# 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)

$$\Delta L = \alpha L_0 \Delta T$$
$$\alpha = \frac{\Delta L}{L_0 \Delta T}$$
$$= 2.0 \times 10^{-5}\,\mathrm{K}^{-1}$$

(b)

$$\Delta L = \alpha L_0 \Delta T$$
$$= -0.27\,\mathrm{mm}$$

### 17.1.2

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

**17.1.3**

$$\frac{\Delta L}{L_0} = \alpha \Delta T$$

$$Y = \frac{F/A}{\Delta L/L_0}$$

$$\frac{\Delta L}{L_0} = \frac{F}{AY}$$

$$\alpha \Delta T + \frac{F}{AY} = 0$$

$$\frac{F}{AY} = -\alpha \Delta T$$

$$F = -\alpha AY \Delta T$$

$$= -(2.0 \times 10^{-5})(\pi 0.005^2)(9.0 \times 10^{10})(-12)$$

$$= 1.70 \times 10^3 \, \text{N}$$

Tensile

**17.1.4**

$$\Delta L = \alpha_A L_A \Delta T + \alpha_B L_B \Delta T$$

$$\frac{\Delta L}{\Delta T} = \alpha_A L_A + \alpha_B (L - L_A)$$

$$= (\alpha_A - \alpha_B) L_A + \alpha_B L$$

$$L_A = \frac{1}{\alpha_A - \alpha_B} \left( \frac{\Delta L}{\Delta T} - \alpha_B L \right)$$

**17.1.5**

$$0 = m_{Al} c_{Al} \Delta T_{Al} + m_W c_W \Delta T_W$$

$$= m_{Al} c_{Al} (T - T_{Al}) + m_W c_W (T - T_W)$$

$$m_{Al} = -\frac{m_W c_W (T - T_W)}{c_{Al} (T - T_{Al})}$$

$$= 0.20 \, \text{kg}$$

**17.1.6**

$$0 = m_I L_f + m_C c_C \Delta T$$

$$= m_I L_f - m_C c_C T$$

$$T = \frac{m_I L_f}{m_C c_C}$$

$$= 14.0 \, ^\circ\text{C}$$

**17.1.7**

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

**17.1.8**

Cooling the silver to $0 \, ^\circ \text{C}$ 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.

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

**17.1.9**

(a)

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

(b)

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

**17.1.10**

(a)

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

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

(b)

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

**17.1.11**

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

**17.1.12**

(a)

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

(b)

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

## 17.2    Exercises and Problems

**17.2.15**

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

**17.2.25**

$$Q = (m_{Al}c_{Al} + m_W c_W)\Delta T$$
$$= 5.55 \times 10^5\,\text{J}$$

**17.2.33**

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

**17.2.35**

(a)

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

(b) Water because it has a higher specific heat

(c) It would be too small

**17.2.45**

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

**17.2.55**

$$k_C A \frac{T_H - T}{L} = kA\frac{T}{L}$$

$$k_C T_H - k_C T = kT$$

$$k_C T_H = (k + k_C)T$$

$$T = \frac{k_C}{k + k_C}T_H$$

$$0.71 = \frac{k_C}{k + k_C}$$

$$0.71(k + k_C) = k_C$$

$$0.71k + 0.71k_C = k_C$$

$$0.71k = 0.29k_C$$

$$k = \frac{0.29}{0.71}k_C$$

$$\approx 157\,\mathrm{W/(m\,K)}$$

**17.2.57**

(a)

$$k_W \frac{T - T_C}{L_W} = k_S \frac{T_H - T}{L_S}$$

$$\left(\frac{k_W}{L_W} + \frac{k_S}{L_S}\right)T = \frac{k_S}{L_S}T_H + \frac{k_W}{L_W}T_C$$

$$T = \frac{\frac{k_S}{L_S}T_H + \frac{k_W}{L_W}T_C}{\frac{k_W}{L_W} + \frac{k_S}{L_S}}$$

$$= -0.86\,^{\circ}\mathrm{C}$$

(b)

$$H = k_W \frac{T - T_C}{L_W}$$

$$= 24.4\,\mathrm{W/m^2}$$

**17.2.65**

$$H = Ae\sigma T^4$$

$$A = \frac{H}{e\sigma T^4}$$

$$= 2.1\,\mathrm{cm^2}$$

**17.2.69**

$$\Delta L = (\alpha_B L_B + \alpha_S L_S)\Delta T$$

$$T = T_0 + \frac{\Delta L}{\alpha_B L_B + \alpha_S L_S}$$

$$= 35.0\,^\circ\text{C}$$

**17.2.71**

$$Q = mc\Delta T$$

$$= \rho V c \Delta T$$

$$\Delta T = \frac{Q}{\rho V c}$$

$$\Delta V = \beta V \Delta T$$

$$= \frac{\beta Q}{\rho c}$$

$$c = \frac{\beta Q}{\rho \Delta V}$$

**17.2.73**

(a)

$$0.0\,^\circ\text{M} = -39\,^\circ\text{C}$$

$$100.0\,^\circ\text{M} = 357\,^\circ\text{C}$$

$$T_M = \frac{T_C + 39\,^\circ\text{C}}{3.96}$$

$$\frac{100\,^\circ\text{C} + 39\,^\circ\text{C}}{3.96} = 35.1\,^\circ\text{M}$$

(b)

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

**17.2.75**

$$Ah + \beta_G Ah(T - T_0) = Ah' + \beta_O Ah'(T - T_0)$$

$$Ah + \beta_G AhT - \beta_G AhT_0 = Ah' + \beta_O Ah'T - \beta_O Ah'T_0$$

$$(\beta_G Ah - \beta_O Ah')T = (Ah' - \beta_O Ah'T_0) - (Ah - \beta_G AhT_0)$$

$$T = \frac{(1 - \beta_O T_0)h' - (1 - \beta_G T_0)h}{\beta_G h - \beta_O h'}$$

$$= 69.4\,^\circ\text{C}$$

**17.2.79**

(a)

$$Y = \frac{F/A}{\Delta L/L_0}$$

$$\Delta L = \frac{FL_0}{AY}$$

$$\Delta L = \alpha L_0 \Delta T$$

$$\Delta L = \alpha L_0 \Delta T + \frac{FL_0}{AY}$$

$$\frac{F}{A} = Y\left(\frac{\Delta L}{L_0} - \alpha\Delta T\right)$$

(b)

$$\Delta L_B = \alpha_B L_{B0} \Delta T$$

$$\frac{\Delta L_B}{L_{B0}} = \alpha_B \Delta T$$

$$\frac{F}{A} = Y_S(\alpha_B - \alpha_S)\Delta T$$

$$= 1.9 \times 10^8 \, \text{Pa}$$

**17.2.85**

(a)

$$\frac{dQ}{dT} = nk\frac{T^3}{\theta^3}$$

$$Q = \int_a^b nk\frac{T^3}{\theta^3}$$

$$= \frac{nk}{\theta^3}\left[\frac{1}{4}T^4\right]_a^b$$

$$= \frac{nk}{4\theta^3}(b^4 - a^4)$$

$$= 83.6 \, \text{J}$$

(b)

$$Q = nC\Delta T$$

$$C = \frac{Q}{n\Delta T}$$

$$= 1.86 \, \text{J/(mol K)}$$

(c)

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

**17.2.95**

(a)

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

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

**17.2.99**

(a)

$$H = kA\frac{T_H - T_C}{L}$$
$$= 94\,\text{W}$$

(b)

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

**17.2.105**

(b)

$$\frac{dQ}{dt} = k\frac{T_H - T_C}{L}$$

$$\frac{dQ}{dL} = \rho L_f$$

$$\frac{dL}{dt} = \frac{dL}{dQ}\frac{dQ}{dt}$$

$$= \frac{1}{\rho L_f}k\frac{T_H - T_C}{L}$$

$$L\frac{dL}{dt} = \frac{k(T_H - T_C)}{\rho L_f}$$

$$\int_0^t L\frac{dL}{dt}\,dt = \int_0^t \frac{k(T_H - T_C)}{\rho L_f}\,dt$$

$$\int_0^L L'\,dL' = \frac{k(T_H - T_C)}{\rho L_f}t$$

$$\frac{1}{2}L^2 = \frac{k(T_H - T_C)}{\rho L_f}t$$

$$L = \sqrt{\frac{2k(T_H - T_C)}{\rho L_f}t}$$

(c)

$$t = \frac{L^2 \rho L_f}{2k(T_H - T_C)}$$

$$= 7.5\,\text{days}$$

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

**17.2.107**

$$A = 2\pi \left(\frac{d}{2}\right)^2 + 2\pi \left(\frac{d}{2}\right) h$$

$$= 8.34 \times 10^{-2} \, \text{m}^2$$

$$H = Ae\sigma(T^4 - T_s^4)$$

$$= Ae\sigma(T^4 - T_s^4)$$

$$= -3.38 \times 10^{-2} \, \text{W}$$

$$m = \frac{H \times 60 \times 60}{L_v}$$

$$= 5.82 \times 10^{-3} \, \text{kg/h}$$

$$= 5.82 \, \text{g/h}$$

**17.2.113**

$$r(x) = R_2 - (R_2 - R_1)\frac{x}{L}$$

$$A(x) = \pi r(x)^2$$

$$= \pi \left[R_2 - (R_2 - R_1)\frac{x}{L}\right]^2$$

$$H = kA(x)\frac{dT}{dx}$$

$$= k\pi \left[R_2 - (R_2 - R_1)\frac{x}{L}\right]^2 \frac{dT}{dx}$$

$$\frac{1}{\left[R_2 - (R_2 - R_1)\frac{x}{L}\right]^2} H \, dx = k\pi \, dT$$

$$\int_0^L \frac{1}{\left[R_2 - (R_2 - R_1)\frac{x}{L}\right]^2} H \, dx = \int_{T_H}^{T_C} k\pi \, dT$$

$$\frac{HL}{R_2 - R_1} \left[\frac{1}{R_2 - (R_2 - R_1)\frac{x}{L}}\right]_0^L = k\pi(T_C - T_H)$$

$$\frac{HL}{R_2 - R_1} \left(\frac{1}{R_1} - \frac{1}{R_2}\right) = k\pi(T_C - T_H)$$

$$\frac{HL}{R_2 - R_1} \frac{R_2 - R_1}{R_1 R_2} = k\pi(T_C - T_H)$$

$$H = \frac{k\pi R_1 R_2 (T_C - T_H)}{L}$$

**17.2.115**

(a)

$$H = k(2\pi r L)\frac{dT}{dr}$$

$$\frac{1}{r}H\,dr = 2\pi kL\,dT$$

$$\int_a^b \frac{1}{r}H\,dr = \int_{T_1}^{T_2} 2\pi kL\,dT$$

$$H\ln\frac{b}{a} = 2\pi kL(T_2 - T_1)$$

$$H = \frac{2\pi kL(T_2 - T_1)}{\ln b/a}$$

(b)

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

$$\frac{T - T_2}{\ln r/a} = \frac{T_2 - T_1}{\ln b/a}$$

$$T - T_2 = \frac{\ln r/a}{\ln b/a}(T_2 - T_1)$$

$$T = T_2 + \frac{\ln r/a}{\ln b/a}(T_2 - T_1)$$

**17.2.117**

a

**17.2.119**

a