}
\end{aligned}
$$

17.2.35

(a)

$$
\begin{aligned}
0 &= m_m c_m \Delta T_m + m_w c_w \Delta T_w \\
c_m &= -\frac{m_w c_w \Delta T_w}{m_m \Delta T_m} \\
&= 215\,\mathrm{J/(kg\,K)}
\end{aligned}
$$

(b) Water because it has a higher specific heat

(c) It would be too small

17.2.45

$$
\begin{aligned}
\frac{1}{2}mv^2 &= mc\Delta T + mL_F \\
v &= \sqrt{2(c\Delta T + L_F)} \\
&= 366\,\mathrm{m/s}
\end{aligned}
$$

17.2.55

$$\begin{aligned}
k_C A \frac{T_H - T}{L} &= kA\frac{T}{L} \\
k_C T_H - k_C T &= kT \\
k_C T_H &= (k + k_C)T \\
T &= \frac{k_C}{k + k_C} T_H \\
0.71 &= \frac{k_C}{k + k_C} \\
0.71(k + k_C) &= k_C \\
0.71k + 0.71k_C &= k_C \\
0.71k &= 0.29k_C \\
k &= \frac{0.29}{0.71} k_C \\
&\approx 157\,\mathrm{W/(m\,K)}
\end{aligned}$$

17.2.57

(a)

$$\begin{aligned}
k_W \frac{T - T_C}{L_W} &= k_S \frac{T_H - T}{L_S} \\
\left(\frac{k_W}{L_W} + \frac{k_S}{L_S}\right) T &= \frac{k_S}{L_S} T_H + \frac{k_W}{L_W} T_C \\
T &= \frac{\frac{k_S}{L_S} T_H + \frac{k_W}{L_W} T_C}{\frac{k_W}{L_W} + \frac{k_S}{L_S}} \\
&= -0.86\,{}^\circ\mathrm{C}
\end{aligned}$$

(b)

$$\begin{aligned}
H &= k_W \frac{T - T_C}{L_W} \\
&= 24.4\,\mathrm{W/m^2}
\end{aligned}$$

17.2.65

$$\begin{aligned}
H &= Ae\sigma T^4 \\
A &= \frac{H}{e\sigma T^4} \\
&= 2.1\,\mathrm{cm^2}
\end{aligned}$$

17.2.69

$$\begin{aligned}\Delta L &= (\alpha_B L_B + \alpha_S L_S)\Delta T\\ T &= T_0 + \frac{\Delta L}{\alpha_B L_B + \alpha_S L_S}\\ &= 35.0\,^\circ\mathrm{C}\end{aligned}$$

17.2.71

$$\begin{aligned}Q &= mc\Delta T\\ &= \rho V c\Delta T\\ \Delta T &= \frac{Q}{\rho V c}\\ \Delta V &= \beta V \Delta T\\ &= \frac{\beta Q}{\rho c}\\ c &= \frac{\beta Q}{\rho \Delta V}\end{aligned}$$

17.2.73

(a)

$$\begin{aligned}0.0\,^\circ\mathrm{M} &= -39\,^\circ\mathrm{C}\\ 100.0\,^\circ\mathrm{M} &= 357\,^\circ\mathrm{C}\\ T_M &= \frac{T_C + 39\,^\circ\mathrm{C}}{3.96}\\ \frac{100\,^\circ\mathrm{C} + 39\,^\circ\mathrm{C}}{3.96} &= 35.1\,^\circ\mathrm{M}\end{aligned}$$

(b)

$$10\,\mathrm{M}^\circ = 10\frac{357\,^\circ\mathrm{C} - (-39\,^\circ\mathrm{C})}{100} = 39.6\,\mathrm{C}^\circ$$

17.2.75

$$\begin{aligned}Ah + \beta_G Ah(T - T_0) &= Ah' + \beta_O Ah'(T - T_0)\\ Ah + \beta_G AhT - \beta_G AhT_0 &= Ah' + \beta_O Ah'T - \beta_O Ah'T_0\\ (\beta_G Ah - \beta_O Ah')T &= (Ah' - \beta_O Ah'T_0) - (Ah - \beta_G AhT_0)\\ T &= \frac{(1 - \beta_O T_0)h' - (1 - \beta_G T_0)h}{\beta_G h - \beta_O h'}\\ &= 69.4\,^\circ\mathrm{C}\end{aligned}$$

17.2.79

(a)

$$\begin{aligned}
Y &= \frac{F/A}{\Delta L/L_0} \\
\Delta L &= \frac{FL_0}{AY} \\
\Delta L &= \alpha L_0 \Delta T \\
\Delta L &= \alpha L_0 \Delta T + \frac{FL_0}{AY} \\
\frac{F}{A} &= Y\left(\frac{\Delta L}{L_0} - \alpha \Delta T\right)
\end{aligned}$$

(b)

$$\begin{aligned}
\Delta L_B &= \alpha_B L_{B0} \Delta T \\
\frac{\Delta L_B}{L_{B0}} &= \alpha_B \Delta T \\
\frac{F}{A} &= Y_S(\alpha_B - \alpha_S)\Delta T \\
&= 1.9 \times 10^8\,\mathrm{Pa}
\end{aligned}$$

17.2.85

(a)

$$\begin{aligned}
\frac{dQ}{dT} &= nk\frac{T^3}{\theta^3} \\
Q &= \int_a^b nk\frac{T^3}{\theta^3} \\
&= \frac{nk}{\theta^3}\left[\frac{1}{4}T^4\right]_a^b \\
&= \frac{nk}{4\theta^3}(b^4 - a^4) \\
&= 83.6\,\mathrm{J}
\end{aligned}$$

(b)

$$\begin{aligned}
Q &= nC\Delta T \\
C &= \frac{Q}{n\Delta T} \\
&= 1.86\,\mathrm{J/(mol\,K)}
\end{aligned}$$

(c)

$$C = 5.60\,\mathrm{J/(mol\,K)}$$

17.2.95

(a)

$$\begin{aligned}
0 &= m_I L_f + m_I c_W \Delta T_I + m_C c_C \Delta T_I - m_S L_v + m_S c_W \Delta T_S \\
&= m_I L_f + m_I c_W T + m_C c_C T - m_S L_v + m_S c_W (T - T_S) \\
T &= \frac{m_S (L_v + c_W T_S) - m_I L_f}{m_I c_W + m_C c_C + m_S c_W} \\
&= 86.1\,^\circ\mathrm{C}
\end{aligned}$$

(b) No ice, 0.13 kg water, no steam

17.2.99

(a)

$$\begin{aligned}
H &= kA \frac{T_H - T_C}{L} \\
&= 94\,\mathrm{W}
\end{aligned}$$

(b)

$$\begin{aligned}
H_{\text{wood}} &= 12.4\,\mathrm{W} \\
H_{\text{glass}} &= 45.0\,\mathrm{W} \\
H' &= H + (H_{\text{glass}} - H_{\text{wood}}) \\
&= 126.6\,\mathrm{W} \\
\frac{H'}{H} &= 1.35
\end{aligned}$$

17.2.105

(b)

$$
\begin{aligned}
\frac{dQ}{dt} &= k\frac{T_H - T_C}{L} \\
\frac{dQ}{dL} &= \rho L_f \\
\frac{dL}{dt} &= \frac{dL}{dQ}\frac{dQ}{dt} \\
&= \frac{1}{\rho L_f} k \frac{T_H - T_C}{L} \\
L\frac{dL}{dt} &= \frac{k(T_H - T_C)}{\rho L_f} \\
\int_0^t L\frac{dL}{dt}\,dt &= \int_0^t \frac{k(T_H - T_C)}{\rho L_f}\,dt \\
\int_0^L L'\,dL' &= \frac{k(T_H - T_C)}{\rho L_f} t \\
\frac{1}{2}L^2 &= \frac{k(T_H - T_C)}{\rho L_f} t \\
L &= \sqrt{\frac{2k(T_H - T_C)}{\rho L_f} t}
\end{aligned}
$$

(c)

$$
\begin{aligned}
t &= \frac{L^2 \rho L_f}{2k(T_H - T_C)} \\
&= 7.5\,\text{days}
\end{aligned}
$$

(d) $t \approx 530\,\text{years}$; no

17.2.107

$$\begin{aligned}
A &= 2\pi \left(\frac{d}{2}\right)^2 + 2\pi \left(\frac{d}{2}\right) h \\
&= 8.34 \times 10^{-2}\,\mathrm{m}^2 \\
H &= Ae\sigma(T^4 - T_s^4) \\
&= Ae\sigma(T^4 - T_s^4) \\
&= -3.38 \times 10^{-2}\,\mathrm{W} \\
m &= \frac{H \times 60 \times 60}{L_v} \\
&= 5.82 \times 10^{-3}\,\mathrm{kg/h} \\
&= 5.82\,\mathrm{g/h}
\end{aligned}$$

17.2.113

$$\begin{aligned}
r(x) &= R_2 - (R_2 - R_1)\frac{x}{L} \\
A(x) &= \pi r(x)^2 \\
&= \pi \left[R_2 - (R_2 - R_1)\frac{x}{L}\right]^2 \\
H &= kA(x)\frac{dT}{dx} \\
&= k\pi \left[R_2 - (R_2 - R_1)\frac{x}{L}\right]^2 \frac{dT}{dx} \\
\frac{1}{\left[R_2 - (R_2 - R_1)\frac{x}{L}\right]^2} H\,dx &= k\pi\,dT \\
\int_0^L \frac{1}{\left[R_2 - (R_2 - R_1)\frac{x}{L}\right]^2} H\,dx &= \int_{T_H}^{T_C} k\pi\,dT \\
\frac{HL}{R_2 - R_1}\left[\frac{1}{R_2 - (R_2 - R_1)\frac{x}{L}}\right]_0^L &= k\pi(T_C - T_H) \\
\frac{HL}{R_2 - R_1}\left(\frac{1}{R_1} - \frac{1}{R_2}\right) &= k\pi(T_C - T_H) \\
\frac{HL}{R_2 - R_1}\frac{R_2 - R_1}{R_1 R_2} &= k\pi(T_C - T_H) \\
H &= \frac{k\pi R_1 R_2 (T_C - T_H)}{L}
\end{aligned}$$

17.2.115

(a)

$$
\begin{aligned}
H &= k(2\pi r L)\frac{dT}{dr} \\
\frac{1}{r}H\,dr &= 2\pi k L\,dT \\
\int_a^b \frac{1}{r}H\,dr &= \int_{T_1}^{T_2} 2\pi k L\,dT \\
H\ln\frac{b}{a} &= 2\pi k L(T_2 - T_1) \\
H &= \frac{2\pi k L(T_2 - T_1)}{\ln b/a}
\end{aligned}
$$

(b)

$$
\begin{aligned}
\frac{2\pi k L(T - T_2)}{\ln r/a} &= \frac{2\pi k L(T_2 - T_1)}{\ln b/a} \\
\frac{T - T_2}{\ln r/a} &= \frac{T_2 - T_1}{\ln b/a} \\
T - T_2 &= \frac{\ln r/a}{\ln b/a}(T_2 - T_1) \\
T &= T_2 + \frac{\ln r/a}{\ln b/a}(T_2 - T_1)
\end{aligned}
$$

17.2.117

a

17.2.119

a

18 Thermal Properties of Matter

18.1 Guided Practice

18.1.1

(a)

$$\begin{aligned}
pV &= nRT \\
\frac{p}{T} &= \frac{nR}{V} \\
\frac{p_1}{T_1} &= \frac{p_2}{T_2} \\
p_2 &= p_1 \frac{T_2}{T_1} \\
&= 4.67 \times 10^5\,\mathrm{Pa}
\end{aligned}$$

(b)

$$\begin{aligned}
pV &= nRT \\
n &= \frac{pV}{RT} \\
&= 0.280\,\mathrm{mol}
\end{aligned}$$

18.1.2

(a)

$$\begin{aligned}
pV &= nRT \\
\frac{p_1 V_1}{T_1} &= \frac{p_2 V_2}{T_2} \\
V_2 &= \frac{V_1 p_1 T_2}{p_2 T_1} \\
&= 1.2 \times 10^3\,\mathrm{m}^3
\end{aligned}$$

(b)

$$\begin{aligned}
\frac{V_2}{V_1} &= \frac{\frac{4}{3}\pi r_2^3}{\frac{4}{3}\pi r_1^3} \\
&= \left(\frac{r_2}{r_1}\right)^3 \\
\frac{r_2}{r_1} &= \sqrt[3]{\frac{V_2}{V_1}} \\
&= 4.5
\end{aligned}$$

18.1.3

(a)

$$\begin{aligned}
pV &= nRT \\
n &= \frac{pV}{RT} \\
&= 2.9 \times 10^{-3}\,\mathrm{mol/m^3}
\end{aligned}$$

(b)

$$8.0 \times 10^{-5}\,\mathrm{kg/m^3}$$

18.1.4

(a)

$$\begin{aligned}
pV &= \frac{m_{\mathrm{total}}}{M} RT \\
\frac{p}{\rho T} &= \frac{R}{M} \\
\frac{p_1}{\rho_1 T_1} &= \frac{p_2}{\rho_2 T_2} \\
&= \frac{p_2}{\rho_1 (p_2/p_1)^{3/5} T_2} \\
T_2 &= \left(\frac{p_2}{p_1}\right)^{2/5} T_1
\end{aligned}$$

(b)

$$\begin{aligned}
\frac{\rho_2}{\rho_1} &= \frac{\rho_1 (p_2/p_1)^{3/5}}{\rho_1} \\
&= \left(\frac{\frac{1}{2}p_1}{p_1}\right)^{3/5} \\
&= \left(\frac{1}{2}\right)^{3/5} \\
&\approx 0.660 \\
\frac{T_2}{T_1} &= \frac{(p_2/p_1)^{2/5} T_1}{T_1} \\
&= \left(\frac{\frac{1}{2}p_1}{p_1}\right)^{2/5} \\
&= \left(\frac{1}{2}\right)^{2/5} \\
&\approx 0.758
\end{aligned}$$

(c)

$$\frac{\rho_2}{\rho_1} = 2^{3/5}$$
$$\approx 1.52$$
$$\frac{T_2}{T_1} = 2^{2/5}$$
$$\approx 1.32$$

18.1.5

$$\sqrt{\frac{3RT}{M_{\mathrm{H}}}} = \sqrt{\frac{3RT_{\mathrm{N}}}{M_{\mathrm{N}}}}$$
$$T = \frac{M_{\mathrm{H}}}{M_{\mathrm{N}}} T_{\mathrm{N}}$$
$$= 41.9\,\mathrm{K}$$
$$= -231\,^{\circ}\mathrm{C}$$

18.1.6

(a)

$$K_{\mathrm{tr}} = \frac{3}{2} kT = 6.21 \times 10^{-20}\,\mathrm{J}$$

(b)

$$v_{\mathrm{rms}} = \sqrt{\frac{3RT}{M}} = 8.63 \times 10^{3}\,\mathrm{m/s}$$

18.1.7

(a)

$$pV = \frac{N}{N_A} RT$$
$$N = \frac{N_A pV}{RT}$$
$$= 1.50 \times 10^{27}$$

(b)

$$K_{\mathrm{tr}} = \frac{3}{2} nRT = 9.11 \times 10^{6}\,\mathrm{J}$$

(c)

$$\begin{aligned}\frac{1}{2}mv^2 &= K_{\text{tr}}\\ v &= \sqrt{\frac{2K_{\text{tr}}}{m}}\\ &= 110\,\text{m/s}\end{aligned}$$

18.1.8

(a) 5.5

(b) 38.5

(c) 6.2

18.1.9

(a)

$$\lambda = \frac{kT}{4\pi\sqrt{2}r^2p} = 6.8\times10^{-6}\,\text{m}$$

(b)

$$\begin{aligned}\lambda_{\text{Earth}} &= 5.54\times10^{-8}\,\text{m}\\ \frac{\lambda_{\text{Mars}}}{\lambda_{\text{Earth}}} &= 1.2\times10^{2}\end{aligned}$$

18.1.10

(a)

$$\begin{aligned}\lambda &= \frac{kT}{4\pi\sqrt{2}r^2p}\\ p &= \frac{kT}{4\pi\sqrt{2}r^2\lambda}\\ &= 5.7\times10^{-3}\,\text{Pa}\end{aligned}$$

(b)

$$\begin{aligned}pV &= nRT\\ n &= \frac{pV}{RT}\\ &= 2.3\times10^{-6}\,\text{mol}\end{aligned}$$

18.1.11

(a)

$$\begin{aligned}
pV &= nRT \\
p &= \frac{nRT}{V} \\
&= 2.0 \times 10^{7}\,\mathrm{Pa} \\
\lambda &= \frac{kT}{4\pi\sqrt{2}r^2 p} \\
&= 1.2 \times 10^{-8}\,\mathrm{m}
\end{aligned}$$

(b)

$$\begin{aligned}
v_{\mathrm{rms}} &= \sqrt{\frac{3RT}{M}} \\
&= 1.4 \times 10^{3}\,\mathrm{m/s} \\
\lambda &= v t_{\mathrm{mean}} \\
t_{\mathrm{mean}} &= \frac{\lambda}{v} \\
&= 8.6 \times 10^{-12}\,\mathrm{s}
\end{aligned}$$

18.1.12

(a)

$$\begin{aligned}
v_{\mathrm{rms}} t_{\mathrm{mean}} &= \lambda \\
\sqrt{\frac{3kT}{m}} t_{\mathrm{mean}} &= \frac{kT}{4\pi\sqrt{2}r^2 p} \\
t_{\mathrm{mean}} &= \frac{kT}{4\pi\sqrt{2}r^2 p}\sqrt{\frac{m}{3kT}} \\
&= \frac{1}{4\pi r^2 p}\sqrt{\frac{mkT}{6}}
\end{aligned}$$

(b) Doubling r.

18.1.13

(a)

$$\begin{aligned}
v_{\text{rms}} &= \sqrt{\frac{3RT}{M}} \\
&= 515\,\text{m/s} \\
\frac{1}{2}mv_{\text{rms}}^2 &= mgh \\
h &= \frac{v_{\text{rms}}^2}{2g} \\
&= 102\,\text{km}
\end{aligned}$$

(b)

$$\begin{aligned}
&\int_{2025}^{\infty} 4\pi \left(\frac{m}{2\pi kT}\right)^{3/2} v^2 e^{-mv^2/2kT}\,dv \\
&= (3.03\times 10^{-8}) \int_{2025}^{\infty} v^2 e^{-(5.65\times 10^{-6})v^2}\,dv \\
&= 4.8\times 10^{-10}
\end{aligned}$$

Yes, some escape.

18.2 Exercises and Problems

18.2.7

$$\begin{aligned}
pV &= nRT \\
\frac{p_1V_1}{T_1} &= \frac{p_2V_2}{T_2} \\
T_2 &= \frac{p_2V_2T_1}{p_1V_1} \\
&= 776\,\text{K} \\
&= 503\,^\circ\text{C}
\end{aligned}$$

18.2.9

$$\begin{aligned}
pV &= nRT \\
\frac{p_1V_1}{T_1} &= \frac{p_2V_2}{T_2} \\
p_2 &= \frac{p_1V_1T_2}{T_1V_2} \\
&= 1.97\times 10^4\,\text{Pa}
\end{aligned}$$

18.2.13

$$\begin{aligned} \frac{p_1V_1}{T_1} &= \frac{p_2V_2}{T_2} \\ V_2 &= \frac{p_1T_2}{T_1p_2}V_1 \\ &= (5.08 \times 10^{-2})V_1 \end{aligned}$$

18.2.17

(a)

$$\begin{aligned} pV &= \frac{m_{\text{total}}}{M}RT \\ m_{\text{total}} &= \frac{pVM}{RT} \\ &= 6.91 \times 10^{-16}\,\text{kg} \end{aligned}$$

(b)

$$\rho = \frac{m_{\text{total}}}{V} = 2.30 \times 10^{-13}\,\text{kg/m}^3$$

18.2.21

(a)

$$\begin{aligned} pV &= \frac{N}{N_A}RT \\ N &= \frac{pVN_A}{RT} \\ &= 2.19 \times 10^6 \end{aligned}$$

(b)

$$2.44 \times 10^{19}$$

18.2.23

(a)

$$
\begin{aligned}
pV &= \frac{N}{N_A}RT \\
\frac{V}{N} &= \frac{RT}{N_A p} \\
s &= \sqrt[3]{\frac{V}{N}} \\
&= \sqrt[3]{\frac{RT}{N_A p}} \\
&= 3.45 \times 10^{-9}\,\mathrm{m}
\end{aligned}
$$

18.2.25

(a)

$$
\begin{aligned}
K_{\mathrm{tr}} &= \frac{3}{2}nRT \\
&= \frac{3}{2}pV \\
&= 5.82 \times 10^{7}\,\mathrm{J}
\end{aligned}
$$

(b)

$$
\begin{aligned}
\frac{1}{2}mv^2 &= K_{\mathrm{tr}} \\
v &= \sqrt{\frac{2K_{\mathrm{tr}}}{m}} \\
&= 241\,\mathrm{m/s}
\end{aligned}
$$

18.2.27

$$
\begin{aligned}
pV &= nRT \\
p &= \frac{nR}{V}T \\
\frac{nR}{V} &= m \\
n &= \frac{mV}{R} \\
&= 1.07\,\mathrm{mol} \\
N &= nN_A \\
&= 6.44 \times 10^{23}
\end{aligned}
$$

18.2.29

(a)

$$\begin{aligned} v_{\mathrm{rms}} &= \sqrt{\frac{3kT}{m}} \\ &= 1.93 \times 10^{6}\,\mathrm{m/s} \\ &= 0.006c \end{aligned}$$

Not a significant fraction of c.

(b)

$$\begin{aligned} 0.10c &= \sqrt{\frac{3kT}{m}} \\ (0.10c)^2 &= \frac{3kT}{m} \\ T &= \frac{(0.10c)^2 m}{3k} \\ &= 7.26 \times 10^{10}\,\mathrm{K} \end{aligned}$$

18.2.31

(a)

$$\frac{3}{2}kT = 6.21 \times 10^{-21}\,\mathrm{J}$$

(b)

$$(v^2)_{\mathrm{av}} = \frac{2}{m}\left(\frac{3}{2}kT\right) = 2.34 \times 10^{5}\,(\mathrm{m/s})^2$$

(c)

$$v_{\mathrm{rms}} = \sqrt{(v^2)_{\mathrm{av}}} = 484\,\mathrm{m/s}$$

(d)

$$p = mv = \frac{M}{N_A}v = 2.57 \times 10^{-23}\,\mathrm{kg\,m/s}$$

(e)

$$\begin{aligned} \Delta P &= 2P \\ &= 5.14 \times 10^{-23}\,\mathrm{kg\,m/s} \\ \Delta t &= \frac{2l}{v} \\ &= 4.13 \times 10^{-4}\,\mathrm{s} \\ F_{\mathrm{av}} &= \frac{\Delta P}{\Delta t} \\ &= 1.24 \times 10^{-19}\,\mathrm{N} \end{aligned}$$

(f)

$$p_{\text{av}} = \frac{F_{\text{av}}}{A} = 1.24 \times 10^{-17}\,\text{Pa}$$

(g)

$$\begin{aligned} p &= N p_{\text{av}} \\ N &= \frac{p}{p_{\text{av}}} \\ &= 8.15 \times 10^{21} \end{aligned}$$

(h)

$$\begin{aligned} pV &= \frac{N}{N_A} RT \\ N &= \frac{pVN_A}{RT} \\ &= 2.44 \times 10^{22} \end{aligned}$$

18.2.33

$$\begin{aligned} \sqrt{\frac{3RT}{M_{\text{N}}}} &= \sqrt{\frac{3RT_{\text{H}}}{M_{\text{H}}}} \\ T &= \frac{M_{\text{N}}}{M_{\text{H}}} T_{\text{H}} \\ &= 4074\,\text{K} \\ &= 3800\,^{\circ}\text{C} \end{aligned}$$

18.2.35

$$
\begin{aligned}
C_V &= \frac{5}{2}R \\
v_{\mathrm{rms}} &= \sqrt{\frac{3RT}{M}} \\
T &= \frac{Mv_{\mathrm{rms}}^2}{3R} \\
Q &= nC_V\Delta T \\
\Delta T &= \frac{Q}{nC_V} \\
v'_{\mathrm{rms}} &= \sqrt{\frac{3R(T+\Delta T)}{M}} \\
&= \sqrt{\frac{3R\left(\frac{Mv_{\mathrm{rms}}^2}{3R}+\frac{Q}{nC_V}\right)}{M}} \\
&= \sqrt{v_{\mathrm{rms}}^2+\frac{3RQ}{Mn\frac{5}{2}R}} \\
&= \sqrt{v_{\mathrm{rms}}^2+\frac{6Q}{5Mn}} \\
&= 1.02\times 10^3\,\mathrm{m/s}
\end{aligned}
$$

18.2.39

(a)

$$
\begin{aligned}
c_{V,\mathrm{N}} &= \frac{5}{2}R \\
&= 742\,\mathrm{J/(kg\,K)} \\
c_{V,\mathrm{water}} &= 4190\,\mathrm{J/(kg\,K)} \\
&= 5.6C_{V,\mathrm{N}}
\end{aligned}
$$

(b)

$$\begin{aligned}
Q &= mc_{V,\text{water}}\Delta T \\
&= 4.19\times 10^4\,\text{J} \\
m &= \frac{Q}{c_{V,\text{N}}\Delta T} \\
&= 5.65\,\text{kg} \\
pV &= \frac{m_{\text{total}}}{M}RT \\
V &= \frac{m_{\text{total}}RT}{Mp} \\
&= 4.87\,\text{m}^3 \\
&= 4.87\times 10^3\,\text{L}
\end{aligned}$$

18.2.41

(a)

$$v_{\text{mp}} = \sqrt{\frac{2kT}{m}} = 337\,\text{m/s}$$

(b)

$$v_{\text{av}} = 380\,\text{m/s}$$

(c)

$$v_{\text{rms}} = 412\,\text{m/s}$$

18.2.43

(a)

$$\frac{v_{\text{rms}}}{v} = \sqrt{\frac{3RT}{M}}\sqrt{\frac{M}{\gamma RT}} = \sqrt{\frac{3}{\gamma}} = 1.34$$

(b)

$$\frac{v_{\text{av}}}{v} = \sqrt{\frac{8RT}{\pi M}}\sqrt{\frac{M}{\gamma RT}} = \sqrt{\frac{8}{\pi\gamma}} = 1.23$$

18.2.45

(a) The minimum pressure is $p_1 = 611.657\,\text{Pa}$. If $p < p_1$ the ice sublimates directly to gas.

(b) The maximum pressure is $p_2 = 2.212\times 10^7\,\text{Pa}$. The ice melts to water, then the properties of the water gradually change to those of steam with no phase transition.

18.2.49

(a)

$$\begin{aligned} p' - p &= -\rho g h \\ &= -1.18 \times 10^4\,\mathrm{Pa} \end{aligned}$$

(b)

$$\begin{aligned} p_1 V_1 &= p_2 V_2 \\ V_2 &= \frac{p_1}{p_2} V_1 \\ &= 0.56\,\mathrm{L} \end{aligned}$$

18.2.51

$$\begin{aligned} 0 &= \rho_{\mathrm{cold}} V g - \rho_{\mathrm{hot}} V g - m g \\ &= \rho_{\mathrm{cold}} V - \rho_{\mathrm{hot}} V - m \\ \rho_{\mathrm{hot}} &= \rho_{\mathrm{cold}} - \frac{m}{V} \\ \frac{Mp}{RT} &= \rho_{\mathrm{cold}} - \frac{m}{V} \\ T &= \frac{Mp}{R(\rho_{\mathrm{cold}} - m/V)} \\ &= 542\,\mathrm{K} \\ &= 269\,^\circ\mathrm{C} \end{aligned}$$

18.2.53

$$\begin{aligned} pV &= \frac{m_{\mathrm{total}}}{M} RT \\ m_{\mathrm{total}} &= \frac{pVM}{RT} \\ &= 0.285\,\mathrm{kg} \\ m'_{\mathrm{total}} &= 0.0896\,\mathrm{kg} \\ \Delta m &= 0.195\,\mathrm{kg} \end{aligned}$$

18.2.57

(a)

$$\begin{aligned}0 &= \rho V g - (m_{\text{adventurer}} + m_{\text{bell}} + m_{\text{water}})g \\ &= \rho V - m_{\text{adventurer}} - m_{\text{bell}} - m_{\text{water}} \\ m_{\text{water}} &= \rho V - m_{\text{adventurer}} - m_{\text{bell}} \\ &= 98\,\text{kg} \\ V_{\text{water}} &= \frac{m_{\text{water}}}{\rho_{\text{water}}} \\ &= 0.0956\,\text{m}^3\end{aligned}$$

(b)

$$\begin{aligned}pV &= nRT \\ p &= \frac{nRT}{V} \\ p &= \rho g y \\ \rho g y &= \frac{nRT}{V} \\ n &= \frac{\rho g V}{RT} y \\ \frac{dn}{dt} &= \frac{\rho g V}{RT}\frac{dy}{dt} \\ &= 18.2\,\text{mol/s}\end{aligned}$$

(c)

$$\begin{aligned}pV &= nRT \\ n &= \frac{pV}{RT} \\ &= 756\,\text{mol} \\ \frac{n}{dn/dt} &= 41.5\,\text{m}\end{aligned}$$

18.2.59

(a)

$$
\begin{aligned}
pV &= nRT \\
n_{\text{balloon}} &= \frac{pV}{RT} \\
&= (9.11 \times 10^6)\frac{1}{T} \\
n_{\text{cylinder}} &= \frac{pV}{RT} \\
&= (2.97 \times 10^5)\frac{1}{T} \\
\frac{n_{\text{balloon}}}{n_{\text{cylinder}}} &= 30.7
\end{aligned}
$$

(b)

$$
\begin{aligned}
0 &= \rho V g - Mng - mg \\
mg &= (\rho V - Mn)g \\
&= 8420\,\mathrm{N}
\end{aligned}
$$

(c)

$$
mg = 7810\,\mathrm{N}
$$

18.2.67

(c)

$$U(r) = U_0 \left[\left(\frac{R_0}{r} \right)^{12} - 2 \left(\frac{R_0}{r} \right)^{6} \right]$$

$$F(r) = 12 \frac{U_0}{R_0} \left[\left(\frac{R_0}{r} \right)^{13} - \left(\frac{R_0}{r} \right)^{7} \right]$$

$$\begin{aligned}
0 &= U_0 \left[\left(\frac{R_0}{r_1} \right)^{12} - 2 \left(\frac{R_0}{r_1} \right)^{6} \right] \\
&= \left(\frac{R_0}{r_1} \right)^{12} - 2 \left(\frac{R_0}{r_1} \right)^{6} \\
&= \left(\frac{R_0}{r_1} \right)^{6} - 2 \\
2 &= \left(\frac{R_0}{r_1} \right)^{6} \\
2r_1^6 &= R_0^6 \\
r_1 &= \frac{1}{\sqrt[6]{2}} R_0 \\
&\approx 0.89 R_0
\end{aligned}$$

$$\begin{aligned}
0 &= 12 \frac{U_0}{R_0} \left[\left(\frac{R_0}{r_2} \right)^{13} - \left(\frac{R_0}{r_2} \right)^{7} \right] \\
0 &= \left(\frac{R_0}{r_2} \right)^{13} - \left(\frac{R_0}{r_2} \right)^{7} \\
&= \left(\frac{R_0}{r_2} \right)^{6} - 1 \\
r_2 &= R_0
\end{aligned}$$

$$\frac{r_1}{r_2} = \frac{1}{\sqrt[6]{2}}$$

(d)

$$\begin{aligned}
W &= \int_{r_2}^{\infty} -F\,dr \\
&= \int_{R_0}^{\infty} -12\frac{U_0}{R_0}\left[\left(\frac{R_0}{r}\right)^{13} - \left(\frac{R_0}{r}\right)^{7}\right] dr \\
&= -12\frac{U_0}{R_0}\left(-\frac{R_0}{12}\right) \\
&= U_0
\end{aligned}$$

18.2.69

(a)

$$C_V = 2R = 16.63\,\mathrm{J/(mol\,K)}$$

(b) Less than because vibrational energy will play a smaller role.

18.2.71

(a)

$$\begin{aligned}
\frac{1}{2}mv^2 &\geq \frac{GmM}{R_p} \\
&\geq gmR_p
\end{aligned}$$

(b)

$$\begin{aligned}
\frac{3}{2}kT &\geq mgR_p \\
T_\mathrm{N} &\geq \frac{2mgR_p}{3k} \\
&\geq 1.40 \times 10^5\,\mathrm{K} \\
T_\mathrm{H} &\geq 1.02 \times 10^4\,\mathrm{K}
\end{aligned}$$

(c)

$$\begin{aligned}
T_\mathrm{N} &\geq 6.37 \times 10^3\,\mathrm{K} \\
T_\mathrm{H} &\geq 459\,\mathrm{K}
\end{aligned}$$

(d) Because it's very easy to atmospheric particles to escape.

18.2.73

$$
\begin{aligned}
\int_0^\infty v^2 f(v)\,dv &= 4\pi\left(\frac{m}{2\pi kT}\right)^{3/2}\int_0^\infty v^4 e^{-mv^2/2kT}\,dv \\
&= 4\pi\left(\frac{m}{2\pi kT}\right)^{3/2}\frac{3}{2^3(m/2kT)^2}\sqrt{\frac{\pi}{(m/2kT)}} \\
&= 4\pi\left(\frac{m}{2\pi kT}\right)^{3/2}\frac{3}{8}\left(\frac{2kT}{m}\right)^2\sqrt{\frac{2\pi kT}{m}} \\
&= \frac{3kT}{m}
\end{aligned}
$$

18.2.75

(b)

$$
\begin{aligned}
v_{\mathrm{mp}} &= \sqrt{\frac{2kT}{m}} \\
&= 395\,\mathrm{m/s} \\
f(v_{\mathrm{mp}}) &= 2.10\times 10^{-3} \\
\Delta N &\approx N f(v_{\mathrm{mp}})\Delta v \\
&\approx (4.20\times 10^{-2})N
\end{aligned}
$$

(c)

$$
\begin{aligned}
7v_{\mathrm{mp}} &= 2765\,\mathrm{m/s} \\
f(7v_{\mathrm{mp}}) &= 1.43\times 10^{-22} \\
\Delta N &\approx (2.85\times 10^{-21})N
\end{aligned}
$$

18.2.77

(a)

$$
\begin{aligned}
0 &= pA - p_0A - mg \\
p &= p_0 + \frac{mg}{A} \\
&= p_0 + \frac{mg}{\pi r^2}
\end{aligned}
$$

(b)

$$\begin{aligned}
p_1V_1 &= p_2V_2 \\
p_2 &= \frac{V_1}{V_2}p_1 \\
&= \frac{Ah}{A(h+y)}p_1 \\
&= \frac{h}{h+y}p_1 \\
&\approx \left(1-\frac{y}{h}\right)p_1 \\
F &= \left(1-\frac{y}{h}\right)p_1\pi r^2 - p_0\pi r^2 - mg \\
&= \left(1-\frac{y}{h}\right)\left(p_0+\frac{mg}{\pi r^2}\right)\pi r^2 - p_0\pi r^2 - mg \\
&= \left(1-\frac{y}{h}\right)(p_0\pi r^2 + mg) - p_0\pi r^2 - mg \\
&= -\frac{y}{h}(p_0\pi r^2 + mg)
\end{aligned}$$

(c)

$$\begin{aligned}
F &= -kx \\
k &= \frac{1}{h}(p_0\pi r^2 + mg) \\
\omega &= \sqrt{\frac{k}{m}} \\
&= \sqrt{\frac{1}{h}\left(\frac{p_0\pi r^2}{m}+g\right)} \\
f &= \frac{\omega}{2\pi} \\
&= \frac{1}{2\pi}\sqrt{\frac{g}{h}\left(1+\frac{p_0\pi r^2}{gm}\right)}
\end{aligned}$$

If the displacement is not small the oscillation is not simple harmonic because we can't use the approximation $\frac{h}{h+y} \approx 1-\frac{y}{h}$.

18.2.81

(a)

$$I = 2mr^2 = 4.1 \times 10^{-46}\,\mathrm{kg\,m^2}$$

(b)

$$
\begin{aligned}
2\left(\frac{1}{2}(2m)v_i^2\right) &= 2\left(\frac{1}{2}(2m)v_f^2 + \frac{1}{2}I\omega^2\right) \\
2mv_i^2 &= 2mv_f^2 + 2mr^2\omega^2 \\
v_i^2 &= v_f^2 + r^2\omega^2
\end{aligned}
$$

$$
\begin{aligned}
-2r(2m)v_i &= -2I\omega \\
2mrv_i &= 2mr^2\omega \\
v_i &= r\omega
\end{aligned}
$$

(c)

$$\omega = \frac{v_i}{r}$$

$$
\begin{aligned}
v_i^2 &= v_f^2 + r^2\left(\frac{v_i}{r}\right)^2 \\
v_f &= 0
\end{aligned}
$$

(d)

$$
\begin{aligned}
v_{\text{rms}} &= \sqrt{\frac{3kT}{m}} \\
&= 514\,\text{m/s} \\
\omega &= 5.47 \times 10^{12}\,\text{rad/s}
\end{aligned}
$$

18.2.83

(a)

$$
\begin{aligned}
\lambda &= \frac{V}{4\pi\sqrt{2}r^2N} \\
&= 4.50 \times 10^{11}\,\text{m}
\end{aligned}
$$

(b)

$$
\begin{aligned}
v_{\text{rms}} &= \sqrt{\frac{3kT}{m}} \\
&= 704\,\text{m/s} \\
t_{\text{mean}} &= \frac{\lambda}{v_{\text{rms}}} \\
&= 6.39 \times 10^{8}\,\text{s} \\
&= 20\,\text{years}
\end{aligned}
$$

(c)

$$
\begin{aligned}
pV &= NkT \\
p &= \frac{NkT}{V} \\
&= 1.38 \times 10^{-14}\,\mathrm{Pa}
\end{aligned}
$$

(d)

$$
\begin{aligned}
m_{\mathrm{total}} &= \rho V \\
&= \rho \frac{4}{3}\pi \left(\frac{d}{2}\right)^3 \\
&= 2.96 \times 10^{32}\,\mathrm{kg}
\end{aligned}
$$

$$
\begin{aligned}
\frac{1}{2}mv^2 &= \frac{Gmm_{\mathrm{total}}}{r} \\
v &= \sqrt{\frac{4Gm_{\mathrm{total}}}{d}} \\
&= 640\,\mathrm{m/s}
\end{aligned}
$$

It would evaporate.

(f)

$$
\begin{aligned}
T_{\mathrm{ISM}} &= \frac{(N/V)_{\mathrm{nebula}}}{(N/V)_{\mathrm{ISM}}} T_{\mathrm{nebula}} \\
&= 2.0 \times 10^{5}\,\mathrm{K}
\end{aligned}
$$

34 times hotter than the sun.

18.2.85

a

18.2.87

c

19 The First Law of Thermodynamics

19.1 Guided Practice

19.1.1

(a)

$$\begin{aligned}\Delta U &= Q - W \\ Q &= \Delta U + W \\ &= 5.75 \times 10^3\,\mathrm{J}\end{aligned}$$

(b)

$$\begin{aligned}\Delta U &= Q - W \\ &= -3.2 \times 10^4\,\mathrm{J}\end{aligned}$$

(c)

$$\begin{aligned}\Delta U &= Q - W \\ W &= Q - \Delta U \\ &= -1.85 \times 10^3\,\mathrm{J}\end{aligned}$$

19.1.2

(a)

$$W = p(V_2 - V_1) = 155\,\mathrm{J}$$

(b)

$$W = 0$$

(c)

$$W = p(V_2 - V_1) = -375\,\mathrm{J}$$

(d)

$$W = \frac{1}{2}(p_1 + p_2)(V_2 - V_1) = 875\,\mathrm{J}$$

19.1.3

(a)

$$\begin{aligned}W &= p(V_2 - V_1) \\ &= -240\,\mathrm{J} \\ \Delta U &= Q - W \\ &= 1.80 \times 10^3\,\mathrm{J}\end{aligned}$$

(b)

$$\begin{aligned}
W &= p(V_2 - V_1) \\
&= -720\,\mathrm{J} \\
\Delta U &= Q - W \\
Q &= \Delta U + W \\
&= 1.08 \times 10^3\,\mathrm{J}
\end{aligned}$$

19.1.4

(a)

$$Q = mL = 3.43 \times 10^6\,\mathrm{J}$$

(b)

$$W = p(V_2 - V_1) = 3.43 \times 10^5\,\mathrm{J}$$

(c)

$$\Delta U = Q - W = 3.09 \times 10^6\,\mathrm{J}$$

19.1.5

(a)

$$\Delta U = \Delta Q = nC_V \Delta T = 998\,\mathrm{J}$$

(b)

$$\Delta U = \Delta Q = nC_V \Delta T = 748\,\mathrm{J}$$

(c)

$$\Delta U = \Delta Q = nC_V \Delta T = 599\,\mathrm{J}$$

19.1.6

(a)

$$V = \frac{nRT}{p} = 5.24 \times 10^{-2}\,\mathrm{m}^3$$

(b) (i)

$$\begin{aligned}
T &= 327\,^\circ\mathrm{C} \\
\Delta U &= Q \\
&= nC_V \Delta T \\
&= 1.31 \times 10^4\,\mathrm{J}
\end{aligned}$$

(ii)

$$\begin{aligned}
T &= 327\,^\circ\mathrm{C} \\
\Delta U &= Q \\
&= nC_V \Delta T \\
&= 1.31 \times 10^4\,\mathrm{J}
\end{aligned}$$

(iii)

$$\begin{aligned}
T &= 927\,^\circ\mathrm{C} \\
\Delta U &= 3.92 \times 10^4\,\mathrm{J}
\end{aligned}$$

19.1.7

(a)

$$\begin{aligned}
pV &= nRT \\
\frac{pV}{R} &= nT
\end{aligned}$$

$$\begin{aligned}
(2p) &= nR(2T) \\
\Delta T &= T
\end{aligned}$$

$$\begin{aligned}
\Delta U &= Q - W \\
&= nC_V \Delta T \\
&= C_V(nT) \\
&= \frac{3}{2}R\frac{pV}{R} \\
&= \frac{3}{2}pV \\
&= 4.50 \times 10^4\,\mathrm{J}
\end{aligned}$$

(b)

$$\begin{aligned} pV &= nRT \\ \frac{pV}{R} &= nT \end{aligned}$$

$$\begin{aligned} pV &= nRT \\ p\left(\frac{1}{2}V\right) &= nR\left(\frac{1}{2}T\right) \\ \Delta T &= -\frac{1}{2}T \end{aligned}$$

$$\begin{aligned} \Delta U &= nC_V \Delta T \\ &= C_V\left(-\frac{1}{2}nT\right) \\ &= -\frac{3}{4}R\frac{pV}{R} \\ &= -\frac{3}{4}pV \\ &= -2.25 \times 10^4 \text{ J} \end{aligned}$$

(c)

$$\Delta U = 1.17 \times 10^5 \text{ J}$$

19.1.8

(a)

$$\begin{aligned} Q &= nC_V \Delta T \\ &= \frac{5}{2}nRT \end{aligned}$$

$$W = 0$$

$$\begin{aligned} \Delta U &= Q - W \\ &= \frac{5}{2}nRT \end{aligned}$$

(b)

$$\begin{aligned} Q &= nC_P \Delta T \\ &= \frac{7}{2} nRT \end{aligned}$$

$$W = p(V_2 - V_1)$$

$$\begin{aligned} \Delta U &= \frac{7}{2} nRT - p(V_2 - V_1) \\ &= \frac{7}{2} nRT - 2nRT + nRT \\ &= \frac{5}{2} nRT \end{aligned}$$

(c)

$$Q = 0$$

$$\begin{aligned} W &= nC_V (T_1 - T_2) \\ &= -\frac{5}{2} nRT \end{aligned}$$

$$\begin{aligned} \Delta U &= Q - W \\ &= \frac{5}{2} nRT \end{aligned}$$

19.1.9

(a)

$$\gamma = \frac{C_P}{C_V} = \frac{\frac{5}{2}R}{\frac{3}{2}R} = \frac{5}{3}$$

(b)

$$\begin{aligned} p_1 V_1^\gamma &= p_2 V_2^\gamma \\ p_2 &= \left(\frac{V_1}{V_2}\right)^\gamma p_1 \\ &= 6.41 \times 10^4 \,\mathrm{Pa} \end{aligned}$$

(c)

$$\begin{aligned} W &= \frac{1}{\gamma - 1} (p_1 V_1 - p_2 V_2) \\ &= 623 \,\mathrm{J} \end{aligned}$$

19.1.10

(a)

$$\gamma = \frac{C_P}{C_V} = \frac{\frac{7}{2}R}{\frac{5}{2}R} = \frac{7}{5}$$

(b)

$$\begin{aligned} T_1 V_1^{\gamma-1} &= T_2 V_2^{\gamma-1} \\ V_2^{\gamma-1} &= \frac{T_1}{T_2} V_1^{\gamma-1} \\ V_2 &= \left(\frac{T_1}{T_2}\right)^{1/(\gamma-1)} V_1 \\ &= 5.79 \times 10^{-4}\,\mathrm{m}^3 \end{aligned}$$

(c)

$$\begin{aligned} p_1 V_1^{\gamma} &= p_2 V_2^{\gamma} \\ p_2 &= \left(\frac{V_1}{V_2}\right)^{\gamma} p_1 \\ &= 2.95 \times 10^{6}\,\mathrm{Pa} \end{aligned}$$

(d)

$$\begin{aligned} W &= \frac{1}{\gamma - 1}(p_1 V_1 - p_2 V_2) \\ &= -2.65 \times 10^{3}\,\mathrm{J} \end{aligned}$$

19.1.11

(a)

$$\begin{aligned} pV &= nRT \\ p &= \frac{nRT}{V} \\ &= 3.17 \times 10^{5}\,\mathrm{Pa} \end{aligned}$$

(b)

$$\begin{aligned} p_1 V_1^{\gamma} &= p_2 V_2^{\gamma} \\ p_2 &= \left(\frac{V_1}{V_2}\right)^{\gamma} p_1 \\ &= 8.21 \times 10^{4}\,\mathrm{Pa} \end{aligned}$$

(c)

$$
\begin{aligned}
T_1 V_1^{\gamma-1} &= T_2 V_2^{\gamma-1} \\
T_2 &= \left(\frac{V_1}{V_2}\right)^{\gamma-1} T_1 \\
&= 178\,\mathrm{K}
\end{aligned}
$$

(d)

$$
\begin{aligned}
W &= \frac{1}{\gamma-1}(p_1 V_1 - p_2 V_2) \\
&= 7.94 \times 10^3\,\mathrm{J}
\end{aligned}
$$

19.1.12

(a)

$$
\begin{aligned}
\left[p + \left(\frac{an^2}{V^2}\right)\right](V - nb) &= nRT \\
p + \left(\frac{an^2}{V^2}\right) &= \frac{nRT}{V - nb} \\
p &= \frac{nRT}{V - nb} - \frac{an^2}{V^2}
\end{aligned}
$$

$$
\begin{aligned}
W &= \int_{V_1}^{V_2} p\,dV \\
&= \int_{V_1}^{V_2} \left(\frac{nRT}{V - nb} - \frac{an^2}{V^2}\right) dV \\
&= \left[nRT\ln(V - nb) + \frac{an^2}{V}\right]_{V_1}^{V_2} \\
&= nRT\ln(V_2 - nb) + \frac{an^2}{V_2} - nRT\ln(V_1 - nb) - \frac{an^2}{V_1} \\
&= nRT\ln\frac{V_2 - nb}{V_1 - nb} + an^2\frac{V_1 - V_2}{V_1 V_2}
\end{aligned}
$$

(b) (i)

$$
W = 2.80 \times 10^3\,\mathrm{J}
$$

(ii)

$$
\begin{aligned}
W &= \int_{V_1}^{V_2} p\,dV \\
&= \int_{V_1}^{V_2} \frac{nRT}{V}\,dV \\
&= nRT[\ln V]_{V_1}^{V_2} \\
&= 3.11 \times 10^3\,\mathrm{J}
\end{aligned}
$$

19.2 Exercises and Problems

19.2.1

(b)

$$
\begin{aligned}
W &= p(V_2 - V_1) \\
&= nR(T_2 - T_1) \\
&= 1.33 \times 10^3\,\mathrm{J}
\end{aligned}
$$

19.2.3

(b)

$$
\begin{aligned}
p_1V_1 &= nRT \\
p_2V_2 &= nRT \\
3p_1V_2 &= nRT \\
V_2 &= \frac{1}{3}V_1 \\
W &= \int_{V_1}^{V_2} p\,dV \\
&= \int_{V_1}^{V_1/3} \frac{nRT}{V}\,dV \\
&= nRT\ln\frac{1}{3} \\
&= -6.18 \times 10^3\,\mathrm{J}
\end{aligned}
$$

19.2.5

(a)

$$\begin{aligned}
pV &= nRT \\
V &= \frac{nRT}{p}
\end{aligned}$$

$$\begin{aligned}
W &= \int_{V_1}^{V_2} p\,dV \\
&= \int_{nRT/p_1}^{nRT/p_2} \frac{nRT}{V}\,dV \\
&= nRT \ln \frac{nRT/p_2}{nRT/p_1} \\
&= nRT \ln \frac{p_1}{p_2} \\
\frac{W}{nRT} &= \ln \frac{p_1}{p_2} \\
p_1 &= p_2 e^{W/nRT} \\
&= 1.05 \times 10^5\,\mathrm{Pa} \\
&= 1.04\,\mathrm{atm}
\end{aligned}$$

19.2.9

(a)

$$W = p(V_2 - V_1) = 3.47 \times 10^4\,\mathrm{J}$$

(b)

$$\Delta U = Q - W = 8.03 \times 10^4\,\mathrm{J}$$

(c) No, because it's an isobaric process.

19.2.11

(a)

$$\begin{aligned}
T_a &= \frac{pV}{nR} \\
&= 278\,\mathrm{K} \\
T_b &= 694\,\mathrm{K} \\
T_c &= 1250\,\mathrm{K}
\end{aligned}$$

The lowest temperature is 278 K and it occured at point a.

(b)

$$
\begin{aligned}
W_{\mathrm{ab}} &= 0 \\
W_{\mathrm{bc}} &= 162\,\mathrm{J}
\end{aligned}
$$

(c)

$$\Delta U = Q - W = 52\,\mathrm{J}$$

19.2.13

(a)

$$
\begin{aligned}
T_a &= \frac{pV}{nR} \\
&= 5.35 \times 10^{2}\,\mathrm{K} \\
T_b &= 9.36 \times 10^{3}\,\mathrm{K} \\
T_c &= 1.50 \times 10^{4}\,\mathrm{K}
\end{aligned}
$$

(b)

$$W = 2.10 \times 10^{4}\,\mathrm{J}$$

(c)

$$Q = \Delta U + W = 3.60 \times 10^{4}\,\mathrm{J}$$

19.2.17

(b)

$$
\begin{aligned}
V_1 &= \frac{nRT_1}{p_1} \\
&= 6.18 \times 10^{-3}\,\mathrm{m}^3 \\
V_2 &= 8.23 \times 10^{-3}\,\mathrm{m}^3 \\
W &= p(V_2 - V_1) \\
&= 207\,\mathrm{J}
\end{aligned}
$$

(c) The piston

(d)

$$
\begin{aligned}
C_V &= \frac{5}{2}R \\
C_P &= \frac{7}{2}R \\
\Delta U &= nC_P\Delta T \\
&= 727\,\mathrm{J} \\
Q &= \Delta U + W \\
&= 934\,\mathrm{J}
\end{aligned}
$$

19.2.19

(a)

$$
\begin{aligned}
\Delta U &= Q - W \\
&= Q - 0 \\
&= nC_V \Delta T \\
\Delta T &= \frac{\Delta U}{nC_V} \\
&= 168\,\mathrm{K} \\
T_2 &= T_1 + \Delta T \\
&= 948\,\mathrm{K}
\end{aligned}
$$

(b)

$$
\begin{aligned}
Q &= nC_P \Delta T \\
\Delta T &= \frac{Q}{nC_P} \\
&= 120\,\mathrm{K} \\
T_2 &= T_1 + \Delta T \\
&= 900\,\mathrm{K}
\end{aligned}
$$

19.2.21

$$
\begin{aligned}
C_V &= \frac{3}{2}R \\
C_P &= \frac{5}{2}R \\
Q &= nC_P \Delta T \\
&= \frac{5}{2}nR(T_2 - T_1) \\
W &= p(V_2 - V_1) \\
&= nR(T_2 - T_1) \\
\frac{W}{Q} &= \frac{2}{5}
\end{aligned}
$$

19.2.23

(a)

$$
\begin{aligned}
\Delta U &= Q - W \\
&= 747\,\mathrm{J}
\end{aligned}
$$

(b)

$$\begin{aligned}
Q &= nC_P\Delta T \\
C_P &= \frac{Q}{n\Delta T} \\
&= 37.0\,\mathrm{J/(mol\,k)} \\
C_V &= C_P - R \\
&= 28.6\,\mathrm{J/(mol\,K)} \\
\gamma &= \frac{C_P}{C_V} \\
&= 1.29
\end{aligned}$$

19.2.25

(a)

$$\begin{aligned}
V_1 &= \frac{nRT}{p_1} \\
&= 3.46 \times 10^{-3}\,\mathrm{m}^3 \\
V_2 &= 8.64 \times 10^{-4}\,\mathrm{m}^3 \\
W &= \int_{V_1}^{V_2} p\,dV \\
&= \int_{V_1}^{V_2} \frac{nRT}{V}\,dV \\
&= nRT \ln\frac{V_2}{V_1} \\
&= -606\,\mathrm{J}
\end{aligned}$$

(b)

$$\Delta U = 0\,\mathrm{J}$$

(c) Yes, liberate

$$Q = \Delta U + W = -606\,\mathrm{J}$$

19.2.27

(a)

$$\begin{aligned} C_V &= \frac{3}{2}R \\ C_P &= \frac{5}{2}R \\ \gamma &= \frac{C_P}{C_V} \\ &= \frac{5}{3} \\ p_1V_1^\gamma &= p_2V_2^\gamma \\ p_2 &= \left(\frac{V_1}{V_2}\right)^\gamma p_1 \\ &= 4.76 \times 10^5\,\mathrm{Pa} \end{aligned}$$

(b)

$$\begin{aligned} W &= \frac{C_V}{R}(p_1V_1 - p_2V_2) \\ &= -1.06 \times 10^4\,\mathrm{J} \end{aligned}$$

(c)

$$\begin{aligned} T_1V_1^{\gamma-1} &= T_2V_2^{\gamma-1} \\ \frac{T_2}{T_1} &= \left(\frac{V_1}{V_2}\right)^{\gamma-1} \\ &= 1.59 \end{aligned}$$

Heated

19.2.29

(b)

$$\begin{aligned} W &= nC_V(T_1 - T_2) \\ &= 314\,\mathrm{J} \end{aligned}$$

(c)

$$\begin{aligned} \Delta U &= Q - W \\ &= 0 - W \\ &= -314\,\mathrm{J} \end{aligned}$$

19.2.31

$$\begin{aligned}
T_1 V_1^{\gamma-1} &= T_2 V_2^{\gamma-1} \\
T_1 \left(\frac{nRT_1}{p_1}\right)^{\gamma-1} &= T_2 \left(\frac{nRT_2}{p_2}\right)^{\gamma-1} \\
T_2^{\gamma} &= T_1^{\gamma} \left(\frac{p_2}{p_1}\right)^{\gamma-1} \\
T_2 &= T_1 \left(\frac{p_2}{p_1}\right)^{(\gamma-1)/\gamma} \\
&= 285\,\mathrm{K} \\
&= 11.6\,^{\circ}\mathrm{C}
\end{aligned}$$

19.2.33

$$\begin{aligned}
C_V &= \frac{3}{2}R \\
C_P &= \frac{5}{2}R \\
\gamma &= \frac{5}{3} \\
T_1 V_1^{\gamma-1} &= T_2 V_2^{\gamma-1} \\
T_1 \left(\frac{nRT_1}{p_1}\right)^{\gamma-1} &= 2T_1 \left(\frac{2nRT_1}{p_2}\right)^{\gamma-1} \\
\frac{1}{p_1^{\gamma-1}} &= \frac{2^{\gamma}}{p_2^{\gamma-1}} \\
p_1^{\gamma-1} &= \frac{p_2^{\gamma-1}}{2^{\gamma}} \\
p_2 &= 2^{\gamma/(\gamma-1)} p_1 \\
&= 2^{5/2} p_1 \\
&= 4\sqrt{2} p_1
\end{aligned}$$

19.2.35

(a) Increase

(b)

$$W = \frac{1}{2}(p_a + p_b)(V_B - V_A) = 4.8\,\mathrm{kJ}$$

19.2.37

(a)

$$\begin{aligned} pV &= nRT \\ n &= \frac{pV}{RT} \\ &= 0.678\,\mathrm{mol} \end{aligned}$$

(b)

$$\begin{aligned} pV &= nRT \\ V &= \frac{nRT}{p} \\ &= 3.33 \times 10^{-2}\,\mathrm{m}^3 \end{aligned}$$

(c)

$$\begin{aligned} W &= \int_{V_1}^{V_2} p\,dV \\ &= \int_{V_1}^{V_2} \frac{nRT}{V}\,dV \\ &= nRT \ln \frac{V_2}{V_1} \\ &= 2.22\,\mathrm{kJ} \end{aligned}$$

(d)

$$\Delta U = 0$$

19.2.39

(a)

$$\begin{aligned} \Delta U &= Q - W \\ &= 30.0\,\mathrm{J} \\ Q &= \Delta U + W \\ &= 45.0\,\mathrm{J} \end{aligned}$$

(b) Liberate

$$Q = \Delta U + W = -65.0\,\mathrm{J}$$

(c)

$$\begin{aligned}
\Delta U_{\mathrm{ad}} &= 8.0\,\mathrm{J} \\
W_{\mathrm{ad}} &= 15.0\,\mathrm{J} \\
Q_{\mathrm{ad}} &= \Delta U_{\mathrm{ad}} + W_{\mathrm{ad}} \\
&= 23.0\,\mathrm{J} \\
Q_{\mathrm{db}} &= \Delta U_{\mathrm{ab}} - \Delta U_{\mathrm{ad}} \\
&= 22.0\,\mathrm{J}
\end{aligned}$$

19.2.43

(a)

$$\begin{aligned}
p_1 V_1 &= p_2 V_2 \\
V_2 &= \frac{p_1}{p_2} V_1 \\
&= 8.0 \times 10^{-4}\,\mathrm{m}^3 \\
&= 0.80\,\mathrm{L}
\end{aligned}$$

(b)

$$\begin{aligned}
T_a &= \frac{pV}{nR} \\
&= 304\,\mathrm{K} \\
T_b &= 1.21 \times 10^3\,\mathrm{K} \\
T_c &= 1.21 \times 10^3\,\mathrm{K}
\end{aligned}$$

(c)

$$
\begin{aligned}
\Delta U_{\mathrm{ab}} &= Q_{\mathrm{ab}} - W_{\mathrm{ab}} \\
&= Q_{\mathrm{ab}} \\
&= nC_V \Delta T \\
&= 74.0\,\mathrm{J} \text{ into the gas}
\end{aligned}
$$

$$
\begin{aligned}
V_c &= \frac{nRT_c}{p_c} \\
&= 7.97 \times 10^{-4}\,\mathrm{m}^3 \\
\Delta U_{\mathrm{ca}} &= Q_{\mathrm{ca}} - W_{\mathrm{ca}} \\
nC_V \Delta T &= Q_{\mathrm{ca}} - p(V_a - V_c) \\
Q_{\mathrm{ca}} &= nC_V \Delta T + p(V_a - V_c) \\
&= -104\,\mathrm{J} \text{ out of the gas}
\end{aligned}
$$

$$
\begin{aligned}
\Delta U_{\mathrm{bc}} &= Q_{\mathrm{bc}} - W_{\mathrm{bc}} \\
Q_{\mathrm{bc}} &= \Delta U_{\mathrm{bc}} + W_{\mathrm{bc}} \\
&= nC_V \Delta T + \int_{V_b}^{V_c} p\,dV \\
&= nRT \ln \frac{V_c}{V_b} \\
&= 55.6\,\mathrm{J} \text{ into the gas}
\end{aligned}
$$

(d)

$$\Delta U_{\mathrm{ab}} = 74.0\,\mathrm{J} \text{ increase}$$

$$\Delta U_{\mathrm{bc}} = 0.0\,\mathrm{J} \text{ no change}$$

$$
\begin{aligned}
\Delta U_{\mathrm{ca}} &= nC_V \Delta T \\
&= -74.0\,\mathrm{J} \text{ decrease}
\end{aligned}
$$

19.2.47

(b)

$$V_2 = \frac{p_1}{p_2} V_1 = 6.0\,\mathrm{L}$$

(c)

$$\begin{aligned}
n &= \frac{pV}{RT} \\
&= 6.01 \times 10^{-2}\,\mathrm{mol} \\
W_{12} &= \int_{V_1}^{V_2} p\,dV \\
&= nRT_1 \ln\frac{V_2}{V_1} \\
&= 208\,\mathrm{J}
\end{aligned}$$

$$\begin{aligned}
W_{23} &= p_2(V_3 - V_2) \\
&= -113\,\mathrm{J}
\end{aligned}$$

$$W = 95.0\,\mathrm{J}$$

(d) Heat it at constant volume

19.2.49

(a) As the wind descends it experiences greater atmospheric pressure. This compresses the wind, increasing its temperature. It's important that it be moving fast so it's an adiabatic process.

(b)

$$\begin{aligned}
T_2 &= \left(\frac{p_2}{p_1}\right)^{(\gamma-1)/\gamma} T_1 \\
&= 287\,\mathrm{K} \\
&= 13.9\,^\circ\mathrm{C} \\
\Delta T &= T_2 - T_1 \\
&= 11.9\,\mathrm{C}^\circ
\end{aligned}$$

19.2.51

(a)

$$\begin{aligned}
p_1 V_1^\gamma &= p_2 V_2^\gamma \\
p_1 (Ah)^\gamma &= p_2 [A(h - \Delta h)]^\gamma \\
\frac{p_1}{p_2} h^\gamma &= (h - \Delta h)^\gamma \\
\left(\frac{p_1}{p_2}\right)^{1/\gamma} h &= h - \Delta h \\
\Delta h &= h \left[1 - \left(\frac{p_1}{p_2}\right)^{1/\gamma}\right] \\
&= 16.8\,\mathrm{cm}
\end{aligned}$$

(b)

$$\begin{aligned}
T_1 V_1^{\gamma-1} &= T_2 V_2^{\gamma-1} \\
T_2 &= \left(\frac{V_1}{V_2}\right)^{\gamma-1} T_1 \\
&= \left(\frac{Ah}{A(h - \Delta h)}\right)^{\gamma-1} T_1 \\
&= \left(\frac{1}{1 - \Delta h/h}\right)^{\gamma-1} T_1 \\
&= 469\,\mathrm{K} \\
&= 196\,^\circ\mathrm{C}
\end{aligned}$$

(c)

$$W = nC_V (T_1 - T_2) = -7.03 \times 10^4\,\mathrm{J}$$

19.2.59

(a) a is abiabatic, b is isochoric, c is isobaric

(b)

$$\begin{aligned}
\Delta U &= Q_b - W_b \\
&= Q_b - 0 \\
&= Q_b
\end{aligned}$$

$$\begin{aligned}
\Delta U &= Q_c - W_c \\
&= Q_c - p(V_2 - V_1) \\
&= Q_c - nR(T_2 - T_1)
\end{aligned}$$

$$\begin{aligned}
Q_b &= Q_c - nR(T_2 - T_1) \\
T_2 &= T_1 + \frac{Q_c - Q_b}{nR} \\
&= 28.0\,^\circ\mathrm{C}
\end{aligned}$$

(c)

$$\begin{aligned}
Q_b &= nC_V \Delta T \\
C_V &= \frac{Q_b}{n\Delta T} \\
&= 12.5\,\mathrm{J/(mol\,K)}
\end{aligned}$$

$$\begin{aligned}
W_a &= nC_V(T_1 - T_2) \\
&= -30.0\,\mathrm{J}
\end{aligned}$$

$$W_b = 0$$

$$\begin{aligned}
\Delta U_c &= Q_c - W_c \\
W_c &= Q_c - \Delta U_c \\
&= Q_c - nC_V \Delta T \\
&= 20.0\,\mathrm{J}
\end{aligned}$$

(d)

$$\begin{aligned}
\gamma &= \frac{C_P}{C_V} \\
&= \frac{C_V + R}{C_V} \\
&= 1.67
\end{aligned}$$

$$\begin{aligned}
T_1 V_1^{\gamma-1} &= T_2 V_2^{\gamma-1} \\
\left(\frac{V_2}{V_1}\right)^{\gamma-1} &= \frac{T_1}{T_2} \\
\frac{V_2}{V_1} &= \left(\frac{T_1}{T_2}\right)^{1/(\gamma-1)} \\
&= 0.961
\end{aligned}$$

$$\Delta V_b = 0$$

$$\begin{aligned}
\frac{V_2}{V_1} &= \frac{nRT_2/p}{nRT_1/p} \\
&= \frac{T_2}{T_1} \\
&= 1.03
\end{aligned}$$

a

(e) Decrease, stay the same, increase

19.2.61

(a)

$$
\begin{aligned}
r &= 1.50\,\mathrm{cm}\\
l_{\max} &= 30.0\,\mathrm{cm}\\
l_{\min} &= l_{\max}/v\\
p &= 101\,\mathrm{kPa}\\
T &= 30.0\,^{\circ}\mathrm{C}\\
V_1 &= \pi r^2 l_{\max}\\
&= 2.12\times 10^{-4}\,\mathrm{m}^3\\
V_2 &= \pi r^2 l_{\min}\\
&= \pi r^2 \frac{l_{\max}}{v}\\
&= \frac{V_1}{v}\\
n &= \frac{pV}{RT}\\
&= 8.50\times 10^{-3}\,\mathrm{mol}\\
T_1 V_1^{\gamma-1} &= T_2 V_2^{\gamma-1}\\
T_2 &= T_1\left(\frac{V_1}{V_2}\right)^{\gamma-1}\\
&= T_1 v^{\gamma-1}\\
W_{\mathrm{adiabatic}} &= nC_V(T_1 - T_2)\\
&= nC_V(T_1 - T_1 v^{\gamma-1})\\
&= nC_V T_1(1 - v^{\gamma-1})\\
&= 53.5(1 - v^{0.4})\\
W_{\mathrm{isothermal}} &= \int_{V_1}^{V_2} p\,dV\\
&= \int_{V_1}^{V_2} \frac{nRT_2}{V}\,dV\\
&= nRT_2 \ln\frac{V_2}{V_1}\\
&= nRT_1 v^{\gamma-1}\ln v\\
&= 21.4 v^{0.4}\ln v\\
W &= 53.5(1 - v^{0.4}) + 21.4 v^{0.4}\ln v\\
&= 53.5 + v^{0.40}(21.4\ln v - 53.5)
\end{aligned}
$$

(b)

$$\begin{aligned}
T_2 &\leq T_{\max} \\
T_1 v^{\gamma-1} &\leq T_{\max} \\
v &\leq \left(\frac{T_{\max}}{T_1}\right)^{1/(\gamma-1)} \\
&\leq 7.35
\end{aligned}$$

The largest integer value of v is 7.

(c) 7

(d) 7

(e)

$$\begin{aligned}
T_2 &= T_1 v^{\gamma-1} \\
&= 660\,\mathrm{K} \\
&= 387\,{}^\circ\mathrm{C} \\
Q &= nC_V \Delta T \\
&= -63.0\,\mathrm{J}
\end{aligned}$$

19.2.63

$$\begin{aligned}
\frac{p_1}{T_1} &= \frac{p_2}{T_2} \\
p_2 &= \frac{T_2}{T_1} p_1 \\
&= 1.27 \times 10^7\,\mathrm{Pa} \\
&= 1.84 \times 10^3\,\mathrm{psi}
\end{aligned}$$

c

19.2.65

$$\begin{aligned}
p_1 V_1 &= p_2 V_2 \\
V_1 &= \frac{p_2}{p_1} V_2 \\
&= 6.01 \times 10^{-5}\,\mathrm{m}^3 \\
&= 6.01 \times 10^{-2}\,\mathrm{L}
\end{aligned}$$

d

20 The Second Law of Thermodynamics

20.1 Guided Practice

20.1.1

(a)

$$W = eQ_H \Rightarrow Q_H = \frac{W}{e} = 6.89 \times 10^4\,\text{J}$$

(b)

$$|W| = |Q_H| - |Q_C| \Rightarrow |Q_C| = |Q_H| - |W| = 5.65 \times 10^4\,\text{J}$$

20.1.2

$$e = \frac{W}{Q_H} = \frac{Q_H + Q_C}{Q_H} = 1 + \frac{Q_C}{Q_H} = 0.173 = 17.3\%$$

20.1.3

(a)

$$(1-e)Q_H = Q_C \Rightarrow Q_H = \frac{Q_C}{1-e} = 6.17 \times 10^8\,\text{J}$$

(b)

$$W = eQ_H = 1.21 \times 10^8\,\text{J}$$

20.1.4

(a)

$$W = 3600P = 3.96 \times 10^8\,\text{J}$$

(b)

$$Q_H = mL_c = 1.70 \times 10^9\,\text{J}$$

(c)

$$e = \frac{W}{Q_H} = 0.233 = 23.3\%$$

20.1.5

(a)

$$\begin{aligned} e_{\text{Carnot}} &= 1 - \frac{T_C}{T_H} \\ &= 1 + \frac{Q_C}{Q_H} \\ &= 1 + \frac{W - Q_H}{Q_H} \\ &= 0.21 \end{aligned}$$

(b)

$$|Q_C| = |Q_H| - |W| = 6.32 \times 10^4\,\mathrm{J}$$

(c)

$$\frac{Q_C}{Q_H} = -\frac{T_C}{T_H} \Rightarrow T_H = -\frac{Q_H}{Q_C} T_C = 377\,\mathrm{K} = 104\,^\circ\mathrm{C}$$

20.1.6

(a)

$$e = 1 - \frac{T_C}{T_H} = 0.6$$

(b)

$$
\begin{aligned}
n &= 0.200\,\mathrm{mol} \\
\gamma &= 1.40 \\
T_H &= 227\,^\circ\mathrm{C} = 500\,\mathrm{K} \\
T_C &= -73\,^\circ\mathrm{C} = 200\,\mathrm{K} \\
p_a &= 10.0 \times 10^5\,\mathrm{Pa} \\
V_a &= \frac{nRT_H}{p_a} \\
&= 8.31 \times 10^{-4}\,\mathrm{m}^3 \\
V_b &= 2V_a \\
&= 1.66 \times 10^{-3}\,\mathrm{m}^3 \\
p_b &= \frac{nRT_H}{V_b} \\
&= 5.01 \times 10^5\,\mathrm{Pa} \\
W_{\mathrm{ab}} &= \int_{V_a}^{V_b} p\,dV \\
&= nRT_H \ln 2 \\
&= 576\,\mathrm{J} \\
V_c &= \left(\frac{T_H}{T_C}\right)^{1/(\gamma-1)} V_b \\
&= 1.64 \times 10^{-2}\,\mathrm{m}^3 \\
p_c &= \frac{nrT_C}{V_c} \\
&= 2.03 \times 10^4\,\mathrm{Pa} \\
W_{\mathrm{bc}} &= \frac{1}{\gamma - 1}(p_b V_b - p_c V_c) \\
&= 1.25\,\mathrm{kJ} \\
V_d &= \frac{1}{2} V_c \\
&= 8.20 \times 10^{-3}\,\mathrm{m}^3 \\
p_d &= 4.06 \times 10^4\,\mathrm{Pa} \\
W_{\mathrm{cd}} &= \int_{V_c}^{V_d} p\,dV \\
&= nRT_C \ln \frac{1}{2} \\
&= -231\,\mathrm{J} \\
W_{\mathrm{da}} &= \frac{1}{\gamma - 1}(p_d V_d - p_a V_a) \\
&= -1.25\,\mathrm{kJ}
\end{aligned}
$$

20.1.7

(a)

$$K = \frac{T_C}{T_H - T_C} = 7.52$$

(b)

$$W = \frac{Q_C}{K} = 5.32 \times 10^5\,\mathrm{J}$$

20.1.8

(a)

$$\begin{aligned} W &= \int_{V_a}^{V_b} p\,dV \\ &= \int_{V_a}^{2V_a} \frac{nRT_H}{V}\,dV \\ &= nRT_H \ln 2 \end{aligned}$$

(b)

$$\begin{aligned} W &= nC_V(T_H - T_C) \\ &= \frac{3}{2}nR(T_H - T_C) \end{aligned}$$

(c)

$$\begin{aligned} nRT_H \ln 2 &= \frac{3}{2}nR(T_H - T_C) \\ \ln 2 &= \frac{3}{2}\left(1 - \frac{T_C}{T_H}\right) \\ \frac{T_C}{T_H} &= 1 - \frac{2}{3}\ln 2 \\ e &= 1 - \frac{T_C}{T_H} \\ &= \frac{2}{3}\ln 2 \\ &= 0.462 \end{aligned}$$

20.1.9

(a)

$$\Delta S = \frac{Q}{T} = \frac{mL_f}{T} = 655\,\mathrm{J/K}$$

(b)

$$\Delta S = mc\int_{159}^{351}\frac{dT}{T} = 1.92\times 10^{3}\,\mathrm{J/K}$$

(c)

$$\Delta S = \frac{Q}{T} = \frac{mL_v}{T} = 2.43\times 10^{3}\,\mathrm{J/K}$$

20.1.10

(a)

$$\begin{aligned}
n &= 5.00\,\mathrm{mol}\\
V_1 &= 0.120\,\mathrm{m}^3\\
T_1 &= 20.0\,^\circ\mathrm{C}\\
V_2 &= 0.360\,\mathrm{m}^3\\
T_2 &= 20.0\,^\circ\mathrm{C}\\
\Delta U &= nC_V\Delta T\\
&= 0\\
Q &= W\\
&= \int_{V_1}^{V_2} p\,dV\\
&= \int_{V_1}^{V_2}\frac{nRT}{V}\,dV\\
&= nRT\ln\frac{V_2}{V_1}\\
&= 1.34\times 10^{4}\,\mathrm{J}\\
\Delta S &= \frac{Q}{T}\\
&= 45.7\,\mathrm{J/K}
\end{aligned}$$

(b) Change in entropy is path independent, so $\Delta S = 45.7\,\mathrm{J/K}$.

20.1.11

(a)

$$\Delta S = 0$$

(b)

$$\Delta S = \frac{Q}{T} = -150\,\mathrm{J/K}$$

(c)

$$\Delta S = \frac{Q}{T} = 218\,\mathrm{J/K}$$

(d)

$$\Delta S = 68\,\mathrm{J/K}$$

The net entropy increases.

20.1.12

(a)

$$\Delta S = \frac{Q}{T} = \frac{mL_f}{T} = 1.22 \times 10^3\,\mathrm{J/K}$$

(b)

$$\begin{aligned}
\Delta S &= \int \frac{dQ}{T} \\
&= mc \int_{368}^{273} \frac{dT}{T} \\
&= -1.05 \times 10^3\,\mathrm{J/K}
\end{aligned}$$

(c)

$$\Delta S = 160\,\mathrm{J/K}$$

The net entropy increases.

20.1.13

(a)

$$\begin{aligned}
0 &= m_i L_f + m_w c(T - T_w) + m_i c(T - T_i) \\
T &= \frac{(m_w T_w + m_i T_i)c - m_i L_f}{(m_w + m_i)c} \\
&= 307\,\mathrm{K} \\
&= 34.3\,^\circ\mathrm{C}
\end{aligned}$$

(b)

$$\begin{aligned}
\Delta S_i &= \frac{Q}{T_1} + \int \frac{dQ}{T} \\
&= \frac{m_i L_f}{T_1} + m_i c \ln \frac{T_2}{T_1} \\
&= 101\,\mathrm{J/K} \\
\Delta S_w &= m_w c \ln \frac{T_2}{T_1} \\
&= -86.0\,\mathrm{J/K} \\
\Delta S &= 15.0\,\mathrm{J/K}
\end{aligned}$$