Chapter 2 Heat, Temperature, and the First Law of Thermodynamics

2.1. Temperature and the Zeroth Law of Thermodynamics

2.2. Thermal Expansion

2.3. Heat and the Absorption of Heat by Solids and Liquids

2.4. Work and Heat in Thermodynamic Processes

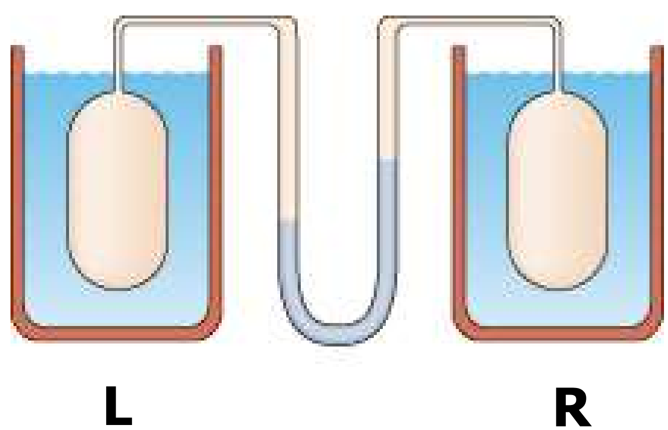
2.5. The First Law of Thermodynamics and Some Special Cases

2.6. Heat Transfer Mechanisms

Homework:

Problems 3, 5, 6, 11, 15, 19, 21, 29, 30, 32, 35, 36, 37, 38, 39, 40 (in Chapter 18, textbook)

3. A gas thermometer is constructed of two gas-containing bulbs, each in a water bath, as shown in the figure below. The pressure difference between the two bulbs is measured by a mercury manometer as shown. Appropriate reservoirs, not shown in the diagram, maintain constant gas volume in the two bulbs. There is no difference in pressure when both baths are at the triple point of water. The pressure difference is 120 torr when one bath is at the triple point and the other is at the boiling point of water. It is 90.0 torr when one bath is at the triple point and the other is at an unknown temperature to be measured. What is the unknown temperature?



$$\frac{T}{p} = \frac{T_3}{p_3} \Rightarrow p = p_3 \times \frac{T}{T_3} \quad \rightarrow \quad p_L = p_3 \times \frac{T_L}{T_3}; \qquad p_R = p_3 \times \frac{T_R}{T_3}$$

- When one bath (L) is at the triple point and the other (R) is at the boiling point of water:

$$T_L = T_3 = 273.16\,(\mathrm{K}) \text{ and } p_L = p_3$$

$$T_R = T_{boiling} = 373.125\,(\mathrm{K}) \qquad \rightarrow \quad p_R - p_L = p_3\left(\frac{T_R}{T_3} - 1\right)$$

- When one bath (L) is at the triple point and the other (R) is at an unknown temperature X=T'$_R$:

$$p_R^{'} - p_L = p_3\left(\frac{T_R^{'}}{T_3} - 1\right) \qquad \rightarrow \quad \frac{p_R - p_L}{p_R^{'} - p_L} = \frac{T_R - T_3}{X - T_3} = \frac{120}{90}$$

$$\rightarrow \quad \frac{373.125 - 273.16}{X - 273.16} = \frac{4}{3} \qquad \rightarrow \quad X \approx 348\,(\mathrm{K})$$

5. At what temperature is the Fahrenheit scale reading equal to (a) twice that of the Celsius scale and (b) half that of the Celsius scale?

$$T_F = \frac{9}{5} T_C + 32^0$$

$$T_F = 2T_C : \qquad T_C = 160^0 C;\ T_F = 320^0 F$$

$$T_F = \frac{1}{2} T_C : \qquad T_C \approx -24.6^0 C;\ T_F = \text{-}12.3^0 F$$

6. On a linear X temperature scale, water freezes at -125.0^0X and boils at 360.0^0X. On a linear Y temperature scale, water freezes at -70.0^0Y and boils at -30.0^0Y. A temperature of 50.0^0Y corresponds to what temperature on the X scale?

For linear scales, the relationship between X and Y can be written by:

$$y = ax + b$$

$$-70 = -125\,a + b$$

$$-30 = 360\,a + b$$

$$\rightarrow a = 0.08,\ b = -60.00$$

$$\rightarrow x = \frac{y - b}{a} = 1330^0\,\mathrm{X}$$

11. What is the volume of a lead ball at 30.0^{0}C if the ball's volume at 60.0^{0}C is 50.0 cm^3?

For a volume expansion:

$$\Delta V = V\beta\Delta T = 50.0\times(3\times 29\times 10^{-6})(60.0-30.0) = 0.13(\mathrm{cm}^3)$$

$$V_{30^0 C} = V - \Delta V = 50.0 - 0.13 = 49.87(\mathrm{cm}^3)$$

15. A steel rod is 3.0 cm in diameter at 25.0^0C. A brass ring has an interior diameter of 2.992 cm at 25.0^0C. At what common temperature will the ring just slide onto the rod?

For a linear expansion of the steel rod:

$$D_{steel} = D_{steel,0} + D_{steel,0}\alpha_s \Delta T$$

For a linear expansion of the brass ring:

$$D_{brass} = D_{brass,0} + D_{brass,0}\alpha_b \Delta T$$

If the ring just slides onto the rod, so $D_{steel} = D_{brass}$

$$\Delta T = \frac{D_{steel,0} - D_{brass,0}}{D_{brass,0}\alpha_b - D_{steel,0}\alpha_s}$$

$$\Delta T = \frac{3.0 - 2.992}{2.992 \times 19 \times 10^{-6} - 3.0 \times 11 \times 10^{-6}} = 335.5^0$$

→ $T = 25 + 335.5 = 360.5^0 C$

19. A 1.28m-long vertical glass tube is half filled with a liquid at 20^0C. How much will the height of the liquid column change when the tube is heated to 30^0C? Take $\alpha_{glass}=1.0\text{x}10^{-5}$/K and $\beta_{liquid}=4.0\text{x}10^{-5}$/K.

Here, we need to consider the cross-sectional area expansion of the glass and the volume expansion of the liquid:

$$\Delta \mathrm{A} = \mathrm{A}_0 (2\alpha)\Delta \mathrm{T}$$

$$\Delta \mathrm{V} = \mathrm{V}_0 \beta \Delta \mathrm{T}$$

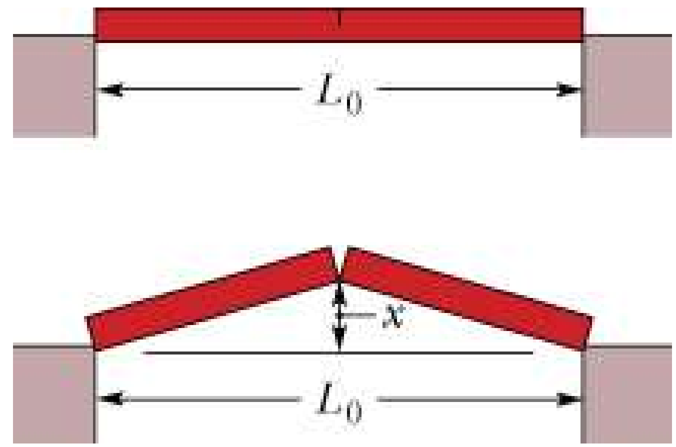
$$\mathrm{h} = \frac{\mathrm{V}}{\mathrm{A}} = \frac{V_0 + \Delta V}{A_0 + \Delta A} = \frac{V_0(1+\beta\Delta T)}{A_0(1+2\alpha\Delta T)} = h_0 \frac{(1+\beta\Delta T)}{(1+2\alpha\Delta T)}$$

$$\Delta \mathrm{h} = \mathrm{h} - \mathrm{h}_0 = h_0\left[\frac{(1+\beta\Delta T)}{(1+2\alpha\Delta T)} - 1\right]$$

$$\mathrm{h}_0 = \frac{1.28}{2} = 0.64\ (\mathrm{m});\ \Delta \mathrm{T} = 30^0\mathrm{C} - 20^0\mathrm{C} = 10^0$$

→ $\Delta \mathrm{h} = 1.28 \times 10^{-4} (\mathrm{m})$

21. As a result of a temperature rise of 32^{0}C, a bar with a crack as its center buckles upward. If the fixed distance L_0 is 3.77 m and the coefficient of linear expansion of the bar is 25 x 10^{-6}/C^0, find the rise x of the center.



For a linear expansion:

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

$$x^2 = l^2 - l_0^2 = \left(l_0 + l_0 \alpha \Delta T\right)^2 - l_0^2$$

where l = L/2; $l_0 = L_0/2$

$$x^2 = l_0^2 \left(1 + \alpha \Delta T\right)^2 - l_0^2 \approx 2 l_0^2 \alpha \Delta T$$ (using the binomial theorem)

$$x = l_0 \sqrt{2 \alpha \Delta T} = \frac{3.77}{2} \sqrt{2 \times 25 \times 10^{-6} \times 32} = 75.4 \times 10^{-3} (m) = 75.4 (mm)$$

25. A certain diet doctor encourages people to diet by drinking ice water. His theory is that the body must burn off enough fat to raise the temperature of the water from 0.00^0C to the body temperature of 37.0^0C. How many liters of ice water would have to be consumed to burn off 454 g (about 1 lb) of fat, assuming that burning this much fat requires 3500 Cal be transferred to the ice water? Why is it not advisable to follow this diet? (One liter : 10^3 cm^3. The density of water is 1.00 g/cm^3.)

1 food calorie = 1000 cal

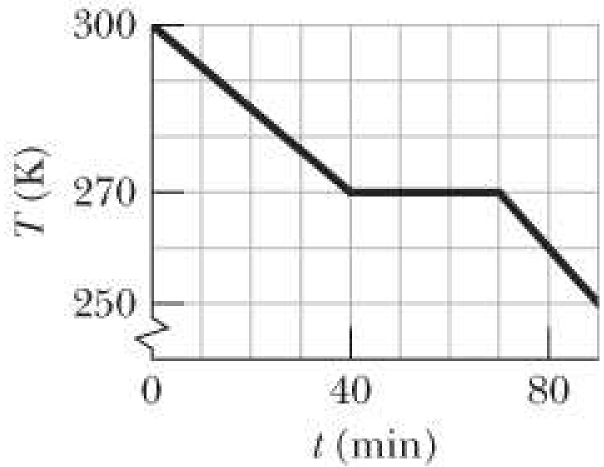
The mass of water needs to drink:

$$m = \frac{Q}{c\Delta T} = \frac{3500 \times 1000\,(cal)}{1(cal/g.K) \times (37-0)^0 C} = 94.6 \times 10^3 (g)$$

$$V = \frac{m}{\rho} = \frac{94.6 \times 10^3 g}{1000\, g/liter} = 94.6(liters)$$

→ impossible, too much water to drink

Problem 30. A 0.4 kg sample is placed in a cooling apparatus that removes energy as heat at a constant rate. The figure below gives T of the sample vs. time t; the sample freezes during the energy removal. The specific heat of the sample in its initial liquid phase is 3000 J/kg K^{-1}. What are (a) the sample's heat of fusion and (b) its specific heat in the frozen phase?



Key issue: The cooling apparatus removes energy as heat at a constant rate.
The rate of removed energy as heat (per minute):

$$R = \frac{Q_{cooling}}{t_{cooling}} = \frac{cm\Delta T}{t_{cooling}}$$

$$R = 900\ (\mathrm{J/min})$$

(a) $$Q_{freezing} = 900\ (\mathrm{J/min}) \times 30\ (\mathrm{min}) = 27000\ (\mathrm{J})\ \text{or}\ 27\ (\mathrm{kJ})$$

$$Q_{freezing} = L_F m \Rightarrow L_F = 67.5\ (\mathrm{kJ/kg})$$

(b) $$Q_{frozen} = cm\Delta T \Rightarrow c = \frac{Q_{frozen}}{m\Delta T} = \frac{R \times 20(\mathrm{min})}{m \times 20(^0)} = 2250\left(\frac{\mathrm{J}}{\mathrm{kg.K}}\right)$$

Problem 32. The specific heat of a substance varies with temperature according to $c = 0.20 + 0.14T + 0.023T^2$, with T in ^0C and c in cal/g K^{-1}. Find the energy required to raise the temperature of 1.0 g of this substance from 5^0C to 15^0C.

$$Q = cm\Delta T$$

In the case here:

$$c = c(T)$$

$$dQ = cmdT$$

$$Q_{total} = \int_{T_1}^{T_2} cmdT = m\int_{T_1}^{T_2} cdT = m\int_{T_1}^{T_2} (0.20 + 0.14T + 0.023T^2)dT$$

Problem 36. A 150 g copper bowl contains 220g of water, both at 20^0C. A very hot 300 g copper cylinder is dropped into the water, causing the water to boil, with 5g being converted to steam. The final temperature of the system is 100^0C. Neglect energy transfers with the environment.

(a) How much energy (in calories) is transferred to the water as heat?
(b) How much to the bowl?
(c) What is the original temperature of the cylinder?

(The specific heats of copper and water are 386 and 4187 J/kg.K, respectively, and the heat of evaporation of water is 2256 KJ/kg, and 1 cal = 4.1868 J)

a) The heat transferred to the water:

$$Q_w = m_w c_w \Delta T + L_v m_s$$

$$Q_w = 0.22(kg)\times 4187(\frac{J}{kg.K})\times(100-20)(K) + 2256\left(\frac{kJ}{kg}\right)5(mg)$$

$$Q_w = 85\ (kJ) = 20.3\ (kcal)$$

b) The heat transferred to the bowl

$$Q_b = m_b c_b \Delta T = 1.11\ (\text{kcal})$$

c) the original temperature of the cylinder

$$Q_w + Q_b = m_c c_c (T_i - T_f)$$

$$T_i = \frac{Q_w + Q_b}{m_c c_c} + T_f = 873\ ^0\text{C}$$