

SOLUTIONS : HEAT TUTORIAL #1 (CH 17)

Exercise 17.7

The pressure of a gas at the triple point of water is 1.35 atm. If its volume remains unchanged, what will its pressure be at the temperature at which CO₂ solidifies (-78 °C)

17.7. IDENTIFY: When the volume is constant, $\frac{T_2}{T_1} = \frac{p_2}{p_1}$, for T in kelvins.

SET UP: $T_{\text{triple}} = 273.16$ K. The temperature at which CO₂ solidifies is -78 °C, i.e. $T_{\text{CO}_2} = 195$ K.

EXECUTE: $p_2 = p_1 \left(\frac{T_2}{T_1} \right) = (1.35 \text{ atm}) \left(\frac{195 \text{ K}}{273.16 \text{ K}} \right) = 0.964 \text{ atm}$

EVALUATE: The pressure decreases when T decreases.

Exercise 17.14 Ensuring a tight fit.

Aluminium rivets used in airplane construction are made slightly larger than the rivet holes and cooled by "dry ice" (solid CO₂) before being driven. If the diameter of a hole is 4.500 mm, what should be the diameter of a rivet at 23.0 °C if its diameter is to equal that of the hole when the rivet is cooled to -78.0 °C, the temperature of dry ice? Assume that the expansion coefficient of aluminium is $2.4 \times 10^{-5} \text{ }^\circ\text{C}^{-1}$ and remains constant. Express your answer using four significant figures.

17.14. IDENTIFY: Apply $L = L_0(1 + \alpha\Delta T)$ to the diameter d of the rivet.

SET UP: For aluminum, $\alpha = 2.4 \times 10^{-5} \text{ (}^\circ\text{C)}^{-1}$. Let d_0 be the diameter at -78.0°C and d be the diameter at 23.0°C.

EXECUTE: $d = d_0 + \Delta d = d_0(1 + \alpha\Delta T) = (0.4500 \text{ cm})(1 + (2.4 \times 10^{-5} \text{ (}^\circ\text{C)}^{-1})(23.0^\circ\text{C} - [-78.0^\circ\text{C}]))$
 $d = 0.4511 \text{ cm} = 4.511 \text{ mm}.$

EVALUATE: We could have let d_0 be the diameter at 23.0°C and d be the diameter at -78.0°C. Then $\Delta T = -78.0^\circ\text{C} - 23.0^\circ\text{C}.$

Exercise 17.18

Description: A steel tank is completely filled with 2.80 m³ of ethanol when both the tank and the ethanol are at a temperature 32.0 °C. When the tank and its contents have cooled to 18.0 °C, what additional volume of ethanol can be put into the tank?

17.18. IDENTIFY: Apply $\Delta V = V_0\beta\Delta T$ to the tank and to the ethanol.

SET UP: For ethanol, $\beta_e = 75 \times 10^{-5} \text{ (}^\circ\text{C)}^{-1}$. For steel, $\beta_s = 3.6 \times 10^{-5} \text{ (}^\circ\text{C)}^{-1}$.

EXECUTE:

$\Delta T = T_f - T_i = 18.0^\circ\text{C} - 32.0^\circ\text{C} = -14.0^\circ\text{C}$

The volume change for the tank is

$\Delta V_s = V_0\beta_s\Delta T = (2.80 \text{ m}^3)(3.6 \times 10^{-5} \text{ (}^\circ\text{C)}^{-1})(-14.0 \text{ }^\circ\text{C}) = -1.41 \times 10^{-3} \text{ m}^3 = -1.41 \text{ L}.$

The volume change for the ethanol is

$\Delta V_e = V_0\beta_e\Delta T = (2.80 \text{ m}^3)(75 \times 10^{-5} \text{ (}^\circ\text{C)}^{-1})(-14.0 \text{ }^\circ\text{C}) = -2.94 \times 10^{-2} \text{ m}^3 = -29.4 \text{ L}.$

The empty volume in the tank is $\Delta V_e - \Delta V_s = -29.4 \text{ L} - (-1.4 \text{ L}) = -28.0 \text{ L}.$ 28.0 L of ethanol can be added to the tank.

EVALUATE: Both volumes decrease. But $\beta_e > \beta_s$, so the magnitude of the volume decrease for the ethanol is greater than it is for the tank.

Exercise 17.27

An aluminium tea kettle with mass 1.50 kg and containing 1.80 kg of water is placed on a stove. If no heat is lost to the surroundings, how much heat must be added to raise the temperature from 20 °C to 85 °C?

17.27. IDENTIFY and SET UP: Apply Eq. (17.13) to the kettle and water.

EXECUTE: kettle

$$Q = mc\Delta T, \quad c = 910 \text{ J/kg} \cdot \text{K} \quad (\text{from Table 17.3})$$

$$Q = (1.50 \text{ kg})(910 \text{ J/kg} \cdot \text{K})(85.0^\circ\text{C} - 20.0^\circ\text{C}) = 8.873 \times 10^4 \text{ J}$$

water

$$Q = mc\Delta T, \quad c = 4190 \text{ J/kg} \cdot \text{K} \quad (\text{from Table 17.3})$$

$$Q = (1.80 \text{ kg})(4190 \text{ J/kg} \cdot \text{K})(85.0^\circ\text{C} - 20.0^\circ\text{C}) = 4.902 \times 10^5 \text{ J}$$

$$\text{Total } Q = 8.873 \times 10^4 \text{ J} + 4.902 \times 10^5 \text{ J} = 5.79 \times 10^5 \text{ J}$$

EVALUATE: Water has a much larger specific heat capacity than aluminum, so most of the heat goes into raising the temperature of the water.

Exercise 17.44

In a container of negligible mass, 0.200 kg of ice at an initial temperature of -40.0°C is mixed with a mass m of water that has an initial temperature of 80.0°C . No heat is lost to the surroundings.

(a) If the final temperature of the system is 20.0°C , what is the mass m of the water that was initially at 80.0°C ? Express your answer to three significant figures and include the appropriate units.

17.44. IDENTIFY: By energy conservation, the heat lost by the water is gained by the ice. This heat must first increase the temperature of the ice from -40.0°C to the melting point of 0.00°C , then melt the ice, and finally increase its temperature to 20.0°C . The target variable is the mass of the water m .

SET UP: $Q_{\text{ice}} = m_{\text{ice}}c_{\text{ice}}\Delta T_{\text{ice}} + m_{\text{ice}}L_f + m_{\text{ice}}c_w\Delta T_{\text{melted ice}}$ and $Q_{\text{water}} = mc_w\Delta T_w$.

EXECUTE: Using $Q_{\text{ice}} = m_{\text{ice}}c_{\text{ice}}\Delta T_{\text{ice}} + m_{\text{ice}}L_f + m_{\text{ice}}c_w\Delta T_{\text{melted ice}}$, with the values given in the table in the text,

$$\text{we have } Q_{\text{ice}} = (0.200 \text{ kg})[2100 \text{ J/(kg} \cdot \text{C}^\circ)](40.0\text{C}^\circ) + (0.200 \text{ kg})(3.34 \times 10^5 \text{ J/kg})$$

$$+ (0.200 \text{ kg})[4190 \text{ J/(kg} \cdot \text{C}^\circ)](20.0\text{C}^\circ) = 1.004 \times 10^5 \text{ J.}$$

$$Q_{\text{water}} = mc_w\Delta T_w = m[4190 \text{ J/(kg} \cdot \text{C}^\circ)](20.0\text{C}^\circ - 80.0\text{C}^\circ) = -(251,400 \text{ J/kg})m.$$

$$Q_{\text{ice}} + Q_{\text{water}} = 0 \text{ gives } 1.004 \times 10^5 \text{ J} = (251,400 \text{ J/kg})m. \quad m = 0.399 \text{ kg.}$$

EVALUATE: There is about twice as much water as ice because the water must provide the heat not only to melt the ice but also to increase its temperature.

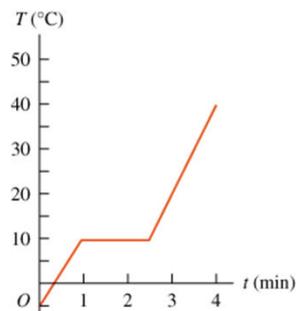
Exercise 17.38

As a physicist, you put heat into a 500.0 g solid sample at the rate of 10.0 kJ/min, while recording its temperature as a function of time. You plot your data and obtain the graph shown in the figure.

(a) What is the latent heat of fusion for this solid?

(b) What is the specific heat of the liquid?

(c) What is the specific heat of the solid state of the material?



17.38. IDENTIFY: The latent heat of fusion L_f is defined by $Q = mL_f$ for the solid \rightarrow liquid phase transition. For a temperature change, $Q = mc\Delta T$.

SET UP: At $t = 1$ min the sample is at its melting point and at $t = 2.5$ min all the sample has melted.

EXECUTE:

(a) It takes 1.5 min for all the sample to melt once its melting point is reached and the heat input during this time interval is $(1.5 \text{ min})(10.0 \times 10^3 \text{ J/min}) = 1.50 \times 10^4 \text{ J}$. $Q = mL_f$.

$$L_f = \frac{Q}{m} = \frac{1.50 \times 10^4 \text{ J}}{0.500 \text{ kg}} = 3.00 \times 10^4 \text{ J/kg.}$$

(b) The liquid's temperature rises 30 C° in 1.5 min. $Q = mc\Delta T$.

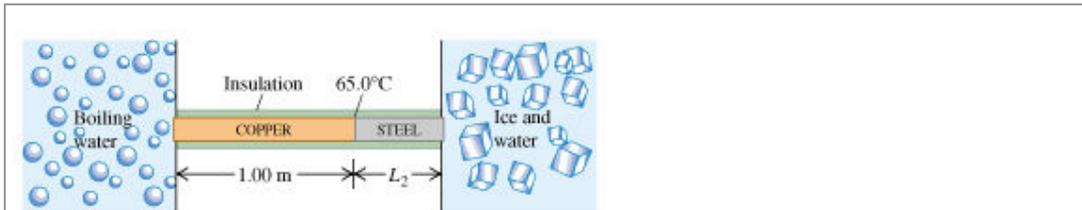
$$c_{\text{liquid}} = \frac{Q}{m\Delta T} = \frac{1.50 \times 10^4 \text{ J}}{(0.500 \text{ kg})(30 \text{ C}^\circ)} = 1.00 \times 10^3 \text{ J/kg} \cdot \text{K.}$$

The solid's temperature rises 15 C° in 1.0 min. $c_{\text{solid}} = \frac{Q}{m\Delta T} = \frac{1.00 \times 10^4 \text{ J}}{(0.500 \text{ kg})(15 \text{ C}^\circ)} = 1.33 \times 10^3 \text{ J/kg} \cdot \text{K.}$

EVALUATE: The specific heat capacities for the liquid and solid states are different. The values of c and L_f that we calculated are within the range of values in Tables 17.3 and 17.4.

Exercise 17.68

A long rod, insulated to prevent heat loss along its sides, is in perfect thermal contact with boiling water (at atmospheric pressure) at one end and with an ice-water mixture at the other. The rod consists of 1.00-m section of copper (one end in steam) joined end-to-end to a length L_2 of steel (one end in ice). Both sections of the rod have cross-section areas of 4.00 cm^2 . The temperature of the copper-steel junction is 65 deg C after a steady state has been set up.



(a) How much heat per second flows from the steam bath to the ice-water mixture?

(b) What is the length L_2 of the steel section?

17.68. IDENTIFY: $\frac{Q}{t} = \frac{kA\Delta T}{L}$. Q/t is the same for both sections of the rod.

SET UP: For copper, $k_c = 385 \text{ W/m} \cdot \text{K}$. For steel, $k_s = 50.2 \text{ W/m} \cdot \text{K}$.

EXECUTE:

(a) For the copper section, $\frac{Q}{t} = \frac{(385 \text{ W/m} \cdot \text{K})(4.00 \times 10^{-4} \text{ m}^2)(100^\circ\text{C} - 65.0^\circ\text{C})}{1.00 \text{ m}} = 5.39 \text{ J/s}$.

(b) For the steel section, $L = \frac{kA\Delta T}{(Q/t)} = \frac{(50.2 \text{ W/m} \cdot \text{K})(4.00 \times 10^{-4} \text{ m}^2)(65.0^\circ\text{C} - 0^\circ\text{C})}{5.39 \text{ J/s}} = 0.242 \text{ m}$.

EVALUATE: The thermal conductivity for steel is much less than that for copper, so for the same ΔT and A a smaller L for steel would be needed for the same heat current as in copper.

Exercise 17.69

A pot with a steel bottom 8.50 mm thick rests on a hot stove. The area of the bottom of the pot is 0.150 m^2 . The water inside the pot is at 100.0°C , and 0.390 kg are evaporated every 3.00 minutes. Find the temperature of the lower surface of the pot, which is in contact with the stove.

17.69. IDENTIFY and SET UP: The heat conducted through the bottom of the pot goes into the water at 100°C to convert it to steam at 100°C . We can calculate the amount of heat flow from the mass of material that changes phase. Then use Eq. (17.21) to calculate T_H , the temperature of the lower surface of the pan.

$$\text{EXECUTE: } Q = mL_v = (0.390 \text{ kg})(2256 \times 10^3 \text{ J/kg}) = 8.798 \times 10^5 \text{ J}$$

$$H = Q/t = 8.798 \times 10^5 \text{ J}/180 \text{ s} = 4.888 \times 10^3 \text{ J/s}$$

$$\text{Then } H = kA(T_H - T_C)/L \text{ says that } T_H - T_C = \frac{HL}{kA} = \frac{(4.888 \times 10^3 \text{ J/s})(8.50 \times 10^{-3} \text{ m})}{(50.2 \text{ W/m} \cdot \text{K})(0.150 \text{ m}^2)} = 5.52 \text{ C}^\circ$$

$$T_H = T_C + 5.52 \text{ C}^\circ = 100^\circ\text{C} + 5.52 \text{ C}^\circ = 105.5^\circ\text{C}$$

EVALUATE: The larger $T_H - T_C$ is the larger H is and the faster the water boils.

Exercise 17.75

Description: The hot glowing surfaces of stars emit energy in the form of electromagnetic radiation. It is a good approximation to assume $e=1$ for these surfaces.

(a) Find the radius of the star (assumed to be spherical) Rigel, the bright blue star in the constellation Orion, that radiates energy at a rate of $2.7 \times 10^{32} \text{ W}$ and has surface temperature 11000 K .

(b) Find the radius of the star (assumed to be spherical) Procyon B (only visible using a telescope), that radiates energy at a rate of $2.1 \times 10^{23} \text{ W}$ and has surface temperature 10000 K .

(c) Compare your answers to the radius of the earth, the radius of the sun, and the distance between the earth and the sun. (Rigel is an example of a supergiant star, and Procyon B is an example of a white dwarf star.) Essay answers are limited to about 500 words (3800 characters maximum, including spaces).

17.75. IDENTIFY: Apply $H = Ae\sigma T^4$ and calculate A .

SET UP: For a sphere of radius R , $A = 4\pi R^2$. $\sigma = 5.67 \times 10^{-8} \text{ W/m}^2 \cdot \text{K}^4$. The radius of the earth is $R_E = 6.38 \times 10^6 \text{ m}$, the radius of the sun is $R_{\text{sun}} = 6.96 \times 10^8 \text{ m}$, and the distance between the earth and the sun is $r = 1.50 \times 10^{11} \text{ m}$.

$$\text{EXECUTE: } \text{The radius is found from } R = \sqrt{\frac{A}{4\pi}} = \sqrt{\frac{H/(\sigma T^4)}{4\pi}} = \sqrt{\frac{H}{4\pi\sigma}} \frac{1}{T^2}.$$

$$\text{(a) } R_a = \sqrt{\frac{(2.7 \times 10^{32} \text{ W})}{4\pi(5.67 \times 10^{-8} \text{ W/m}^2 \cdot \text{K}^4)}} \frac{1}{(11,000 \text{ K})^2} = 1.61 \times 10^{11} \text{ m}$$

$$\text{(b) } R_b = \sqrt{\frac{(2.10 \times 10^{23} \text{ W})}{4\pi(5.67 \times 10^{-8} \text{ W/m}^2 \cdot \text{K}^4)}} \frac{1}{(10,000 \text{ K})^2} = 5.43 \times 10^6 \text{ m}$$

EVALUATE: (c) The radius of Procyon B is comparable to that of the earth, and the radius of Rigel is comparable to the earth-sun distance.