Chapter M - Problems

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Problem M.1

A constant volume gas thermometer is calibrated using dry ice (at $T = -80.0$ °C) and boiling water (at $T = 100$ °C). The pressure with dry ice is 1.81 atm and with boiling water is 3.49 atm.
(a) With this calibration, what is the value of absolute zero given by the thermometer?
(b) What is the pressure at 0 °C?

Solution to M.1

(a) We are given two points (T_1, P_1) and (T_2, P_2) we can find the equation of the line.

$$m = \frac{P_2 - P_1}{T_2 - T_1} = \frac{3.49 - 1.81}{100 - -80} = 0.009333$$

$$P - P_1 = m\,(T - T_1) \implies P - 1.81 = m\,(T + 80)$$

The value of absolute zero is found by finding the temperature value where the pressure is zero.

$$0 - P_1 = m\,(T - T_1) \implies -1.81 = m\,(T + 80) \implies T = -273.9\text{ °C}$$

(b) We now need to find P at $T = 0$.

$$T = 0\text{ °C} \implies P = 2.56\text{ atm}$$

Problem M.2

At what temperature are the numerical values of the Fahrenheit and Celsius scales the same?

Solution to M.2

$$T_F = \frac{9}{5}\,T_C + 32 \;\text{ and }\; T = T_F = T_C \implies T = \frac{9}{5}\,T + 32 \implies T = -40$$

Problem M.3

Liquid nitrogen is at 77 K. What is this in Celsius and in Fahrenheit?

Solution to M.3

$$T_C = T_K - 273 = -196\text{ °C}$$

$$T_F = \frac{9}{5}\,T_C + 32 = -321\text{ °F}$$

Problem M.4

The total vertical fall of Naigara Falls is about 55 m. If the water temperature at the top of the Falls is 15 °C then what is the temperature at the bottom? Assume all of the potential energy goes into heat in the water and also assume there is no evaporation, which would tend to decrease the temperature.

Solution to M.4

If a mass m of water drops from a height $h = 55$ m then the change in potential energy is $\Delta U = m\,g\,\Delta y = -m\,g\,h$. The available energy is $|\Delta U| = m\,g\,h$. All of this energy goes into heat which causes a temerature increase of the water, $|\Delta U| = Q = m\,c\,\Delta T$. Combining these two expressions gives

$$m\,g\,h = Q = m\,c\,\Delta\,T.$$

$$m\;9.80\times 55 = m\;4186\;\Delta\,T \implies \Delta\,T = 0.129\,\text{C}° \implies T_f = 15\,°\text{C} + 0.129 = 15.13\,°\text{C}.$$

Problem M.5

The temperature of a 2 kg mass of an unknown substance increases by 15 C° when 8400 J of heat is added to it. What is the specific heat of the unknown?

Solution to M.5

$$Q = m\,c\,\Delta\,T \implies 8400 = 2\,c\,15 \implies c = 280\,\frac{\text{J}}{\text{kg}\cdot\text{C}°}$$

Problem M.6

A 4 kg chunk of iron at 500 °C is dropped into a bucket with 25 kg of water that is initially at 20 °C. Assuming no heat loss to the environment or bucket then what is the equilibrium temperature of the water and iron?

Solution to M.6

$$0 = Q_{\text{tot}} = m_{\text{iron}}\,c_{\text{iron}}\,\Delta\,T_{\text{iron}} + m_{\text{water}}\,c_{\text{water}}\,\Delta\,T_{\text{water}}$$
$$= 4\times 448\,(T - 500) + 25\times 4186\,(T - 20)$$
$$\implies T = 28.1\,°\text{C}$$

Problem M.7

How much heat must be added to completely melt 2 kg of lead at 20 °C ?

Solution to M.7

The total amount of heat to completely melt the lead is the sum of two terms. First is the amount of heat it takes to take lead at 20 °C to its melting point 327.3 °C, where we need the specific heat of lead. The second term is the amount of heat it takes to melt lead after it is brought to the melting point; this involve the latent heat of fusion of lead.

$$Q = m\,c\,\Delta T + m\,L_f = 2\times 128\,(327.3 - 20) + 2\times 2.24\times 10^4 = 123\,500\text{ J}$$

Problem M.8

A quantity of mass m of water at 20 °C is added to 2 kg of ice at −10 °C . There are three possible final states: all ice at a temperature less than 0 °C , ice-water at 0 °C or all water at some temperature greater than 0 °C . What values of m will give each of the three possibilities?

Solution to M.8

For different values of m there are different final states:

All ice: For small m all of the water will be frozen and we will end up with ice at some temperature less than 0 °C.

Ice-water: For intermmediate values of m all the water will be brought to the freezing point but it will not all freeze.

All water: For large amounts of water all the ice will melt and we will end up with all water.

Define the critical values of the masses to be m_1 and m_2, where

$$\text{All ice: } m < m_1$$
$$\text{Ice-water: } m_1 < m < m_2$$
$$\text{All water: } m_2 < m$$

First we will find m_1. This occurs when the we end up with all ice at 0 °C. To find this we must consider the heat to increase the temperature of the ice to 0 °C, the heat removed from the water to lower it to 0 °C and then the heat removed to freeze the water.

$$0 = Q_{\text{tot}} = m_I\,c_I\,\Delta T_I - m\,L_f + m\,c_w\,\Delta T_w$$

$$= 2 \times 2090 \times 10 - m\,3.33 \times 10^5 + m\,4186 \times (-20)$$
$$\implies \quad m_1 = m = 0.1003\ \text{kg}$$

m_2 is the mass of water when we end up with all water at 0 °C. To find this we must consider the heat to increase the temperature of the ice to 0 °C, the heat to melt all the ice and then the heat removed to lower the water to 0 °C.

$$0 = Q_{\text{tot}} = m_I\, c_I\, \Delta T_I + m_I\, L_f + m\, c_w\, \Delta T_w$$
$$= 2 \times 2090 \times 10 + 2 \times\ 3.33 \times 10^5 + m\,4186 \times (-20)$$
$$\implies \quad m_2 = m = 8.45\ \text{kg}$$