Contents

1 Chapter 17 - Temperature and Heat

To convert Celsius to Fahrenheit:

$$T_F = \frac{9}{5}T_C + 32^\circ \tag{1}$$

To convert Fahrenheit to Celsius:

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

To convert from Celsius to Kelvin:

$$T_K = T_C + 273.15 \tag{3}$$

1.1 17.3

(a)

$$T_{F_0} = -4.0°$$
$$T_{F_1} = 45.0°$$

$$\Delta T_F = T_{F_1} - T_{F_0}$$
$$\Delta T_F = 45.0° - -4.0°$$
$$\Delta T_F = 49.0°$$

$$(100)\Delta T_F = (180)T_C$$
$$T_C = 27.2\,°\mathrm{C}$$

1.2 17.5

$$\Delta T_K = 10.0\,\mathrm{K}$$

(a)

$$T_{F_1} = \frac{9}{5}(10.0\,°\mathrm{C} + 32.0°)$$
$$T_{F_1} = 18.0°$$

$$T_{F_0} = \frac{9}{5}(0 + 32.0°)$$
$$T_{F_0} = 57.6°$$

$$T_F = T_{F_1} - T_{F_0}$$
$$T_F = 18.0°$$

2 Linear Thermal Expansion

$$\Delta L = \alpha L_0 \Delta T \tag{4}$$

2.1 Expanding Holes and Volume Expansion

$$\Delta V = \beta V_0 \Delta T, \quad \beta = 3\alpha \tag{5}$$

2.2 17.11

$$\begin{aligned} L_0 &= 1410\,\mathrm{m} \\ T_0 &= -5.0\,^\circ\mathrm{C} \\ T_1 &= 18.0\,^\circ\mathrm{C} \\ \alpha_{steel} &= 1.2\times10^{-5}\,^\circ\mathrm{C}^{-1} \\ \Delta L &= ? \end{aligned}$$

$$\begin{aligned} \Delta L &= L_0\alpha\Delta T \\ \Delta L &= (1410\,\mathrm{m})(1.2\times10^{-5}\,^\circ\mathrm{C}^{-1})(18.0\,^\circ\mathrm{C}-(-5.0\,^\circ\mathrm{C}) \\ \Delta L &= 0.389\,16\,\mathrm{m} \end{aligned}$$

2.3 17.15

$$\begin{aligned} T_0 &= 20.0\,^\circ\mathrm{C} \\ \beta_{copper} &= 5.1\times10^{-5}\,^\circ\mathrm{C}^{-1} \\ V_1 &= (0.0015)V_0 \end{aligned}$$

$$\begin{aligned} \Delta V &= V_0\beta\Delta T \\ \Delta T &= \frac{\Delta V}{V_0\beta} \\ \Delta T &= \frac{(0.0015)V_0}{V_0\beta} \\ \Delta T &= \frac{0.0015}{5.1\times10^{-5}\,^\circ\mathrm{C}^{-1}} \\ \Delta T &= 29.4118\,^\circ\mathrm{C} \end{aligned}$$

2.4 17.16

$$\begin{aligned} d &= 55.0\,\mathrm{m} \\ T_{winter} &= -15\,^\circ\mathrm{C} \\ T_{summer} &= 35\,^\circ\mathrm{C} \\ \beta_{aluminum} &= 7.2\times10^{-5}\,^\circ\mathrm{C}^{-1} \\ \Delta V &= ? \end{aligned}$$

$$\begin{aligned} \Delta V &= V_0\beta\Delta T \\ \Delta V &= \left(\frac{2}{3}\pi\frac{55.0\,\mathrm{m}}{2}\right)(7.2\times10^{-5}\,^\circ\mathrm{C}^{-1})(35\,^\circ\mathrm{C}-(-15\,^\circ\mathrm{C})) \\ \Delta V &= 156.805\,\mathrm{m}^3 \end{aligned}$$

2.5 17.19

$$\begin{aligned} d &= 1.35\,\text{cm} = 0.0135\,\text{m} \\ T_0 &= 25.0\,^\circ\text{C} \\ \alpha_{steel} &= 1.2 \times 10^{-5}\,^\circ\text{C}^{-1} \end{aligned}$$

(a)

$$\begin{aligned} A_0 &= \pi r^2 \\ A_0 &= \pi \left(\frac{0.0135\,\text{m}}{2}\right)^2 \\ A_0 &= 0.001\,43\,\text{m}^2 \end{aligned}$$

(b)

$$\begin{aligned} \Delta A &= 2\alpha A_0 \Delta T \\ \Delta A &= 2(1.2 \times 10^{-5}\,^\circ\text{C}^{-1})(0.001\,43\,\text{m}^2)(175\,^\circ\text{C} - 25.0\,^\circ\text{C}) \\ \Delta A &= 5.148 \times 10^{-6}\,\text{m}^2 \end{aligned}$$

$$\begin{aligned} A &= A_0 + \Delta A \\ A &= 0.001\,43\,\text{m}^2 + 5.148 \times 10^{-6}\,\text{m}^2 \\ A &= 0.001\,435\,\text{m}^2 \end{aligned}$$

3 Thermal Expansion of Water

3.1 Thermal Stress

$$\frac{F}{A} = -Y\alpha\Delta T \tag{6}$$

3.2 17.22

$$\begin{aligned} L_0 &= 185\,\text{cm} = 1.85\,\text{m} \\ d &= 1.60\,\text{cm} = 0.016\,\text{m} \\ T_0 &= 120.0\,^\circ\text{C} \\ T_1 &= 10.0\,^\circ\text{C} \\ Y_{brass} &= 9.0 \times 10^{10}\,\text{Pa} \\ \alpha_{brass} &= 2.0 \times 10^{-5}\,^\circ\text{C}^{-1} \\ F &= ? \end{aligned}$$

$$
\begin{aligned}
\frac{F}{A} &= -Y\alpha\Delta T \\
F &= -AY\alpha\Delta T \\
F &= -\left(\pi\left(\frac{0.016\,\mathrm{m}}{2}\right)^2\right)(9.0\times10^{10}\,\mathrm{Pa})(2.0\times10^{-5}\,^\circ\mathrm{C}^{-1})(10.0\,^\circ\mathrm{C}-120.0\,^\circ\mathrm{C}) \\
F &= 39\,810.3\,\mathrm{N}
\end{aligned}
$$

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

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:

$$Q = mc\Delta T \tag{7}$$

$$1\,\mathrm{cal} = 4.186\,\mathrm{J} \tag{8}$$

Specific heat is found by:

$$dQ = mcdT$$

$$c = \frac{1}{m}\frac{dQ}{dT} \tag{9}$$

4.1 17.29

$$
\begin{aligned}
w &= 28.4\,\mathrm{N} \\
Q &= 1.25\times10^4\,\mathrm{J} \\
\Delta T &= 18.0\,^\circ\mathrm{C} \\
c &= ?
\end{aligned}
$$

$$
\begin{aligned}
Q &= mc\Delta T \\
c &= \frac{Q}{\frac{w}{g}\Delta T} \\
c &= \frac{1.25\times10^4\,\mathrm{J}}{\left(\frac{28.4\,\mathrm{N}}{9.80\,\mathrm{m\,s^{-2}}}\right)(18.0\,^\circ\mathrm{C})} \\
c &= 239.632\,\mathrm{J\,kg^{-1}\,K}
\end{aligned}
$$

4.2 17.25

$$\begin{aligned} m_{kettle} &= 1.10\,\mathrm{kg} \\ m_{water} &= 1.80\,\mathrm{kg} \\ T_0 &= 20.0\,^\circ\mathrm{C} \\ T_1 &= 85.0\,^\circ\mathrm{C} \\ c_{aluminum} &= 910\,\mathrm{J\,kg^{-1}\,K} \\ c_{water} &= 4190\,\mathrm{J\,kg^{-1}\,K} \\ Q &= ? \end{aligned}$$

$$\begin{aligned} Q_{water} &= m_{water} c_{water} \Delta T \\ Q_{water} &= (1.80\,\mathrm{kg})(4190\,\mathrm{J\,kg^{-1}\,K})(85.0\,^\circ\mathrm{C} - 20.0\,^\circ\mathrm{C}) \\ Q_{water} &= 490\,230\,\mathrm{J} \end{aligned}$$

$$\begin{aligned} Q_{aluminum} &= m_{aluminum} c_{aluminum} \Delta T \\ Q_{aluminum} &= (1.10\,\mathrm{kg})(910\,\mathrm{J\,kg^{-1}\,K})(85.0\,^\circ\mathrm{C} - 20.0\,^\circ\mathrm{C}) \\ Q_{aluminum} &= 65\,065\,\mathrm{J} \end{aligned}$$

$$\begin{aligned} Q &= Q_{water} + Q_{aluminum} \\ Q &= 490\,230\,\mathrm{J} + 65\,065\,\mathrm{J} \\ Q &= 555\,295\,\mathrm{J} \end{aligned}$$

4.3 17.31

$$\begin{aligned} y_1 &= 225\,\mathrm{m} \\ m &= 1.00\,\mathrm{L} \\ y_0 &= 0 \\ c_{water} &= 4190\,\mathrm{J\,kg^{-1}\,K} \\ \Delta T &= ? \end{aligned}$$

$$\begin{aligned} U &= Q \\ mgy_1 &= mc\Delta T \\ \Delta T &= \frac{gy_1}{c} \\ \Delta T &= \frac{(9.80\,\mathrm{m\,s^{-2}})(225\,\mathrm{m})}{4190\,\mathrm{J\,kg^{-1}\,K}} \\ \Delta T &= 0.5262\,^\circ\mathrm{C} \end{aligned}$$

4.4 17.33

$$\begin{aligned} m_{bullet} &= 15.0\,\mathrm{g} = 0.015\,\mathrm{kg} \\ v_0 &= 865\,\mathrm{m\,s^{-1}} \\ m_{water} &= 13.5\,\mathrm{kg} \\ v_1 &= 534\,\mathrm{m\,s^{-1}} \\ c_{water} &= 4190\,\mathrm{J\,kg^{-1}\,K} \\ \Delta T &= ? \end{aligned}$$

$$\begin{aligned} E_0 &= E_1 \\ \frac{1}{2} m_{bullet} v_0^2 &= \frac{1}{2} m_{bullet} v_1^2 + m_{water} c_{water} \Delta T \\ \Delta T &= \frac{m_{bullet}(v_0^2 - v_1^2)}{2 m_{water} c_{water}} \\ \Delta T &= \frac{(0.015\,\mathrm{kg}\left[(865\,\mathrm{m\,s^{-1}})^2 - (534\,\mathrm{m\,s^{-1}})^2\right])}{2(13.5\,\mathrm{kg})(4190\,\mathrm{J\,kg^{-1}\,K})} \\ \Delta T &= 0.613\,99\,{}^\circ\mathrm{C} \end{aligned}$$

5 Molar Heat Capacity

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

$$m = nM \tag{10}$$

$$Q = nMc\Delta T \tag{11}$$

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

$$Q = nC\Delta T \tag{12}$$

5.1 Phase Changes

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

$$Q = \pm mL \tag{13}$$

5.2 Problem

(a)

$$\begin{aligned} m_{water} &= 1\,\mathrm{kg} \\ T_{water} &= 100\,{}^\circ\mathrm{C} \\ m_{water\_vapor} &= 1\,\mathrm{kg} \\ T_{water\_vapor} &= 100\,{}^\circ\mathrm{C} \end{aligned}$$

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

5.3 17.34

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

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

5.4 17.36

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

$$
\begin{aligned}
m_{ice} L_{ice} + m_{human} c_{human} \Delta T = 0 \\
m_{ice} &= -\frac{m_{human} c_{human} \Delta T}{L_{ice}} \\
m_{ice} &= -\frac{(70.0\,\mathrm{kg})(3480\,\mathrm{J\,kg^{-1}\,^\circ C^{-1}})(32.0\,^\circ\mathrm{C} - 37.0\,^\circ\mathrm{C})}{334 \times 10^3\,\mathrm{J\,kg^{-1}}} \\
m_{ice} &= 3.646\,71\,\mathrm{kg}
\end{aligned}
$$

5.5 17.37

$$
\begin{aligned}
m_{iron} &= 1.20\,\text{kg} \\
T_{iron_0} &= 650.0\,°\text{C} \\
T_{water} &= 15.0\,°\text{C} \\
T_{iron_1} &= 120.0\,°\text{C} \\
m_{water} &= ?
\end{aligned}
$$

$$
\begin{aligned}
Q_0 + Q_1 + Q_2 &= 0 \\
m_{iron}c_{iron}\Delta T_{iron} + m_{water}c_{water}\Delta T_{water} + m_{water}L_{water\_vapor} &= 0
\end{aligned}
$$

$$
\begin{aligned}
m_{water} &= -\frac{m_{iron}c_{iron}\Delta T_{iron}}{c_{water}\Delta T_{water} + L_{water\_vapor}} \\
m_{water} &= -\frac{(1.20\,\text{kg})(0.47\times10^3\,\text{J}\,\text{kg}^{-1}\,\text{K}^{-1})(120.0\,°\text{C} - 650.0\,°\text{C})}{(4190\,\text{J}\,\text{kg}^{-1}\,\text{K}^{-1})(100.0\,°\text{C} - 15.0\,°\text{C}) + 2256\times10^3\,\text{J}\,\text{kg}^{-1}} \\
m_{water} &= 0.114\,\text{kg}
\end{aligned}
$$

5.6 17.40

$$
\begin{aligned}
m_{ice} &= 0.200\,\text{kg} \\
T_{ice_0} &= -40.0\,°\text{C} \\
m_{water} &= ? \\
T_{water_0} &= 80.0\,°\text{C} \\
T_1 &= 28.0\,°\text{C}
\end{aligned}
$$

$$
\begin{aligned}
Q_0 + Q_1 + Q_2 + Q_3 &= 0 \\
m_{ice}c_{ice}\Delta T_{ice} + m_{ice}L_{ice} + m_{ice}c_{water}\Delta T_{melted} + m_{water}c_{water}\Delta T_{water} &= 0
\end{aligned}
$$

$$
\begin{aligned}
m_{water} &= -\frac{m_{ice}\left[c_{ice}\Delta T_{ice} + L_{ice} + c_{water}\Delta T_{melted}\right]}{c_{water}\Delta T_{water}} \\
m_{water} &= -\frac{0.200\,\text{kg}\left[(2100\,\text{J}\,\text{kg}^{-1}\,°\text{C}^{-1})(0 - -40.0\,°\text{C}) + 334\times10^3\,\text{J}\,\text{kg}^{-1} + (4190\,\text{J}\,\text{kg}^{-1}\,\text{K}^{-1})(28.0\,°\text{C} - 0)\right]}{(4190\,\text{J}\,\text{kg}^{-1}\,\text{K}^{-1})(28.0\,°\text{C} - 80.0\,°\text{C})} \\
m_{water} &= 0.491\,39\,\text{kg}
\end{aligned}
$$

5.7 17.49

$$\begin{aligned} d_{asteroid} &= 10\,\text{km} = 10\,000\,\text{m} \\ m_{asteroid} &= 2.60 \times 10^{15}\,\text{kg} \\ v_{asteroid} &= 32.0\,\text{km}\,\text{s}^{-1} = 32\,000\,\text{m}\,\text{s}^{-1} \\ T_{water_0} &= 10.0\,^{\circ}\text{C} \\ m_{water} &= ? \end{aligned}$$

$$\begin{aligned} KE &= Q_0 + Q_1 \\ \frac{1}{2} m_a v_a^2 &= m_w c_w \Delta T + m_w L_w \\ m_w &= \frac{m_a v_a^2}{c_w \Delta T + L_w} \\ m_w &= \frac{0.01(2.60 \times 10^{15}\,\text{kg})(32\,000\,\text{m}\,\text{s}^{-1})^2}{2\left[(4190\,\text{J}\,\text{kg}^{-1}\,\text{K}^{-1})(100.0\,^{\circ}\text{C} - 10.0\,^{\circ}\text{C}) + 2256 \times 10^3\,\text{J}\,\text{kg}^{-1}\right]} \\ m_w &= 5.055\,64 \times 10^{15}\,\text{kg} \end{aligned}$$

5.8 17.51

$$\begin{aligned} m_{water} &= 0.250\,\text{kg} \\ T_{water_0} &= 75.0\,^{\circ}\text{C} \\ T_{ice} &= -20.0\,^{\circ}\text{C} \\ m_{ice} &= ? \\ T_1 &= 40.0\,^{\circ}\text{C} \end{aligned}$$

$$\begin{aligned} Q_{ice,water} + Q_{water} + Q_{water,system} &= Q_{water,system} \\ m_{ice} c_{ice} \Delta T_{ice,water} + m_{ice} L_{water} + m_{ice} c_{water} \Delta T_{water,system} &= m_{water} c_{water} \Delta T_{water,system} \end{aligned}$$

$$\begin{aligned} m_{ice} &= \frac{m_{water} c_{water} \Delta T_{water,system}}{c_{ice} \Delta T_{ice,water} + L_{water} + c_{water} \Delta T_{water,system}} \\ m_{ice} &= \frac{(0.250\,\text{kg})(4190\,\text{J}\,\text{kg}^{-1}\,^{\circ}\text{C}^{-1})(40.0\,^{\circ}\text{C} - 75.0\,^{\circ}\text{C})}{(2100\,\text{J}\,\text{kg}^{-1}\,^{\circ}\text{C}^{-1})(0 - -20.0\,^{\circ}\text{C}) + 334 \times 10^3\,\text{J}\,\text{kg}^{-1} + (4190\,\text{J}\,\text{kg}^{-1}\,\text{K}^{-1})(40.0\,^{\circ}\text{C} - 0)} \\ m_{ice} &= -0.0674\,\text{kg} \end{aligned}$$

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.

$$H = \frac{dQ}{dt} = kA\frac{T_H - T_C}{L} \tag{14}$$

6.1 17.56

$$\begin{aligned}
T_1 &= 100.0\,^\circ\mathrm{C} \\
T_0 &= 0.00\,^\circ\mathrm{C} \\
L &= 60.0\,\mathrm{cm} = 0.60\,\mathrm{m} \\
A &= 1.25\,\mathrm{cm}^2 = 0.000\,125\,\mathrm{m}^2 \\
m_{ice} &= 8.50\,\mathrm{g} = 0.008\,50\,\mathrm{kg} \\
\Delta t &= 10.0\,\mathrm{min} = 600\,\mathrm{s} \\
k &= ?
\end{aligned}$$

$$\begin{aligned}
\frac{Q}{\Delta t} &= \frac{kA(T_1 - T_0)}{L} \\
k &= \frac{mLL}{\Delta t A(T_1 - T_0)} \\
k &= \frac{(0.008\,50\,\mathrm{kg})(334 \times 10^3\,\mathrm{J\,kg^{-1}})(0.60\,\mathrm{m})}{(600\,\mathrm{s})(0.000\,125\,\mathrm{m}^2)(100.0\,^\circ\mathrm{C} - 0.00\,^\circ\mathrm{C})} \\
k &= 227.12\,\mathrm{J\,m^{-1}\,s^{-1}\,^\circ C^{-1}} = 227.12\,\mathrm{W\,m^{-1}\,^\circ C^{-1}}
\end{aligned}$$