

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