

Contents

1	Chapter 17 - Temperature and Heat	1
1.1	17.3	2
1.2	17.5	2
2	Linear Thermal Expansion	2
2.1	Expanding Holes and Volume Expansion	2
2.2	17.11	3
2.3	17.15	3
2.4	17.16	3
2.5	17.19	4
3	Thermal Expansion of Water	4
3.1	Thermal Stress	4
3.2	17.22	4
4	Quantity of Heat	5
4.1	17.29	5
4.2	17.25	6
4.3	17.31	6
4.4	17.33	7
5	Molar Heat Capacity	7
5.1	Phase Changes	7
5.2	Problem	7
5.3	17.34	8
5.4	17.36	8
5.5	17.37	9
5.6	17.40	9
5.7	17.49	10
5.8	17.51	10
6	Mechanisms of Heat Transfer	10
6.1	17.56	11
6.2	17.57	12
6.3	17.60	13

1 Chapter 17 - Temperature and Heat

To convert Celsius to Fahrenheit:

$$T_F = \frac{9}{5}T_C + 32^\circ \quad (1)$$

To convert Fahrenheit to Celsius:

$$T_C = \frac{5}{9}(T_F - 32^\circ) \quad (2)$$

To convert from Celsius to Kelvin:

$$T_K = T_C + 273.15 \quad (3)$$

1.1 17.3

(a)

$$T_{F_0} = -4.0^\circ$$

$$T_{F_1} = 45.0^\circ$$

$$\Delta T_F = T_{F_1} - T_{F_0}$$

$$\Delta T_F = 45.0^\circ - -4.0^\circ$$

$$\Delta T_F = 49.0^\circ$$

$$(100)\Delta T_F = (180)T_C$$

$$T_C = 27.2^\circ\text{C}$$

1.2 17.5

$$\Delta T_K = 10.0\text{ K}$$

(a)

$$T_{F_1} = \frac{9}{5}(10.0^\circ\text{C} + 32.0^\circ)$$

$$T_{F_1} = 18.0^\circ$$

$$T_{F_0} = \frac{9}{5}(0 + 32.0^\circ)$$

$$T_{F_0} = 57.6^\circ$$

$$T_F = T_{F_1} - T_{F_0}$$

$$T_F = 18.0^\circ$$

2 Linear Thermal Expansion

$$\Delta L = \alpha L_0 \Delta T \quad (4)$$

2.1 Expanding Holes and Volume Expansion

$$\Delta V = \beta V_0 \Delta T, \quad \beta = 3\alpha \quad (5)$$

2.2 17.11

$$\begin{aligned}L_0 &= 1410 \text{ m} \\T_0 &= -5.0^\circ\text{C} \\T_1 &= 18.0^\circ\text{C} \\\alpha_{steel} &= 1.2 \times 10^{-5}^\circ\text{C}^{-1} \\\Delta L &=?\end{aligned}$$

$$\begin{aligned}\Delta L &= L_0 \alpha \Delta T \\\Delta L &= (1410 \text{ m})(1.2 \times 10^{-5}^\circ\text{C}^{-1})(18.0^\circ\text{C} - (-5.0^\circ\text{C})) \\\Delta L &= 0.38916 \text{ m}\end{aligned}$$

2.3 17.15

$$\begin{aligned}T_0 &= 20.0^\circ\text{C} \\\beta_{copper} &= 5.1 \times 10^{-5}^\circ\text{C}^{-1} \\V_1 &= (0.0015)V_0\end{aligned}$$

$$\begin{aligned}\Delta V &= V_0 \beta \Delta T \\\Delta T &= \frac{\Delta V}{V_0 \beta} \\\Delta T &= \frac{(0.0015)V_0}{V_0 \beta} \\\Delta T &= \frac{0.0015}{5.1 \times 10^{-5}^\circ\text{C}^{-1}} \\\Delta T &= 29.4118^\circ\text{C}\end{aligned}$$

2.4 17.16

$$\begin{aligned}d &= 55.0 \text{ m} \\T_{winter} &= -15^\circ\text{C} \\T_{summer} &= 35^\circ\text{C} \\\beta_{aluminum} &= 7.2 \times 10^{-5}^\circ\text{C}^{-1} \\\Delta V &=?\end{aligned}$$

$$\begin{aligned}\Delta V &= V_0 \beta \Delta T \\\Delta V &= \left(\frac{2}{3}\pi \frac{55.0 \text{ m}}{2}\right)(7.2 \times 10^{-5}^\circ\text{C}^{-1})(35^\circ\text{C} - (-15^\circ\text{C})) \\\Delta V &= 156.805 \text{ m}^3\end{aligned}$$

2.5 17.19

$$d = 1.35 \text{ cm} = 0.0135 \text{ m}$$

$$T_0 = 25.0^\circ\text{C}$$

$$\alpha_{steel} = 1.2 \times 10^{-5} \text{ }^\circ\text{C}^{-1}$$

(a)

$$A_0 = \pi r^2$$

$$A_0 = \pi \left(\frac{0.0135 \text{ m}}{2} \right)^2$$

$$A_0 = 0.00143 \text{ m}^2$$

(b)

$$\Delta A = 2\alpha A_0 \Delta T$$

$$\Delta A = 2(1.2 \times 10^{-5} \text{ }^\circ\text{C}^{-1})(0.00143 \text{ m}^2)(175^\circ\text{C} - 25.0^\circ\text{C})$$

$$\Delta A = 5.148 \times 10^{-6} \text{ m}^2$$

$$A = A_0 + \Delta A$$

$$A = 0.00143 \text{ m}^2 + 5.148 \times 10^{-6} \text{ m}^2$$

$$A = 0.001435 \text{ m}^2$$

3 Thermal Expansion of Water

3.1 Thermal Stress

$$\frac{F}{A} = -Y\alpha\Delta T \quad (6)$$

3.2 17.22

$$L_0 = 185 \text{ cm} = 1.85 \text{ m}$$

$$d = 1.60 \text{ cm} = 0.016 \text{ m}$$

$$T_0 = 120.0^\circ\text{C}$$

$$T_1 = 10.0^\circ\text{C}$$

$$Y_{brass} = 9.0 \times 10^{10} \text{ Pa}$$

$$\alpha_{brass} = 2.0 \times 10^{-5} \text{ }^\circ\text{C}^{-1}$$

$$F = ?$$

$$\frac{F}{A} = -Y\alpha\Delta T$$

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

$$F = -\left(\pi\left(\frac{0.016\text{ m}}{2}\right)^2\right)(9.0 \times 10^{10}\text{ Pa})(2.0 \times 10^{-5}\text{ }^\circ\text{C}^{-1})(10.0\text{ }^\circ\text{C} - 120.0\text{ }^\circ\text{C})$$

$$F = 39\,810.3\text{ N}$$

$$F_0 = F_1 = \frac{F}{2} = \frac{39\,810.3\text{ N}}{2} = 19\,905.1\text{ N}$$

4 Quantity of Heat

The quantity of heat Q required to increase the temperature of a mass m of a certain material by ΔT is:

$$Q = mc\Delta T \quad (7)$$

$$1\text{ cal} = 4.186\text{ J} \quad (8)$$

Specific heat is found by:

$$dQ = mcdT$$

$$c = \frac{1}{m} \frac{dQ}{dT} \quad (9)$$

4.1 17.29

$$w = 28.4\text{ N}$$

$$Q = 1.25 \times 10^4\text{ J}$$

$$\Delta T = 18.0\text{ }^\circ\text{C}$$

$$c = ?$$

$$Q = mc\Delta T$$

$$c = \frac{Q}{\frac{w}{g}\Delta T}$$

$$c = \frac{1.25 \times 10^4\text{ J}}{\left(\frac{28.4\text{ N}}{9.80\text{ m s}^{-2}}\right)(18.0\text{ }^\circ\text{C})}$$

$$c = 239.632\text{ J kg}^{-1}\text{ K}$$

4.2 17.25

$$m_{kettle} = 1.10 \text{ kg}$$

$$m_{water} = 1.80 \text{ kg}$$

$$T_0 = 20.0^\circ\text{C}$$

$$T_1 = 85.0^\circ\text{C}$$

$$c_{aluminum} = 910 \text{ J kg}^{-1} \text{ K}$$

$$c_{water} = 4190 \text{ J kg}^{-1} \text{ K}$$

$$Q = ?$$

$$Q_{water} = m_{water} c_{water} \Delta T$$

$$Q_{water} = (1.80 \text{ kg})(4190 \text{ J kg}^{-1} \text{ K})(85.0^\circ\text{C} - 20.0^\circ\text{C})$$

$$Q_{water} = 490\,230 \text{ J}$$

$$Q_{aluminum} = m_{aluminum} c_{aluminum} \Delta T$$

$$Q_{aluminum} = (1.10 \text{ kg})(910 \text{ J kg}^{-1} \text{ K})(85.0^\circ\text{C} - 20.0^\circ\text{C})$$

$$Q_{aluminum} = 65\,065 \text{ J}$$

$$Q = Q_{water} + Q_{aluminum}$$

$$Q = 490\,230 \text{ J} + 65\,065 \text{ J}$$

$$Q = 555\,295 \text{ J}$$

4.3 17.31

$$y_1 = 225 \text{ m}$$

$$m = 1.00 \text{ L}$$

$$y_0 = 0$$

$$c_{water} = 4190 \text{ J kg}^{-1} \text{ K}$$

$$\Delta T = ?$$

$$U = Q$$

$$mgy_1 = mc\Delta T$$

$$\Delta T = \frac{gy_1}{c}$$

$$\Delta T = \frac{(9.80 \text{ m s}^{-2})(225 \text{ m})}{4190 \text{ J kg}^{-1} \text{ K}}$$

$$\Delta T = 0.5262^\circ\text{C}$$

4.4 17.33

$$m_{bullet} = 15.0 \text{ g} = 0.015 \text{ kg}$$

$$v_0 = 865 \text{ m s}^{-1}$$

$$m_{water} = 13.5 \text{ kg}$$

$$v_1 = 534 \text{ m s}^{-1}$$

$$c_{water} = 4190 \text{ J kg}^{-1} \text{ K}$$

$$\Delta T = ?$$

$$E_0 = E_1$$

$$\frac{1}{2}m_{bullet}v_0^2 = \frac{1}{2}m_{bullet}v_1^2 + m_{water}c_{water}\Delta T$$

$$\Delta T = \frac{m_{bullet}(v_0^2 - v_1^2)}{2m_{water}c_{water}}$$

$$\Delta T = \frac{(0.015 \text{ kg} [(865 \text{ m s}^{-1})^2 - (534 \text{ m s}^{-1})^2])}{2(13.5 \text{ kg})(4190 \text{ J kg}^{-1} \text{ K})}$$

$$\Delta T = 0.61399^\circ \text{C}$$

5 Molar Heat Capacity

Total mass m of material = Mass per mole $M \times$ Number of moles n :

$$m = nM \quad (10)$$

$$Q = nMc\Delta T \quad (11)$$

The produce Mc is called the **molar heat capacity**.

$$Q = nC\Delta T \quad (12)$$

5.1 Phase Changes

The **latent heat**, L , is the heat per unit mass that is transferred in a phase change.

$$Q = \pm mL \quad (13)$$

5.2 Problem

(a)

$$m_{water} = 1 \text{ kg}$$

$$T_{water} = 100^\circ \text{C}$$

$$m_{water_vapor} = 1 \text{ kg}$$

$$T_{water_vapor} = 100^\circ \text{C}$$

$$\begin{aligned}
Q_{water} &= m_{water}L_{water} \\
Q_w &= (1 \text{ kg})(2256 \times 10^3 \text{ J kg}^{-1}) \\
Q_w &= 2.256 \times 10^6 \text{ J}
\end{aligned}$$

5.3 17.34

$$\begin{aligned}
m_{water} &= 750 \text{ g} = 0.750 \text{ kg} \\
T_{water_0} &= 10.0^\circ\text{C} \\
T_{water_1} &= 75.0^\circ\text{C} \\
T_{boil_0} &= 100.0^\circ\text{C} \\
T_{boil_1} &= 75.0^\circ\text{C}
\end{aligned}$$

$$\begin{aligned}
m_{water}c_{water}\Delta T_{water} + m_{boil}c_{water}\Delta T_{boil} &= 0 \\
m_{boil} &= -\frac{m_{water}\Delta T_{water}}{\Delta T_{boil}} \\
m_{boil} &= -\frac{(0.750 \text{ kg})(75.0^\circ\text{C} - 10.0^\circ\text{C})}{75.0^\circ\text{C} - 100.0^\circ\text{C}} \\
m_{boil} &= 1.95 \text{ kg}
\end{aligned}$$

5.4 17.36

$$\begin{aligned}
T_1 &= 32.0^\circ\text{C} \\
m_{patient} &= 70.0 \text{ kg} \\
T_{ice} &= 0^\circ\text{C} \\
m_{ice} &=? \\
c_{human} &= 3480 \text{ J kg}^{-1}^\circ\text{C}^{-1} \\
T_{human} &= 37.0^\circ\text{C}
\end{aligned}$$

$$\begin{aligned}
m_{ice}L_{ice} + m_{human}c_{human}\Delta T &= 0 \\
m_{ice} &= -\frac{m_{human}c_{human}\Delta T}{L_{ice}} \\
m_{ice} &= -\frac{(70.0 \text{ kg})(3480 \text{ J kg}^{-1}^\circ\text{C}^{-1})(32.0^\circ\text{C} - 37.0^\circ\text{C})}{334 \times 10^3 \text{ J kg}^{-1}} \\
m_{ice} &= 3.64671 \text{ kg}
\end{aligned}$$

5.5 17.37

$$m_{iron} = 1.20 \text{ kg}$$

$$T_{iron0} = 650.0^\circ\text{C}$$

$$T_{water} = 15.0^\circ\text{C}$$

$$T_{iron1} = 120.0^\circ\text{C}$$

$$m_{water} = ?$$

$$Q_0 + Q_1 + Q_2 = 0$$

$$m_{iron}c_{iron}\Delta T_{iron} + m_{water}c_{water}\Delta T_{water} + m_{water}L_{water_vapor} = 0$$

$$m_{water} = -\frac{m_{iron}c_{iron}\Delta T_{iron}}{c_{water}\Delta T_{water} + L_{water_vapor}}$$

$$m_{water} = -\frac{(1.20 \text{ kg})(0.47 \times 10^3 \text{ J kg}^{-1} \text{ K}^{-1})(120.0^\circ\text{C} - 650.0^\circ\text{C})}{(4190 \text{ J kg}^{-1} \text{ K}^{-1})(100.0^\circ\text{C} - 15.0^\circ\text{C}) + 2256 \times 10^3 \text{ J kg}^{-1}}$$

$$m_{water} = 0.114 \text{ kg}$$

5.6 17.40

$$m_{ice} = 0.200 \text{ kg}$$

$$T_{ice0} = -40.0^\circ\text{C}$$

$$m_{water} = ?$$

$$T_{water0} = 80.0^\circ\text{C}$$

$$T_1 = 28.0^\circ\text{C}$$

$$Q_0 + Q_1 + Q_2 + Q_3 = 0$$

$$m_{ice}c_{ice}\Delta T_{ice} + m_{ice}L_{ice} + m_{ice}c_{water}\Delta T_{melted} + m_{water}c_{water}\Delta T_{water} = 0$$

$$m_{water} = -\frac{m_{ice}[c_{ice}\Delta T_{ice} + L_{ice} + c_{water}\Delta T_{melted}]}{c_{water}\Delta T_{water}}$$

$$m_{water} = -\frac{0.200 \text{ kg}[(2100 \text{ J kg}^{-1} \text{ }^\circ\text{C}^{-1})(0 - -40.0^\circ\text{C}) + 334 \times 10^3 \text{ J kg}^{-1} + (4190 \text{ J kg}^{-1} \text{ K}^{-1})(28.0^\circ\text{C} - 0)]}{(4190 \text{ J kg}^{-1} \text{ K}^{-1})(28.0^\circ\text{C} - 80.0^\circ\text{C})}$$

$$m_{water} = 0.491 \text{ kg}$$

5.7 17.49

$$d_{\text{asteroid}} = 10 \text{ km} = 10\,000 \text{ m}$$

$$m_{\text{asteroid}} = 2.60 \times 10^{15} \text{ kg}$$

$$v_{\text{asteroid}} = 32.0 \text{ km s}^{-1} = 32\,000 \text{ m s}^{-1}$$

$$T_{\text{water}_0} = 10.0^\circ\text{C}$$

$$m_{\text{water}} = ?$$

$$KE = Q_0 + Q_1$$

$$\frac{1}{2}m_a v_a^2 = m_w c_w \Delta T + m_w L_w$$

$$m_w = \frac{m_a v_a^2}{c_w \Delta T + L_w}$$

$$m_w = \frac{0.01(2.60 \times 10^{15} \text{ kg})(32\,000 \text{ m s}^{-1})^2}{2[(4190 \text{ J kg}^{-1} \text{ K}^{-1})(100.0^\circ\text{C} - 10.0^\circ\text{C}) + 2256 \times 10^3 \text{ J kg}^{-1}]}$$

$$m_w = 5.055\,64 \times 10^{15} \text{ kg}$$

5.8 17.51

$$m_{\text{water}} = 0.250 \text{ kg}$$

$$T_{\text{water}_0} = 75.0^\circ\text{C}$$

$$T_{\text{ice}} = -20.0^\circ\text{C}$$

$$m_{\text{ice}} = ?$$

$$T_1 = 40.0^\circ\text{C}$$

$$Q_{\text{ice,water}} + Q_{\text{water}} + Q_{\text{water,system}} = Q_{\text{water,system}}$$

$$m_{\text{ice}} c_{\text{ice}} \Delta T_{\text{ice,water}} + m_{\text{ice}} L_{\text{water}} + m_{\text{ice}} c_{\text{water}} \Delta T_{\text{water,system}} = m_{\text{water}} c_{\text{water}} \Delta T_{\text{water,system}}$$

$$m_{\text{ice}} = \frac{m_{\text{water}} c_{\text{water}} \Delta T_{\text{water,system}}}{c_{\text{ice}} \Delta T_{\text{ice,water}} + L_{\text{water}} + c_{\text{water}} \Delta T_{\text{water,system}}}$$

$$m_{\text{ice}} = \frac{(0.250 \text{ kg})(4190 \text{ J kg}^{-1} \text{ }^\circ\text{C}^{-1})(40.0^\circ\text{C} - 75.0^\circ\text{C})}{(2100 \text{ J kg}^{-1} \text{ }^\circ\text{C}^{-1})(0 - -20.0^\circ\text{C}) + 334 \times 10^3 \text{ J kg}^{-1} + (4190 \text{ J kg}^{-1} \text{ K}^{-1})(40.0^\circ\text{C} - 0)}$$

$$m_{\text{ice}} = -0.0674 \text{ kg}$$

6 Mechanisms of Heat Transfer

Three mechanisms of heat transfer:

- **Conduction** occurs within an object or between two objects in contact.
- **Convection** depends on motion of mass from one region of space to another.
- **Radiation** is heat transfer by electromagnetic radiation, such as sunshine, with no need for matter to be present in the space between objects.

$$H = \frac{dQ}{dt} = kA \frac{T_H - T_C}{L} \quad (14)$$

6.1 17.56

$$T_1 = 100.0^\circ\text{C}$$

$$T_0 = 0.00^\circ\text{C}$$

$$L = 60.0\text{ cm} = 0.60\text{ m}$$

$$A = 1.25\text{ cm}^2 = 0.000125\text{ m}^2$$

$$m_{ice} = 8.50\text{ g} = 0.00850\text{ kg}$$

$$\Delta t = 10.0\text{ min} = 600\text{ s}$$

$$k = ?$$

$$\frac{Q}{\Delta t} = \frac{kA(T_1 - T_0)}{L}$$

$$k = \frac{mLL}{\Delta tA(T_1 - T_0)}$$

$$k = \frac{(0.00850\text{ kg})(334 \times 10^3\text{ J kg}^{-1})(0.60\text{ m})}{(600\text{ s})(0.000125\text{ m}^2)(100.0^\circ\text{C} - 0.00^\circ\text{C})}$$

$$k = 227.12\text{ J m}^{-1}\text{ s}^{-1}\text{ }^\circ\text{C}^{-1} = 227.12\text{ W m}^{-1}\text{ }^\circ\text{C}^{-1}$$

6.2 17.57

$$l_{out} = 3.0 \text{ cm} = 0.03 \text{ m}$$

$$l_{in} = 2.2 \text{ cm} = 0.022 \text{ m}$$

$$k_{wood} = 0.080 \text{ W m}^{-1} \text{ K}^{-1}$$

$$k_{styrofoam} = 0.027 \text{ W m}^{-1} \text{ K}^{-1}$$

$$T_{in} = 19.0^\circ \text{C}$$

$$T_{out} = -10.0^\circ \text{C}$$

(a)

$$H_w = k_w A \left(\frac{T - T_{out}}{l_{out}} \right)$$

$$H_s = k_s A \left(\frac{T_{in} - T}{l_{in}} \right)$$

$$k_w A \left(\frac{T - T_{out}}{l_{out}} \right) = k_s A \left(\frac{T_{in} - T}{l_{in}} \right)$$

$$k_w \left(\frac{T - T_{out}}{l_{out}} \right) - k_s \left(\frac{T_{in} - T}{l_{in}} \right) = 0$$

$$T \left[\frac{k_w}{l_{out}} + \frac{k_s}{l_{in}} \right] = \frac{k_w T_{out}}{l_{out}} + \frac{k_s T_{in}}{l_{in}}$$

$$T = \frac{\frac{k_w T_{out}}{l_{out}} + \frac{k_s T_{in}}{l_{in}}}{\frac{k_w}{l_{out}} + \frac{k_s}{l_{in}}}$$

$$T = \frac{\frac{(0.080 \text{ W m}^{-1} \text{ K}^{-1})(-10.0^\circ \text{C})}{0.03 \text{ m}} + \frac{(0.027 \text{ W m}^{-1} \text{ K}^{-1})(19.0^\circ \text{C})}{0.022 \text{ m}}}{\frac{0.080 \text{ W m}^{-1} \text{ K}^{-1}}{0.03 \text{ m}} + \frac{0.027 \text{ W m}^{-1} \text{ K}^{-1}}{0.022 \text{ m}}}$$

$$T = -0.860^\circ \text{C}$$

(b)

$$\frac{H}{A} = k_s \left(\frac{T_{in} - T}{l_{in}} \right)$$

$$\frac{H}{A} = (0.027 \text{ W m}^{-1} \text{ K}^{-1}) \left(\frac{19.0^\circ \text{C} - (-0.860^\circ \text{C})}{0.022 \text{ m}} \right)$$

$$\frac{H}{A} = 24.4 \text{ W m}^{-2}$$

6.3 17.60

$$l_{copper} = 1.00 \text{ m}$$

$$l_{steel} = ?$$

$$A = 4.00 \text{ cm}^2 = 4.0 \times 10^{-4} \text{ m}^2$$

$$T_{steel,copper} = 65.0^\circ\text{C}$$

(a)

$$\frac{Q}{t} = \frac{k_c A (T_{boil} - T_{s,c})}{l_c}$$

$$\frac{Q}{t} = \frac{(385 \text{ W m}^{-1} \text{ K}^{-1})(4.0 \times 10^{-4} \text{ m}^2)(100.0^\circ\text{C} - 65.0^\circ\text{C})}{1.00 \text{ m}}$$

$$\frac{Q}{t} = 5.39 \text{ J s}^{-1}$$

$$l_{steel} = \frac{k_s A (T_{s,c} - T_{ice})}{\left(\frac{Q}{t}\right)^{-1}}$$

$$l_{steel} = \frac{(50.2 \text{ W m}^{-1} \text{ K}^{-1})(4.0 \times 10^{-4} \text{ m}^2)(65.0^\circ\text{C} - 0.00^\circ\text{C})}{(5.39 \text{ J s}^{-1})^{-1}}$$

$$l_{steel} = 0.242 \text{ m}$$