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

$$\begin{aligned}
\Delta V_C &= \beta V_{C0}\Delta T \\
&= (5.1\times10^{-5})(250)(-70) \\
&= -0.893\,\mathrm{cm}^3 \\
\Delta V_E &= \beta V_{E0}\Delta T \\
&= (75\times10^{-5}\,)(250)(-70) \\
&= -13.1\,\mathrm{cm}^3 \\
\Delta V_C - \Delta V_E &= 12.2\,\mathrm{cm}^3 \\
&= 12.2\,\mathrm{mL}
\end{aligned}$$

17.1.3

$$\begin{aligned}
\frac{\Delta L}{L_0} &= \alpha\Delta T \\
Y &= \frac{F/A}{\Delta L/L_0} \\
\frac{\Delta L}{L_0} &= \frac{F}{AY} \\
\alpha\Delta T + \frac{F}{AY} &= 0 \\
\frac{F}{AY} &= -\alpha\Delta T \\
F &= -\alpha AY\Delta T \\
&= -(2.0\times10^{-5})(\pi 0.005^2)(9.0\times10^{10})(-12) \\
&= 1.70\times10^3\,\mathrm{N}
\end{aligned}$$

Tensile

17.1.4

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

17.1.5

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

17.1.6

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

17.1.7

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

17.1.8

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

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

whereas melting all of the ice would take

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

so all of the ice will melt.

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

17.1.9

(a)

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

(b)

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

17.1.10

(a)

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

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

(b)

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

17.1.11

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

17.1.12

(a)

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

(b)

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

17.2 Exercises and Problems

17.2.15

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

17.2.25

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

17.2.33

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

17.2.35

(a)

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

(b) Water because it has a higher specific heat

(c) It would be too small

17.2.45

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

17.2.55

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

17.2.57

(a)

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

(b)

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

17.2.65

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

17.2.69

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

17.2.71

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

17.2.73

(a)

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

(b)

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

17.2.75

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

17.2.79

(a)

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

(b)

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

17.2.85

(a)

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

(b)

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

(c)

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

17.2.95

(a)

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

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

17.2.99

(a)

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

(b)

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

17.2.105

(b)

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

(c)

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

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

17.2.107

$$
\begin{aligned}
A &= 2\pi\left(\frac{d}{2}\right)^2 + 2\pi\left(\frac{d}{2}\right)h \\
&= 8.34\times10^{-2}\,\mathrm{m}^2 \\
H &= Ae\sigma(T^4 - T_s^4) \\
&= Ae\sigma(T^4 - T_s^4) \\
&= -3.38\times10^{-2}\,\mathrm{W} \\
m &= \frac{H\times60\times60}{L_v} \\
&= 5.82\times10^{-3}\,\mathrm{kg/h} \\
&= 5.82\,\mathrm{g/h}
\end{aligned}
$$

17.2.113

$$
\begin{aligned}
r(x) &= R_2 - (R_2 - R_1)\frac{x}{L} \\
A(x) &= \pi r(x)^2 \\
&= \pi\left[R_2 - (R_2 - R_1)\frac{x}{L}\right]^2 \\
H &= kA(x)\frac{dT}{dx} \\
&= k\pi\left[R_2 - (R_2 - R_1)\frac{x}{L}\right]^2\frac{dT}{dx} \\
\frac{1}{\left[R_2 - (R_2 - R_1)\frac{x}{L}\right]^2}H\,dx &= k\pi\,dT \\
\int_0^L \frac{1}{\left[R_2 - (R_2 - R_1)\frac{x}{L}\right]^2}H\,dx &= \int_{T_H}^{T_C} k\pi\,dT \\
\frac{HL}{R_2 - R_1}\left[\frac{1}{R_2 - (R_2 - R_1)\frac{x}{L}}\right]_0^L &= k\pi(T_C - T_H) \\
\frac{HL}{R_2 - R_1}\left(\frac{1}{R_1} - \frac{1}{R_2}\right) &= k\pi(T_C - T_H) \\
\frac{HL}{R_2 - R_1}\frac{R_2 - R_1}{R_1R_2} &= k\pi(T_C - T_H) \\
H &= \frac{k\pi R_1R_2(T_C - T_H)}{L}
\end{aligned}
$$

17.2.115

(a)

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

(b)

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

17.2.117

a

17.2.119

a

18 Thermal Properties of Matter

18.1 Guided Practice

18.1.1

(a)

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

(b)

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

18.1.2

(a)

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

(b)

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

18.1.3

(a)

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

(b)

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

18.1.4

(a)

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

(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)

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

(b)

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

18.1.10

(a)

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

(b)

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

18.1.11

(a)

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

(b)

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

18.1.12

(a)

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

(b) Doubling r.

18.1.13

(a)

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

(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.