

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

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June 2023

Contents

17 Temperature and Heat	3
17.1 Guided Practice	3
17.1.1	3
17.1.2	4
17.1.3	4
17.1.4	4
17.1.5	5
17.1.6	5
17.1.7	5
17.1.8	5
17.1.9	6
17.1.10	6
17.1.11	7
17.1.12	7
17.2 Exercises and Problems	7
17.2.15	7
17.2.25	8
17.2.33	8
17.2.35	8
17.2.45	8
17.2.55	9
17.2.57	9
17.2.65	9
17.2.69	10
17.2.71	10
17.2.73	10
17.2.75	10
17.2.79	11
17.2.85	11
17.2.95	12

17.2.99	12
17.2.105	13
17.2.107	14
17.2.113	14
17.2.115	15
17.2.117	15
17.2.119	15
18 Thermal Properties of Matter	16
18.1 Guided Practice	16
18.1.1	16
18.1.2	16
18.1.3	17
18.1.4	17
18.1.5	18
18.1.6	18
18.1.7	18
18.1.8	19
18.1.9	19
18.1.10	19
18.1.11	20
18.1.12	20
18.1.13	21
18.2 Exercises and Problems	21
18.2.7	21
18.2.9	21
18.2.13	22
18.2.17	22
18.2.21	22
18.2.23	23
18.2.25	23
18.2.27	23
18.2.29	24
18.2.31	24
18.2.33	25
18.2.35	26
18.2.39	26
18.2.41	27
18.2.43	27
18.2.45	27
18.2.49	28
18.2.51	28
18.2.53	28
18.2.57	29
18.2.59	30
18.2.67	31

18.2.69	32
18.2.71	32
18.2.73	33
18.2.75	33
18.2.77	33
18.2.81	34
18.2.83	35
18.2.85	36
18.2.87	36
19 The First Law of Thermodynamics	37
19.1 Guided Practice	37
19.1.1	37
19.1.2	37
19.1.3	37
19.1.4	38
19.1.5	38
19.1.6	38
19.1.7	39
19.1.8	40
19.1.9	41
19.1.10	42
19.1.11	42
19.1.12	43

17 Temperature and Heat

17.1 Guided Practice

17.1.1

(a)

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

(b)

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

17.1.2

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

17.1.3

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

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

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

17.1.6

$$\begin{aligned}
0 &= m_IL_f + m_Cc_C\Delta T \\
&= m_IL_f - m_Cc_CT \\
T &= \frac{m_IL_f}{m_Cc_C} \\
&= 14.0^\circ\text{C}
\end{aligned}$$

17.1.7

$$\begin{aligned}
0 &= m_IL_F + m_Ic_I\Delta T_I + m_Ec_E\Delta T_E \\
&= m_I(L_F + c_I\Delta T_I) + m_Ec_E\Delta T_E \\
m_I &= -\frac{m_Ec_E\Delta T_E}{L_F + c_I\Delta T_I} \\
&= 0.176 \text{ kg}
\end{aligned}$$

17.1.8

Cooling the silver to 0°C would take

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

whereas melting all of the ice would take

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

so all of the ice will melt.

$$\begin{aligned}
0 &= m_{Ag}c_{Ag}\Delta T_{Ag} + m_IL_f + m_Ic_I\Delta T_I + m_Ic_W\Delta T_W \\
&= m_{Ag}c_{Ag}(T - T_{Ag}) + m_IL_f - m_Ic_IT_I + m_Ic_WT \\
&= (m_{Ag}c_{Ag} + m_Ic_W)T - m_{Ag}c_{Ag}T_{Ag} + m_IL_f - m_Ic_IT_I \\
T &= \frac{m_{Ag}c_{Ag}T_{Ag} + m_Ic_IT_I - m_IL_f}{m_{Ag}c_{Ag} + m_Ic_W} \\
&= 3.31^\circ\text{C}
\end{aligned}$$

17.1.9

(a)

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

(b)

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

17.1.10

(a)

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

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

(b)

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

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)

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

(b)

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

17.2 Exercises and Problems

17.2.15

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

17.2.25

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

17.2.33

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

17.2.35

(a)

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

(b) Water because it has a higher specific heat

(c) It would be too small

17.2.45

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

17.2.55

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

17.2.57

(a)

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

(b)

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

17.2.65

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

17.2.69

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

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)

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

(b)

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

17.2.75

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

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)

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

17.2.85

(a)

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

(b)

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

(c)

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

17.2.95

(a)

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

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

17.2.99

(a)

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

(b)

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

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) $t \approx 530$ years; no

17.2.107

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

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)

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

(b)

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

18.1.2

(a)

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

(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)

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

(b)

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

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)

$$\frac{\rho_2}{\rho_1} = 2^{3/5}$$

$$\approx 1.52$$

$$\frac{T_2}{T_1} = 2^{2/5}$$

$$\approx 1.32$$

18.1.5

$$\sqrt{\frac{3RT}{M_{\text{H}}}} = \sqrt{\frac{3RT_{\text{N}}}{M_{\text{N}}}}$$

$$T = \frac{M_{\text{H}}}{M_{\text{N}}} T_{\text{N}}$$

$$= 41.9 \text{ K}$$

$$= -231 \text{ }^{\circ}\text{C}$$

18.1.6

(a)

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

(b)

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

18.1.7

(a)

$$pV = \frac{N}{N_A} RT$$

$$N = \frac{N_A pV}{RT}$$

$$= 1.50 \times 10^{27}$$

(b)

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

(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)

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

(b)

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

18.1.10

(a)

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

(b)

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

18.1.11

(a)

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

(b)

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

18.1.12

(a)

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

(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)

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

Yes, some escape.

18.2 Exercises and Problems

18.2.7

$$\begin{aligned}pV &= nRT \\ \frac{p_1 V_1}{T_1} &= \frac{p_2 V_2}{T_2} \\ T_2 &= \frac{p_2 V_2 T_1}{p_1 V_1} \\&= 776 \text{ K} \\&= 503 \text{ }^\circ\text{C}\end{aligned}$$

18.2.9

$$\begin{aligned}pV &= nRT \\ \frac{p_1 V_1}{T_1} &= \frac{p_2 V_2}{T_2} \\ p_2 &= \frac{p_1 V_1 T_2}{T_1 V_2} \\&= 1.97 \times 10^4 \text{ Pa}\end{aligned}$$

18.2.13

$$\begin{aligned}\frac{p_1 V_1}{T_1} &= \frac{p_2 V_2}{T_2} \\ V_2 &= \frac{p_1 T_2}{T_1 p_2} V_1 \\ &= (5.08 \times 10^{-2}) V_1\end{aligned}$$

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)

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

(b)

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

18.2.23

(a)

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

18.2.25

(a)

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

(b)

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

18.2.27

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

18.2.29

(a)

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

Not a significant fraction of c .

(b)

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

18.2.31

(a)

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

(b)

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

(c)

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

(d)

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

(e)

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

(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)

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

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

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

18.2.39

(a)

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

(b)

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

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)

$$\begin{aligned}p' - p &= -\rho gh \\ &= -1.18 \times 10^4 \text{ Pa}\end{aligned}$$

(b)

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

18.2.51

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

18.2.53

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

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)

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

(c)

$$mg = 7810 \text{ N}$$

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)

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

(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)

$$\begin{aligned} \frac{3}{2}kT &\geq mgR_p \\ T_N &\geq \frac{2mgR_p}{3k} \\ &\geq 1.40 \times 10^5 \text{ K} \\ T_H &\geq 1.02 \times 10^4 \text{ K} \end{aligned}$$

(c)

$$\begin{aligned} T_N &\geq 6.37 \times 10^3 \text{ K} \\ T_H &\geq 459 \text{ K} \end{aligned}$$

(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)

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

(c)

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

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)

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

(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)

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

(b)

$$2 \left(\frac{1}{2} (2m) v_i^2 \right) = 2 \left(\frac{1}{2} (2m) v_f^2 + \frac{1}{2} I \omega^2 \right)$$

$$2m v_i^2 = 2m v_f^2 + 2m r^2 \omega^2$$

$$v_i^2 = v_f^2 + r^2 \omega^2$$

$$-2r(2m)v_i = -2I\omega$$

$$2mr v_i = 2mr^2 \omega$$

$$v_i = r\omega$$

(c)

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

$$v_i^2 = v_f^2 + r^2 \left(\frac{v_i}{r} \right)^2$$

$$v_f = 0$$

(d)

$$v_{\text{rms}} = \sqrt{\frac{3kT}{m}}$$

$$= 514 \text{ m/s}$$

$$\omega = 5.47 \times 10^{12} \text{ rad/s}$$

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)

$$\begin{aligned} v_{\text{rms}} &= \sqrt{\frac{3kT}{m}} \\ &= 704 \text{ m/s} \end{aligned}$$

$$\begin{aligned} t_{\text{mean}} &= \frac{\lambda}{v_{\text{rms}}} \\ &= 6.39 \times 10^8 \text{ s} \\ &= 20 \text{ years} \end{aligned}$$

(c)

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

(d)

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

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

It would evaporate.

(f)

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

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)

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

(b)

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

(c)

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

19.1.2

(a)

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

(b)

$$W = 0$$

(c)

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

(d)

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

19.1.3

(a)

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

(b)

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

19.1.4

(a)

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

(b)

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

(c)

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

19.1.5

(a)

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

(b)

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

(c)

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

19.1.6

(a)

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

(b) (i)

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

(ii)

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

(iii)

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

19.1.7

(a)

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

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

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

(b)

$$pV = nRT$$

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

$$pV = nRT$$

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

$$\Delta T = -\frac{1}{2}T$$

$$\Delta U = nC_V\Delta T$$

$$= C_V\left(-\frac{1}{2}nT\right)$$

$$= -\frac{3}{4}R\frac{pV}{R}$$

$$= -\frac{3}{4}pV$$

$$= -2.25 \times 10^4 \text{ J}$$

(c)

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

19.1.8

(a)

$$Q = nC_V\Delta T$$

$$= \frac{5}{2}nRT$$

$$W = 0$$

$$\Delta U = Q - W$$

$$= \frac{5}{2}nRT$$

(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)

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

(c)

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

19.1.10

(a)

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

(b)

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

(c)

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

(d)

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

19.1.11

(a)

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

(b)

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

(c)

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

(d)

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

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)

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

(ii)

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