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

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

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

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

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)

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

(b)

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

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)

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

(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)

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

18.1.5

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

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)

$$\begin{aligned}pV &= \frac{N}{N_A}RT \\ N &= \frac{N_A pV}{RT} \\ &= 1.50 \times 10^{27}\end{aligned}$$

(b)

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

(c)

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

18.1.8

(a) 5.5

(b) 38.5

(c) 6.2

18.1.9

(a)

$$\lambda = \frac{kT}{4\pi\sqrt{2}r^2p} = 6.8\times 10^{-6}\,\mathrm{m}$$

(b)

$$\begin{aligned}\lambda_{\mathrm{Earth}} &= 5.54\times 10^{-8}\,\mathrm{m}\\ \frac{\lambda_{\mathrm{Mars}}}{\lambda_{\mathrm{Earth}}} &= 1.2\times 10^{2}\end{aligned}$$

18.1.10

(a)

$$\begin{aligned}\lambda &= \frac{kT}{4\pi\sqrt{2}r^2p}\\ p &= \frac{kT}{4\pi\sqrt{2}r^2\lambda}\\ &= 5.7\times 10^{-3}\,\mathrm{Pa}\end{aligned}$$

(b)

$$\begin{aligned}pV &= nRT\\ n &= \frac{pV}{RT}\\ &= 2.3\times 10^{-6}\,\mathrm{mol}\end{aligned}$$

18.1.11

(a)

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

(b)

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

18.1.12

(a)

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

(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)

$$\begin{aligned} &\int_{2025}^{\infty} 4\pi \left(\frac{m}{2\pi kT}\right)^{3/2} v^2 e^{-mv^2/2kT}\,dv \\ &= (3.03\times10^{-8}) \int_{2025}^{\infty} v^2 e^{-(5.65\times10^{-6})v^2}\,dv \\ &= 4.8\times10^{-10} \end{aligned}$$

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

$$\begin{aligned} pV &= nRT \\ \frac{p_1V_1}{T_1} &= \frac{p_2V_2}{T_2} \\ p_2 &= \frac{p_1V_1T_2}{T_1V_2} \\ &= 1.97\times10^{4}\,\text{Pa} \end{aligned}$$

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)

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

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)

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

(c)

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

(d)

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

(e)

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

(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

$$
\begin{aligned}
C_V &= \frac{5}{2}R \\
v_{\mathrm{rms}} &= \sqrt{\frac{3RT}{M}} \\
T &= \frac{Mv_{\mathrm{rms}}^2}{3R} \\
Q &= nC_V\Delta T \\
\Delta T &= \frac{Q}{nC_V} \\
v'_{\mathrm{rms}} &= \sqrt{\frac{3R(T+\Delta T)}{M}} \\
&= \sqrt{\frac{3R\left(\frac{Mv_{\mathrm{rms}}^2}{3R}+\frac{Q}{nC_V}\right)}{M}} \\
&= \sqrt{v_{\mathrm{rms}}^2+\frac{3RQ}{Mn\frac{5}{2}R}} \\
&= \sqrt{v_{\mathrm{rms}}^2+\frac{6Q}{5Mn}} \\
&= 1.02\times10^3\,\mathrm{m/s}
\end{aligned}
$$

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)

$$
\begin{aligned}
Q &= mc_{V,\mathrm{water}}\Delta T \\
&= 4.19\times10^{4}\,\mathrm{J} \\
m &= \frac{Q}{c_{V,\mathrm{N}}\Delta T} \\
&= 5.65\,\mathrm{kg} \\
pV &= \frac{m_{\mathrm{total}}}{M}RT \\
V &= \frac{m_{\mathrm{total}}RT}{Mp} \\
&= 4.87\,\mathrm{m}^3 \\
&= 4.87\times10^{3}\,\mathrm{L}
\end{aligned}
$$

18.2.41

(a)

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

(b)

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

(c)

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

18.2.43

(a)

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

(b)

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

18.2.45

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

(b) The maximum pressure is $p_2 = 2.212\times10^{7}\,\mathrm{Pa}$. 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

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

18.2.53

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

18.2.57

(a)

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

(b)

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

(c)

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

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)

$$
\begin{aligned}
U(r) &= U_0\left[\left(\frac{R_0}{r}\right)^{12} - 2\left(\frac{R_0}{r}\right)^{6}\right] \\
F(r) &= 12\frac{U_0}{R_0}\left[\left(\frac{R_0}{r}\right)^{13} - \left(\frac{R_0}{r}\right)^{7}\right]
\end{aligned}
$$

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

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

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

(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)

$$\begin{aligned}
v_{\text{mp}} &= \sqrt{\frac{2kT}{m}}\\
&= 395\,\text{m/s}\\
f(v_{\text{mp}}) &= 2.10\times10^{-3}\\
\Delta N &\approx N f(v_{\text{mp}})\Delta v\\
&\approx (4.20\times10^{-2})N
\end{aligned}$$

(c)

$$\begin{aligned}
7v_{\text{mp}} &= 2765\,\text{m/s}\\
f(7v_{\text{mp}}) &= 1.43\times10^{-22}\\
\Delta N &\approx (2.85\times10^{-21})N
\end{aligned}$$

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)

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

(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)

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

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

It would evaporate.

(f)

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

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)

$$pV = nRT$$
$$\frac{pV}{R} = nT$$

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

$$\begin{aligned}\Delta U &= nC_V\Delta T \\ &= C_V\left(-\frac{1}{2}nT\right) \\ &= -\frac{3}{4}R\frac{pV}{R} \\ &= -\frac{3}{4}pV \\ &= -2.25\times10^4\,\mathrm{J}\end{aligned}$$

(c)

$$\Delta U = 1.17\times10^5\,\mathrm{J}$$

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)

$$\begin{aligned}
p_1V_1^\gamma &= p_2V_2^\gamma \\
p_2 &= \left(\frac{V_1}{V_2}\right)^\gamma p_1 \\
&= 6.41 \times 10^4\,\mathrm{Pa}
\end{aligned}$$

(c)

$$\begin{aligned}
W &= \frac{1}{\gamma - 1}(p_1V_1 - p_2V_2) \\
&= 623\,\mathrm{J}
\end{aligned}$$

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)

$$\begin{aligned} W &= \frac{1}{\gamma-1}(p_1V_1 - p_2V_2) \\ &= 7.94 \times 10^3\,\mathrm{J} \end{aligned}$$

19.1.12

(a)

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

$$\begin{aligned} W &= \int_{V_1}^{V_2} p\,dV \\ &= \int_{V_1}^{V_2} \left(\frac{nRT}{V-nb} - \frac{an^2}{V^2}\right) dV \\ &= \left[nRT\ln(V-nb) + \frac{an^2}{V}\right]_{V_1}^{V_2} \\ &= nRT\ln(V_2-nb) + \frac{an^2}{V_2} - nRT\ln(V_1-nb) - \frac{an^2}{V_1} \\ &= nRT\ln\frac{V_2-nb}{V_1-nb} + an^2\frac{V_1-V_2}{V_1V_2} \end{aligned}$$

(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)

$$\begin{aligned} p_1 V_1 &= nRT \\ p_2 V_2 &= nRT \\ 3p_1 V_2 &= nRT \\ V_2 &= \frac{1}{3} V_1 \\ W &= \int_{V_1}^{V_2} p\,dV \\ &= \int_{V_1}^{V_1/3} \frac{nRT}{V}\,dV \\ &= nRT \ln \frac{1}{3} \\ &= -6.18 \times 10^3\,\mathrm{J} \end{aligned}$$

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)

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

(c)

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

19.2.13

(a)

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

(b)

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

(c)

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

19.2.17

(b)

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

(c) The piston

(d)

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

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)

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

(b)

$$\begin{aligned}
W &= \frac{C_V}{R}(p_1 V_1 - p_2 V_2) \\
&= -1.06 \times 10^4\,\mathrm{J}
\end{aligned}$$

(c)

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

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)

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

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

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

(d)

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

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

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

19.2.47

(b)

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

(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)

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

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)

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

(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