

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

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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

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

17.1.6

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

17.1.7

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

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.

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

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)

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

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

(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**

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

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)

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

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

(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)

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

(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