

TEMPERATURE AND HEAT

17.1. **IDENTIFY and SET UP:** $T_F = \frac{9}{5}T_C + 32^\circ$.

EXECUTE: (a) $T_F = (9/5)(-62.8) + 32 = -81.0^\circ\text{F}$

(b) $T_F = (9/5)(56.7) + 32 = 134.1^\circ\text{F}$

(c) $T_F = (9/5)(31.1) + 32 = 88.0^\circ\text{F}$

EVALUATE: Fahrenheit degrees are smaller than Celsius degrees, so it takes more F° than C° to express the difference of a temperature from the ice point.

17.2. **IDENTIFY and SET UP:** $T_C = \frac{5}{9}(T_F - 32^\circ)$

EXECUTE: (a) $T_C = (5/9)(41.0 - 32) = 5.0^\circ\text{C}$

(b) $T_C = (5/9)(107 - 32) = 41.7^\circ\text{C}$

(c) $T_C = (5/9)(-18 - 32) = -27.8^\circ\text{C}$

EVALUATE: Fahrenheit degrees are smaller than Celsius degrees, so it takes more F° than C° to express the difference of a temperature from the ice point.

17.3. **IDENTIFY:** Convert each temperature from $^\circ\text{C}$ to $^\circ\text{F}$.

SET UP: $T_F = \frac{9}{5}T_C + 32^\circ\text{C}$

EXECUTE: 18°C equals $\frac{9}{5}(18^\circ) + 32^\circ = 64^\circ\text{F}$ and 39°C equals $\frac{9}{5}(39^\circ) + 32^\circ = 102^\circ\text{F}$. The temperature increase is $102^\circ\text{F} - 64^\circ\text{F} = 38\text{ F}^\circ$.

EVALUATE: The temperature increase is 21 C° , and this corresponds to $(21\text{ C}^\circ)\left(\frac{9\text{ F}^\circ}{5\text{ C}^\circ}\right) = 38\text{ F}^\circ$.

17.4. **IDENTIFY:** Convert $\Delta T = 10\text{ K}$ to F° .

SET UP: $1\text{ K} = 1\text{ C}^\circ = \frac{9}{5}\text{ F}^\circ$.

EXECUTE: A temperature increase of 10 K corresponds to an increase of 18 F° . Beaker *B* has the higher temperature.

EVALUATE: Kelvin and Celsius degrees are the same size. Fahrenheit degrees are smaller, so it takes more of them to express a given ΔT value.

17.5. **IDENTIFY:** Convert ΔT in kelvins to C° and to F° .

SET UP: $1\text{ K} = 1\text{ C}^\circ = \frac{9}{5}\text{ F}^\circ$

EXECUTE: (a) $\Delta T_F = \frac{9}{5}\Delta T_C = \frac{9}{5}(-10.0\text{ C}^\circ) = -18.0\text{ F}^\circ$

(b) $\Delta T_C = \Delta T_K = -10.0\text{ C}^\circ$

EVALUATE: Kelvin and Celsius degrees are the same size. Fahrenheit degrees are smaller, so it takes more of them to express a given ΔT value.

17.6. **IDENTIFY:** Convert ΔT between different scales.

SET UP: ΔT is the same on the Celsius and Kelvin scales. $180\text{ F}^\circ = 100\text{ C}^\circ$, so $1\text{ C}^\circ = \frac{9}{5}\text{ F}^\circ$.

EXECUTE: (a) $\Delta T = 49.0\text{ F}^\circ$. $\Delta T = (49.0\text{ F}^\circ)\left(\frac{1\text{ C}^\circ}{\frac{9}{5}\text{ F}^\circ}\right) = 27.2\text{ C}^\circ$.

(b) $\Delta T = -100\text{ F}^\circ$. $\Delta T = (-100.0\text{ F}^\circ)\left(\frac{1\text{ C}^\circ}{\frac{9}{5}\text{ F}^\circ}\right) = -55.6\text{ C}^\circ$

EVALUATE: The magnitude of the temperature change is larger in F° than in C° .

17.7. **IDENTIFY:** Convert T in $^{\circ}\text{C}$ to $^{\circ}\text{F}$.

SET UP: $T_{\text{F}} = \frac{9}{5}(T_{\text{C}} + 32^{\circ})$

EXECUTE: (a) $T_{\text{F}} = \frac{9}{5}(40.2^{\circ}) + 32^{\circ} = 104.4^{\circ}\text{F}$. Yes, you should be concerned.

(b) $T_{\text{F}} = \frac{9}{5}(T_{\text{C}} + 32^{\circ}) = \frac{9}{5}(12^{\circ}\text{C}) + 32^{\circ} = 54^{\circ}\text{F}$.

EVALUATE: In doing the temperature conversion we account for both the size of the degrees and the different zero points on the two temperature scales.

17.8. **IDENTIFY:** Set $T_{\text{C}} = T_{\text{F}}$ and $T_{\text{F}} = T_{\text{K}}$.

SET UP: $T_{\text{F}} = \frac{9}{5}T_{\text{C}} + 32^{\circ}\text{C}$ and $T_{\text{K}} = T_{\text{C}} + 273.15 = \frac{5}{9}(T_{\text{F}} - 32^{\circ}) + 273.15$

EXECUTE: (a) $T_{\text{F}} = T_{\text{C}} = T$ gives $T = \frac{9}{5}T + 32^{\circ}$ and $T = -40^{\circ}$; $-40^{\circ}\text{C} = -40^{\circ}\text{F}$.

(b) $T_{\text{F}} = T_{\text{K}} = T$ gives $T = \frac{5}{9}(T - 32^{\circ}) + 273.15$ and $T = \frac{5}{9}\left(-\left(\frac{5}{9}\right)(32^{\circ}) + 273.15\right) = 575^{\circ}$; $575^{\circ}\text{F} = 575\text{ K}$.

EVALUATE: Since $T_{\text{K}} = T_{\text{C}} + 273.15$ there is no temperature at which Celsius and Kelvin thermometers agree.

17.9. **IDENTIFY:** Convert to the Celsius scale and then to the Kelvin scale.

SET UP: Combining Eq.(17.2) and Eq.(17.3), $T_{\text{K}} = \frac{5}{9}(T_{\text{F}} - 32^{\circ}) + 273.15$,

EXECUTE: Substitution of the given Fahrenheit temperatures gives

(a) 216.5 K

(b) 325.9 K

(c) 205.4 K

EVALUATE: All temperatures on the Kelvin scale are positive.

17.10. **IDENTIFY:** Convert T_{K} to T_{C} and then convert T_{C} to T_{F} .

SET UP: $T_{\text{K}} = T_{\text{C}} + 273.15$ and $T_{\text{F}} = \frac{9}{5}T_{\text{C}} + 32^{\circ}$.

EXECUTE: (a) $T_{\text{C}} = 400 - 273.15 = 127^{\circ}\text{C}$, $T_{\text{F}} = (9/5)(126.85) + 32 = 260^{\circ}\text{F}$

(b) $T_{\text{C}} = 95 - 273.15 = -178^{\circ}\text{C}$, $T_{\text{F}} = (9/5)(-178.15) + 32 = -289^{\circ}\text{F}$

(c) $T_{\text{C}} = 1.55 \times 10^7 - 273.15 = 1.55 \times 10^7\text{C}$, $T_{\text{F}} = (9/5)(1.55 \times 10^7) + 32 = 2.79 \times 10^7\text{F}$

EVALUATE: All temperatures on the Kelvin scale are positive. T_{C} is negative if the temperature is below the freezing point of water.

17.11. **IDENTIFY:** Convert T_{F} to T_{C} and then convert T_{C} to T_{K} .

SET UP: $T_{\text{C}} = \frac{5}{9}(T_{\text{F}} - 32^{\circ})$. $T_{\text{K}} = T_{\text{C}} + 273.15$.

EXECUTE: (a) $T_{\text{C}} = \frac{5}{9}(-346^{\circ} - 32^{\circ}) = -210^{\circ}\text{C}$

(b) $T_{\text{K}} = -210^{\circ} + 273.15 = 63\text{ K}$

EVALUATE: The temperature is negative on the Celsius and Fahrenheit scales but all temperatures are positive on the Kelvin scale.

17.12. **IDENTIFY:** Apply Eq.(17.5) and solve for p .

SET UP: $p_{\text{triple}} = 325\text{ mm of mercury}$

EXECUTE: $p = (325.0\text{ mm of mercury})\left(\frac{373.15\text{ K}}{273.16\text{ K}}\right) = 444\text{ mm of mercury}$

EVALUATE: mm of mercury is a unit of pressure. Since Eq.(17.5) involves a ratio of pressures, it is not necessary to convert the pressure to units of Pa.

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

SET UP: $T_{\text{triple}} = 273.16\text{ K}$. Figure 17.7 in the textbook gives that the temperature at which CO_2 solidifies is $T_{\text{CO}_2} = 195\text{ K}$.

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.

17.14. **IDENTIFY:** $1\text{ K} = 1\text{ C}^{\circ}$ and $1\text{ C}^{\circ} = \frac{9}{5}\text{F}^{\circ}$, so $1\text{ K} = \frac{9}{5}\text{R}^{\circ}$.

SET UP: On the Kelvin scale, the triple point is 273.16 K.

EXECUTE: $T_{\text{triple}} = (9/5)273.16\text{ K} = 491.69^{\circ}\text{R}$.

EVALUATE: One could also look at Figure 17.7 in the textbook and note that the Fahrenheit scale extends from -460°F to $+32^{\circ}\text{F}$ and conclude that the triple point is about 492°R .

17.15. IDENTIFY and SET UP: Fit the data to a straight line for $p(T)$ and use this equation to find T when $p = 0$.

EXECUTE: (a) If the pressure varies linearly with temperature, then $p_2 = p_1 + \gamma(T_2 - T_1)$.

$$\gamma = \frac{p_2 - p_1}{T_2 - T_1} = \frac{6.50 \times 10^4 \text{ Pa} - 4.80 \times 10^4 \text{ Pa}}{100^\circ\text{C} - 0.01^\circ\text{C}} = 170.0 \text{ Pa/C}^\circ$$

Apply $p = p_1 + \gamma(T - T_1)$ with $T_1 = 0.01^\circ\text{C}$ and $p = 0$ to solve for T .

$$0 = p_1 + \gamma(T - T_1)$$

$$T = T_1 - \frac{p_1}{\gamma} = 0.01^\circ\text{C} - \frac{4.80 \times 10^4 \text{ Pa}}{170 \text{ Pa/C}^\circ} = -282^\circ\text{C}.$$

(b) Let $T_1 = 100^\circ\text{C}$ and $T_2 = 0.01^\circ\text{C}$; use Eq.(17.4) to calculate p_2 . Eq.(17.4) says $T_2/T_1 = p_2/p_1$, where T is in kelvins.

$$p_2 = p_1 \left(\frac{T_2}{T_1} \right) = 6.50 \times 10^4 \text{ Pa} \left(\frac{0.01 + 273.15}{100 + 273.15} \right) = 4.76 \times 10^4 \text{ Pa}; \text{ this differs from the } 4.80 \times 10^4 \text{ Pa that was measured}$$

so Eq.(17.4) is not precisely obeyed.

EVALUATE: The answer to part (a) is in reasonable agreement with the accepted value of -273°C

17.16. IDENTIFY: Apply $\Delta L = \alpha L_0 \Delta T$ and calculate ΔT . Then $T_2 = T_1 + \Delta T$, with $T_1 = 15.5^\circ\text{C}$.

SET UP: Table 17.1 gives $\alpha = 1.2 \times 10^{-5} (\text{C}^\circ)^{-1}$ for steel.

$$\text{EXECUTE: } \Delta T = \frac{\Delta L}{\alpha L_0} = \frac{0.471 \text{ ft}}{[1.2 \times 10^{-5} (\text{C}^\circ)^{-1}][1671 \text{ ft}]} = 23.5 \text{ C}^\circ. \quad T_2 = 15.5^\circ\text{C} + 23.5 \text{ C}^\circ = 39.0^\circ\text{C}.$$

EVALUATE: Since then the lengths enter in the ratio $\Delta L/L_0$, we can leave the lengths in ft.

17.17. IDENTIFY: $\Delta L = L_0 \alpha \Delta T$

SET UP: For steel, $\alpha = 1.2 \times 10^{-5} (\text{C}^\circ)^{-1}$

$$\text{EXECUTE: } \Delta L = (1.2 \times 10^{-5} (\text{C}^\circ)^{-1})(1410 \text{ m})(18.0^\circ\text{C} - (-5.0^\circ\text{C})) = +0.39 \text{ m}$$

EVALUATE: The length increases when the temperature increases. The fractional increase is very small, since $\alpha \Delta T$ is small.

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

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

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

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

17.19. IDENTIFY: Apply $L = L_0(1 + \alpha \Delta T)$ to the diameter D of the penny.

SET UP: $1 \text{ K} = 1 \text{ C}^\circ$, so we can use temperatures in $^\circ\text{C}$.

EXECUTE: Death Valley: $\alpha D_0 \Delta T = (2.6 \times 10^{-5} (\text{C}^\circ)^{-1})(1.90 \text{ cm})(28.0 \text{ C}^\circ) = 1.4 \times 10^{-3} \text{ cm}$, so the diameter is 1.9014 cm. Greenland: $\alpha D_0 \Delta T = -3.6 \times 10^{-3} \text{ cm}$, so the diameter is 1.8964 cm.

EVALUATE: When T increases the diameter increases and when T decreases the diameter decreases.

17.20. IDENTIFY: $\Delta V = \beta V_0 \Delta T$. Use the diameter at -15°C to calculate the value of V_0 at that temperature.

SET UP: For a hemisphere of radius R , the volume is $V = \frac{2}{3} \pi R^3$. Table 17.2 gives $\beta = 7.2 \times 10^{-5} (\text{C}^\circ)^{-1}$ for aluminum.

$$\text{EXECUTE: } V_0 = \frac{2}{3} \pi R^3 = \frac{2}{3} \pi (27.5 \text{ m})^3 = 4.356 \times 10^4 \text{ m}^3.$$

$$\Delta V = (7.2 \times 10^{-5} (\text{C}^\circ)^{-1})(4.356 \times 10^4 \text{ m}^3)(35^\circ\text{C} - [-15^\circ\text{C}]) = 160 \text{ m}^3$$

EVALUATE: We could also calculate $R = R_0(1 + \alpha \Delta T)$ and calculate the new V from R . The increase in volume is $V - V_0$, but we would have to be careful to avoid round-off errors when two large volumes of nearly the same size are subtracted.

17.21. IDENTIFY: Linear expansion; apply Eq.(17.6) and solve for α .

SET UP: Let $L_0 = 40.125 \text{ cm}$; $T_0 = 20.0^\circ\text{C}$. $\Delta T = 45.0^\circ\text{C} - 20.0^\circ\text{C} = 25.0 \text{ C}^\circ$ gives $\Delta L = 0.023 \text{ cm}$

$$\text{EXECUTE: } \Delta L = \alpha L_0 \Delta T \text{ implies } \alpha = \frac{\Delta L}{L_0 \Delta T} = \frac{0.023 \text{ cm}}{(40.125 \text{ cm})(25.0 \text{ C}^\circ)} = 2.3 \times 10^{-5} (\text{C}^\circ)^{-1}.$$

EVALUATE: The value we calculated is the same order of magnitude as the values for metals in Table 17.1.

17.22. IDENTIFY: Apply $\Delta V = V_0\beta\Delta T$.

SET UP: For copper, $\beta = 5.1 \times 10^{-5} (\text{C}^\circ)^{-1}$. $\Delta V/V_0 = 0.150 \times 10^{-2}$.

EXECUTE: $\Delta T = \frac{\Delta V/V_0}{\beta} = \frac{0.150 \times 10^{-2}}{5.1 \times 10^{-5} (\text{C}^\circ)^{-1}} = 29.4 \text{ C}^\circ$. $T_f = T_i + \Delta T = 49.4 \text{ C}^\circ$.

EVALUATE: The volume increases when the temperature increases.

17.23. IDENTIFY: Volume expansion; apply Eq.(17.8) to calculate ΔV for the ethanol.

SET UP: From Table 17.2, β for ethanol is $75 \times 10^{-5} \text{ K}^{-1}$

EXECUTE: $\Delta T = 10.0 \text{ C}^\circ - 19.0 \text{ C}^\circ = -9.0 \text{ K}$. Then $\Delta V = \beta V_0 \Delta T = (75 \times 10^{-5} \text{ K}^{-1})(1700 \text{ L})(-9.0 \text{ K}) = -11 \text{ L}$. The volume of the air space will be $11 \text{ L} = 0.011 \text{ m}^3$.

EVALUATE: The temperature decreases, so the volume of the liquid decreases. The volume change is small, less than 1% of the original volume.

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

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

EXECUTE: The volume change for the tank is

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

The volume change for the ethanol is

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

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 less than it is for the tank.

17.25. IDENTIFY: Apply $\Delta V = V_0\beta\Delta T$ to the volume of the flask and to the mercury. When heated, both the volume of the flask and the volume of the mercury increase.

SET UP: For mercury, $\beta_{\text{Hg}} = 18 \times 10^{-5} (\text{C}^\circ)^{-1}$.

EXECUTE: 8.95 cm³ of mercury overflows, so $\Delta V_{\text{Hg}} - \Delta V_{\text{glass}} = 8.95 \text{ cm}^3$.

EXECUTE: $\Delta V_{\text{Hg}} = V_0\beta_{\text{Hg}}\Delta T = (1000.00 \text{ cm}^3)(18 \times 10^{-5} (\text{C}^\circ)^{-1})(55.0 \text{ C}^\circ) = 9.9 \text{ cm}^3$.

$$\Delta V_{\text{glass}} = \Delta V_{\text{Hg}} - 8.95 \text{ cm}^3 = 0.95 \text{ cm}^3. \quad \beta_{\text{glass}} = \frac{\Delta V_{\text{glass}}}{V_0\Delta T} = \frac{0.95 \text{ cm}^3}{(1000.00 \text{ cm}^3)(55.0 \text{ C}^\circ)} = 1.7 \times 10^{-5} (\text{C}^\circ)^{-1}.$$

EVALUATE: The coefficient of volume expansion for the mercury is larger than for glass. When they are heated, both the volume of the mercury and the inside volume of the flask increase. But the increase for the mercury is greater and it no longer all fits inside the flask.

17.26. IDENTIFY: Apply $\Delta L = L_0\alpha\Delta T$ to each linear dimension of the surface.

SET UP: The area can be written as $A = aL_1L_2$, where a is a constant that depends on the shape of the surface. For example, if the object is a sphere, $a = 4\pi$ and $L_1 = L_2 = r$. If the object is a cube, $a = 6$ and $L_1 = L_2 = L$, the length of one side of the cube. For aluminum, $\alpha = 2.4 \times 10^{-5} (\text{C}^\circ)^{-1}$.

EXECUTE: (a) $A_0 = aL_{01}L_{02}$. $L_1 = L_{01}(1 + \alpha\Delta T)$. $L_2 = L_{02}(1 + \alpha\Delta T)$.

$$A = aL_1L_2 = aL_{01}L_{02}(1 + \alpha\Delta T)^2 = A_0(1 + 2\alpha\Delta T + [\alpha\Delta T]^2). \quad \alpha\Delta T \text{ is very small, so } [\alpha\Delta T]^2 \text{ can be neglected and}$$

$$A = A_0(1 + 2\alpha\Delta T). \quad \Delta A = A - A_0 = (2\alpha)A_0\Delta T$$

$$(b) \Delta A = (2\alpha)A_0\Delta T = (2)(2.4 \times 10^{-5} (\text{C}^\circ)^{-1})(\pi(0.275 \text{ m})^2)(12.5 \text{ C}^\circ) = 1.4 \times 10^{-4} \text{ m}^2$$

EVALUATE: The derivation assumes the object expands uniformly in all directions.

17.27. IDENTIFY and SET UP: Apply the result of Exercise 17.26a to calculate ΔA for the plate, and then $A = A_0 + \Delta A$.

EXECUTE: (a) $A_0 = \pi r_0^2 = \pi(1.350 \text{ cm}/2)^2 = 1.431 \text{ cm}^2$

(b) Exercise 17.26 says $\Delta A = 2\alpha A_0\Delta T$, so $\Delta A = 2(1.2 \times 10^{-5} \text{ C}^\circ)^{-1}(1.431 \text{ cm}^2)(175 \text{ C}^\circ - 25 \text{ C}^\circ) = 5.15 \times 10^{-3} \text{ cm}^2$

$$A = A_0 + \Delta A = 1.436 \text{ cm}^2$$

EVALUATE: A hole in a flat metal plate expands when the metal is heated just as a piece of metal the same size as the hole would expand.

17.28. IDENTIFY: Apply $\Delta L = L_0\alpha\Delta T$ to the diameter D_{ST} of the steel cylinder and the diameter D_{BR} of the brass piston.

SET UP: For brass, $\alpha_{\text{BR}} = 2.0 \times 10^{-5} (\text{C}^\circ)^{-1}$. For steel, $\alpha_{\text{ST}} = 1.2 \times 10^{-5} (\text{C}^\circ)^{-1}$.

EXECUTE: (a) No, the brass expands more than the steel.

(b) Call D_0 the inside diameter of the steel cylinder at 20°C . At 150°C , $D_{\text{ST}} = D_{\text{BR}}$.

$$D_0 + \Delta D_{\text{ST}} = 25.000 \text{ cm} + \Delta D_{\text{BR}}. \text{ This gives } D_0 + \alpha_{\text{ST}} D_0 \Delta T = 25.000 \text{ cm} + \alpha_{\text{BR}} (25.000 \text{ cm}) \Delta T.$$

$$D_0 = \frac{25.000 \text{ cm}(1 + \alpha_{\text{BR}} \Delta T)}{1 + \alpha_{\text{ST}} \Delta T} = \frac{(25.000 \text{ cm})[1 + (2.0 \times 10^{-5} (\text{C}^\circ)^{-1})(130 \text{ C}^\circ)]}{1 + (1.2 \times 10^{-5} (\text{C}^\circ)^{-1})(130 \text{ C}^\circ)} = 25.026 \text{ cm}.$$

EVALUATE: The space inside the steel cylinder expands just like a solid piece of steel of the same size.

17.29. IDENTIFY: Find the change ΔL in the diameter of the lid. The diameter of the lid expands according to Eq.(17.6).

SET UP: Assume iron has the same α as steel, so $\alpha = 1.2 \times 10^{-5} (\text{C}^\circ)^{-1}$.

$$\text{EXECUTE: } \Delta L = \alpha L_0 \Delta T = (1.2 \times 10^{-5} (\text{C}^\circ)^{-1})(725 \text{ mm})(30.0 \text{ C}^\circ) = 0.26 \text{ mm}$$

EVALUATE: In Eq.(17.6), ΔL has the same units as L .

17.30. IDENTIFY: Apply Eq.(17.12) and solve for F .

SET UP: For brass, $Y = 0.9 \times 10^{11} \text{ Pa}$ and $\alpha = 2.0 \times 10^{-5} (\text{C}^\circ)^{-1}$.

$$\text{EXECUTE: } F = -Y\alpha\Delta T A = -(0.9 \times 10^{11} \text{ Pa})(2.0 \times 10^{-5} (\text{C}^\circ)^{-1})(-110 \text{ C}^\circ)(2.01 \times 10^{-4} \text{ m}^2) = 4.0 \times 10^4 \text{ N}$$

EVALUATE: A large force is required. ΔT is negative and a positive tensile force is required.

17.31. IDENTIFY and SET UP: For part (a), apply Eq.(17.6) to the linear expansion of the wire. For part (b), apply Eq.(17.12) and calculate F/A .

EXECUTE: (a) $\Delta L = \alpha L_0 \Delta T$

$$\alpha = \frac{\Delta L}{L_0 \Delta T} = \frac{1.9 \times 10^{-2} \text{ m}}{(1.50 \text{ m})(420^\circ\text{C} - 20^\circ\text{C})} = 3.2 \times 10^{-5} (\text{C}^\circ)^{-1}$$

(b) Eq.(17.12): stress $F/A = -Y\alpha\Delta T$

$$\Delta T = 20^\circ\text{C} - 420^\circ\text{C} = -400 \text{ C}^\circ \quad (\Delta T \text{ always means final temperature minus initial temperature})$$

$$F/A = -(2.0 \times 10^{11} \text{ Pa})(3.2 \times 10^{-5} (\text{C}^\circ)^{-1})(-400 \text{ C}^\circ) = +2.6 \times 10^9 \text{ Pa}$$

EVALUATE: F/A is positive means that the stress is a tensile (stretching) stress. The answer to part (a) is consistent with the values of α for metals in Table 17.1. The tensile stress for this modest temperature decrease is huge.

17.32. IDENTIFY: Apply $\Delta L = L_0\alpha\Delta T$ and stress $F/A = -Y\alpha\Delta T$.

SET UP: For steel, $\alpha = 1.2 \times 10^{-5} (\text{C}^\circ)^{-1}$ and $Y = 2.0 \times 10^{11} \text{ Pa}$.

$$\text{EXECUTE: (a) } \Delta L = L_0\alpha\Delta T = (12.0 \text{ m})(1.2 \times 10^{-5} (\text{C}^\circ)^{-1})(35.0 \text{ C}^\circ) = 5.0 \text{ mm}$$

(b) stress $= -Y\alpha\Delta T = -(2.0 \times 10^{11} \text{ Pa})(1.2 \times 10^{-5} (\text{C}^\circ)^{-1})(35.0 \text{ C}^\circ) = -8.4 \times 10^7 \text{ Pa}$. The minus sign means the stress is compressive.

EVALUATE: Commonly occurring temperature changes result in very small fractional changes in length but very large stresses if the length change is prevented from occurring.

17.33. 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.

17.34. IDENTIFY: The heat required is $Q = mc\Delta T$. $P = 200 \text{ W} = 200 \text{ J/s}$, which is energy divided by time.

SET UP: For water, $c = 4.19 \times 10^3 \text{ J/kg} \cdot \text{K}$.

$$\text{EXECUTE: (a) } Q = mc\Delta T = (0.320 \text{ kg})(4.19 \times 10^3 \text{ J/kg} \cdot \text{K})(60.0 \text{ C}^\circ) = 8.04 \times 10^4 \text{ J}$$

$$\text{(b) } t = \frac{8.04 \times 10^4 \text{ J}}{200.0 \text{ J/s}} = 402 \text{ s} = 6.7 \text{ min}$$

EVALUATE: 0.320 kg of water has volume 0.320 L. The time we calculated in part (b) is consistent with our everyday experience.

17.35. IDENTIFY: Apply $Q = mc\Delta T$. $m = w/g$.

SET UP: The temperature change is $\Delta T = 18.0 \text{ K}$.

$$\text{EXECUTE: } c = \frac{Q}{m\Delta T} = \frac{gQ}{w\Delta T} = \frac{(9.80 \text{ m/s}^2)(1.25 \times 10^4 \text{ J})}{(28.4 \text{ N})(18.0 \text{ K})} = 240 \text{ J/kg} \cdot \text{K}.$$

EVALUATE: The value for c is similar to that for silver in Table 17.3, so it is a reasonable result.

17.36. IDENTIFY and SET UP: Use Eq.(17.13)

EXECUTE: (a) $Q = mc\Delta T$

$$m = \frac{1}{2}(1.3 \times 10^{-3} \text{ kg}) = 0.65 \times 10^{-3} \text{ kg}$$

$$Q = (0.65 \times 10^{-3} \text{ kg})(1020 \text{ J/kg} \cdot \text{K})(37^\circ\text{C} - (-20^\circ\text{C})) = 38 \text{ J}$$

(b) 20 breaths/min (60 min/1 h) = 1200 breaths/h

$$\text{So } Q = (1200)(38 \text{ J}) = 4.6 \times 10^4 \text{ J.}$$

EVALUATE: The heat loss rate is $Q/t = 13 \text{ W}$.

17.37. IDENTIFY: Apply $Q = mc\Delta T$ to find the heat that would raise the temperature of the student's body 7°C .

SET UP: $1 \text{ W} = 1 \text{ J/s}$

EXECUTE: Find Q to raise the body temperature from 37°C to 44°C .

$$Q = mc\Delta T = (70 \text{ kg})(3480 \text{ J/kg} \cdot \text{K})(7^\circ\text{C}) = 1.7 \times 10^6 \text{ J.}$$

$$t = \frac{1.7 \times 10^6 \text{ J}}{1200 \text{ J/s}} = 1400 \text{ s} = 23 \text{ min.}$$

EVALUATE: Heat removal mechanisms are essential to the well-being of a person.

17.38. IDENTIFY and SET UP: Set the change in gravitational potential energy equal to the quantity of heat added to the water.

EXECUTE: The change in mechanical energy equals the decrease in gravitational potential energy, $\Delta U = -mgh$; $|\Delta U| = mgh$. $Q = |\Delta U| = mgh$ implies $mc\Delta T = mgh$

$$\Delta T = gh/c = (9.80 \text{ m/s}^2)(225 \text{ m})/(4190 \text{ J/kg} \cdot \text{K}) = 0.526 \text{ K} = 0.526^\circ\text{C}$$

EVALUATE: Note that the answer is independent of the mass of the object. Note also the small change in temperature that corresponds to this large change in height!

17.39. IDENTIFY: The work done by friction is the loss of mechanical energy. The heat input for a temperature change is $Q = mc\Delta T$

SET UP: The crate loses potential energy mgh , with $h = (8.00 \text{ m})\sin 36.9^\circ$, and gains kinetic energy $\frac{1}{2}mv_2^2$.

$$\text{EXECUTE: (a) } W_f = mgh - \frac{1}{2}mv_2^2 = (35.0 \text{ kg})\left((9.80 \text{ m/s}^2)(8.00 \text{ m})\sin 36.9^\circ - \frac{1}{2}(2.50 \text{ m/s})^2\right) = 1.54 \times 10^3 \text{ J.}$$

(b) Using the results of part (a) for Q gives $\Delta T = (1.54 \times 10^3 \text{ J})/((35.0 \text{ kg})(3650 \text{ J/kg} \cdot \text{K})) = 1.21 \times 10^{-2}^\circ\text{C}$.

EVALUATE: The temperature rise is very small.

17.40. IDENTIFY: The work done by the brakes equals the initial kinetic energy of the train. Use the volume of the air to calculate its mass. Use $Q = mc\Delta T$ applied to the air to calculate ΔT for the air.

SET UP: $K = \frac{1}{2}mv^2$. $m = \rho V$.

EXECUTE: The initial kinetic energy of the train is $K = \frac{1}{2}(25,000 \text{ kg})(15.5 \text{ m/s})^2 = 3.00 \times 10^6 \text{ J}$. Therefore, Q for the air is $3.00 \times 10^6 \text{ J}$. $m = \rho V = (1.20 \text{ kg/m}^3)(65.0 \text{ m})(20.0 \text{ m})(12.0 \text{ m}) = 1.87 \times 10^4 \text{ kg}$. $Q = mc\Delta T$ gives

$$\Delta T = \frac{Q}{mc} = \frac{3.00 \times 10^6 \text{ J}}{(1.87 \times 10^4 \text{ kg})(1020 \text{ J/kg} \cdot \text{K})} = 0.157^\circ\text{C}.$$

EVALUATE: The mass of air in the station is comparable to the mass of the train and the temperature rise is small.

17.41. IDENTIFY: Set $K = \frac{1}{2}mv^2$ equal to $Q = mc\Delta T$ for the nail and solve for ΔT .

SET UP: For aluminum, $c = 0.91 \times 10^3 \text{ J/kg} \cdot \text{K}$.

EXECUTE: The kinetic energy of the hammer before it strikes the nail is

$$K = \frac{1}{2}mv^2 = \frac{1}{2}(1.80 \text{ kg})(7.80 \text{ m/s})^2 = 54.8 \text{ J. Each strike of the hammer transfers } 0.60(54.8 \text{ J}) = 32.9 \text{ J, and with}$$

$$10 \text{ strikes } Q = 329 \text{ J. } Q = mc\Delta T \text{ and } \Delta T = \frac{Q}{mc} = \frac{329 \text{ J}}{(8.00 \times 10^{-3} \text{ kg})(0.91 \times 10^3 \text{ J/kg} \cdot \text{K})} = 45.2^\circ\text{C}$$

EVALUATE: This agrees with our experience that hammered nails get noticeably warmer.

17.42. IDENTIFY and SET UP: Use the power and time to calculate the heat input Q and then use Eq.(17.13) to calculate c .

(a) **EXECUTE:** $P = Q/t$, so the total heat transferred to the liquid is $Q = Pt = (65.0 \text{ W})(120 \text{ s}) = 7800 \text{ J}$

$$\text{Then } Q = mc\Delta T \text{ gives } c = \frac{Q}{m\Delta T} = \frac{7800 \text{ J}}{0.780 \text{ kg}(22.54^\circ\text{C} - 18.55^\circ\text{C})} = 2.51 \times 10^3 \text{ J/kg} \cdot \text{K}$$

(b) **EVALUATE:** Then the actual Q transferred to the liquid is less than 7800 J so the actual c is less than our calculated value; our result in part (a) is an overestimate.

17.43. IDENTIFY: $Q = mc\Delta T$. The mass of n moles is $m = nM$.

SET UP: For iron, $M = 55.845 \times 10^{-3}$ kg/mol and $c = 470$ J/kg · K.

EXECUTE: (a) The mass of 3.00 mol is $m = nM = (3.00 \text{ mol})(55.845 \times 10^{-3} \text{ kg/mol}) = 0.1675$ kg.

$$\Delta T = Q/mc = (8950 \text{ J}) / [(0.1675 \text{ kg})(470 \text{ J/kg} \cdot \text{K})] = 114 \text{ K} = 114 \text{ C}^\circ.$$

(b) For $m = 3.00$ kg, $\Delta T = Q/mc = 6.35 \text{ C}^\circ$.

EVALUATE: (c) The result of part (a) is much larger; 3.00 kg is more material than 3.00 mol.

17.44. 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 $(1.5 \text{ min})(10.0 \times 10^3 \text{ J/min}) = 1.50 \times 10^4$ 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.

17.45. IDENTIFY and SET UP: Heat comes out of the metal and into the water. The final temperature is in the range $0 < T < 100^\circ\text{C}$, so there are no phase changes. $Q_{\text{system}} = 0$.

(a) **EXECUTE:** $Q_{\text{water}} + Q_{\text{metal}} = 0$

$$m_{\text{water}}c_{\text{water}}\Delta T_{\text{water}} + m_{\text{metal}}c_{\text{metal}}\Delta T_{\text{metal}} = 0$$

$$(1.00 \text{ kg})(4190 \text{ J/kg} \cdot \text{K})(2.0 \text{ C}^\circ) + (0.500 \text{ kg})(c_{\text{metal}})(-78.0 \text{ C}^\circ) = 0$$

$$c_{\text{metal}} = 215 \text{ J/kg} \cdot \text{K}$$

(b) **EVALUATE:** Water has a larger specific heat capacity so stores more heat per degree of temperature change.

(c) If some heat went into the styrofoam then Q_{metal} should actually be larger than in part (a), so the true c_{metal} is larger than we calculated; the value we calculated would be smaller than the true value.

17.46. IDENTIFY: Apply $Q = mc\Delta T$ to each object. The net heat flow Q_{system} for the system (man, soft drink) is zero.

SET UP: The mass of 1.00 L of water is 1.00 kg. Let the man be designated by the subscript m and the “water” by w. T is the final equilibrium temperature. $c_w = 4190$ J/kg · K. $\Delta T_k = \Delta T_c$.

EXECUTE: (a) $Q_{\text{system}} = 0$ gives $m_m C_m \Delta T_m + m_w C_w \Delta T_w = 0$. $m_m C_m (T - T_m) + m_w C_w (T - T_w) = 0$.

$$m_m C_m (T_m - T) = m_w C_w (T - T_w). \text{ Solving for } T, T = \frac{m_m C_m T_m + m_w C_w T_w}{m_m C_m + m_w C_w}.$$

$$T = \frac{(70.0 \text{ kg})(3480 \text{ J/kg} \cdot \text{K})(37.0^\circ\text{C}) + (0.355 \text{ kg})(4190 \text{ J/kg} \cdot \text{C}^\circ)(12.0^\circ\text{C})}{(70.0 \text{ kg})(3480 \text{ J/kg} \cdot \text{C}^\circ) + (0.355 \text{ kg})(4190 \text{ J/kg} \cdot \text{C}^\circ)} = 36.85^\circ\text{C}$$

(b) It is possible a sensitive digital thermometer could measure this change since they can read to 0.1°C . It is best to refrain from drinking cold fluids prior to orally measuring a body temperature due to cooling of the mouth.

EVALUATE: Heat comes out of the body and its temperature falls. Heat goes into the soft drink and its temperature rises.

17.47. IDENTIFY: For the man's body, $Q = mc\Delta T$.

SET UP: From Exercise 17.46, $\Delta T = 0.15 \text{ C}^\circ$ when the body returns to 37.0°C .

EXECUTE: The rate of heat loss is Q/t . $\frac{Q}{t} = \frac{mC\Delta T}{t}$ and $t = \frac{mC\Delta T}{(Q/t)}$.

$$t = \frac{(70.355 \text{ kg})(3480 \text{ J/kg} \cdot \text{C}^\circ)(0.15 \text{ C}^\circ)}{7.00 \times 10^6 \text{ J/day}} = 0.00525 \text{ d} = 7.6 \text{ minutes}.$$

EVALUATE: Even if all the BMR energy stays in the body, it takes the body several minutes to return to its normal temperature.

17.48. IDENTIFY: For a temperature change $Q = mc\Delta T$ and for the liquid to solid phase change $Q = -mL_f$.

SET UP: For water, $c = 4.19 \times 10^3 \text{ J/kg} \cdot \text{K}$ and $L_f = 3.34 \times 10^5 \text{ J/kg}$.

EXECUTE: $Q = mc\Delta T - mL_f = (0.350 \text{ kg})([4.19 \times 10^3 \text{ J/kg} \cdot \text{K}][-18.0 \text{ C}^\circ] - 3.34 \times 10^5 \text{ J/kg}) = -1.43 \times 10^5 \text{ J}$. The minus sign says $1.43 \times 10^5 \text{ J}$ must be removed from the water. $(1.43 \times 10^5 \text{ J}) \left(\frac{1 \text{ cal}}{4.186 \text{ J}} \right) = 3.42 \times 10^4 \text{ cal} = 34.2 \text{ kcal}$.

EVALUATE: $Q < 0$ when heat comes out of an object the equation $Q = mc\Delta T$ puts in the correct sign automatically, from the sign of $\Delta T = T_f - T_i$. But in $Q = \pm L$ we must select the correct sign.

17.49. IDENTIFY and SET UP: Use Eq.(17.13) for the temperature changes and Eq.(17.20) for the phase changes.

EXECUTE: Heat must be added to do the following
ice at $-10.0^\circ\text{C} \rightarrow$ ice at 0°C

$$Q_{\text{ice}} = mc_{\text{ice}}\Delta T = (12.0 \times 10^{-3} \text{ kg})(2100 \text{ J/kg} \cdot \text{K})(0^\circ\text{C} - (-10.0^\circ\text{C})) = 252 \text{ J}$$

phase transition ice (0°C) \rightarrow liquid water (0°C) (melting)

$$Q_{\text{melt}} = +mL_f = (12.0 \times 10^{-3} \text{ kg})(334 \times 10^3 \text{ J/kg}) = 4.008 \times 10^3 \text{ J}$$

water at 0°C (from melted ice \rightarrow water at 100°C)

$$Q_{\text{water}} = mc_{\text{water}}\Delta T = (12.0 \times 10^{-3} \text{ kg})(4190 \text{ J/kg} \cdot \text{K})(100^\circ\text{C} - 0^\circ\text{C}) = 5.028 \times 10^3 \text{ J}$$

phase transition water (100°C) \rightarrow steam (100°C) (boiling)

$$Q_{\text{boil}} = +mL_v = (12.0 \times 10^{-3} \text{ kg})(2256 \times 10^3 \text{ J/kg}) = 2.707 \times 10^4 \text{ J}$$

The total Q is $Q = 252 \text{ J} + 4.008 \times 10^3 \text{ J} + 5.028 \times 10^3 \text{ J} + 2.707 \times 10^4 \text{ J} = 3.64 \times 10^4 \text{ J}$

$$(3.64 \times 10^4 \text{ J})(1 \text{ cal}/4.186 \text{ J}) = 8.70 \times 10^3 \text{ cal}$$

$$(3.64 \times 10^4 \text{ J})(1 \text{ Btu}/1055 \text{ J}) = 34.5 \text{ Btu}$$

EVALUATE: Q is positive and heat must be added to the material. Note that more heat is needed for the liquid to gas phase change than for the temperature changes.

17.50. IDENTIFY: $Q = mc\Delta T$ for a temperature change and $Q = +mL_f$ for the solid to liquid phase transition. The ice starts to melt when its temperature reaches 0.0°C . The system stays at 0.00°C until all the ice has melted.

SET UP: For ice, $c = 2.01 \times 10^3 \text{ J/kg} \cdot \text{K}$. For water, $L_f = 3.34 \times 10^5 \text{ J/kg}$.

EXECUTE: (a) Q to raise the temperature of ice to 0.00°C :

$$Q = mc\Delta T = (0.550 \text{ kg})(2.01 \times 10^3 \text{ J/kg} \cdot \text{K})(15.0 \text{ C}^\circ) = 1.66 \times 10^4 \text{ J}. \quad t = \frac{1.66 \times 10^4 \text{ J}}{800.0 \text{ J/min}} = 20.8 \text{ min.}$$

(b) To melt all the ice requires $Q = mL_f = (0.550 \text{ kg})(3.34 \times 10^5 \text{ J/kg}) = 1.84 \times 10^5 \text{ J}$. $t = \frac{1.84 \times 10^5 \text{ J}}{800.0 \text{ J/min}} = 230 \text{ min.}$

The total time after the start of the heating is 251 min.

(c) A graph of T versus t is sketched in Figure 17.50.

EVALUATE: It takes much longer for the ice to melt than it takes the ice to reach the melting point.

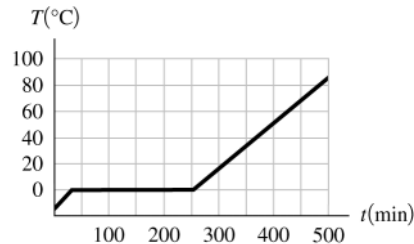


Figure 17.50

17.51. IDENTIFY and SET UP: Use Eq.(17.20) to calculate Q and then $P = Q/t$. Must convert the quantity of ice from lb to kg.

EXECUTE: "two-ton air conditioner" means 2 tons (4000 lbs) of ice can be frozen from water at 0°C in 24 h. Find the mass m that corresponds to 4000 lb (weight of water): $m = (4000 \text{ lb})(1 \text{ kg}/2.205 \text{ lb}) = 1814 \text{ kg}$ (The kg to lb equivalence from Appendix E has been used.) The heat that must be removed from the water to freeze it is

$Q = -mL_f = -(1814 \text{ kg})(334 \times 10^3 \text{ J/kg}) = -6.06 \times 10^8 \text{ J}$. The power required if this is to be done in 24 hours is

$$P = \frac{|Q|}{t} = \frac{6.06 \times 10^8 \text{ J}}{(24 \text{ h})(3600 \text{ s/h})} = 7010 \text{ W} \quad \text{or} \quad P = (7010 \text{ W})((1 \text{ Btu/h})/(0.293 \text{ W})) = 2.39 \times 10^4 \text{ Btu/h.}$$

EVALUATE: The calculated power, the rate at which heat energy is removed by the unit, is equivalent to seventy 100-W light bulbs.

17.52. IDENTIFY: For a temperature change, $Q = mc\Delta T$. For the vapor \rightarrow liquid phase transition, $Q = -mL_v$.

SET UP: For water, $L_v = 2.256 \times 10^6$ J/kg and $c = 4.19 \times 10^3$ J/kg \cdot K.

EXECUTE: (a) $Q = +m(-L_v + c\Delta T)$

$$Q = +(25.0 \times 10^{-3} \text{ kg})(-2.256 \times 10^6 \text{ J/kg} + [4.19 \times 10^3 \text{ J/kg} \cdot \text{K}][-66.0 \text{ C}^\circ]) = -6.33 \times 10^4 \text{ J}$$

$$(b) Q = mc\Delta T = (25.0 \times 10^{-3} \text{ kg})(4.19 \times 10^3 \text{ J/kg} \cdot \text{K})(-66.0 \text{ C}^\circ) = -6.91 \times 10^3 \text{ J}$$

(c) The total heat released by the water that starts as steam is nearly a factor of ten larger than the heat released by water that starts at 100°C . Steam burns are much more severe than hot-water burns.

EVALUATE: For a given amount of material, the heat for a phase change is typically much more than the heat for a temperature change.

17.53. IDENTIFY and SET UP: The heat that must be added to a lead bullet of mass m to melt it is $Q = mc\Delta T + mL_f$

($mc\Delta T$ is the heat required to raise the temperature from 25°C to the melting point of 327.3°C ; mL_f is the heat required to make the solid \rightarrow liquid phase change.) The kinetic energy of the bullet if its speed is v is $K = \frac{1}{2}mv^2$.

EXECUTE: $K = Q$ says $\frac{1}{2}mv^2 = mc\Delta T + mL_f$

$$v = \sqrt{2(c\Delta T + L_f)}$$

$$v = \sqrt{2[(130 \text{ J/kg} \cdot \text{K})(327.3^\circ\text{C} - 25^\circ\text{C}) + 24.5 \times 10^3 \text{ J/kg}]} = 357 \text{ m/s}$$

EVALUATE: This is a typical speed for a rifle bullet. A bullet fired into a block of wood does partially melt, but in practice not all of the initial kinetic energy is converted to heat that remains in the bullet.

17.54. IDENTIFY: For a temperature change, $Q = mc\Delta T$. For the liquid \rightarrow vapor phase change, $Q = +mL_v$.

SET UP: The density of water is 1000 kg/m^3 .

EXECUTE: (a) The heat that goes into mass m of water to evaporate it is $Q = +mL_v$. The heat flow for the man is

$Q = m_{\text{man}}c\Delta T$, where $\Delta T = -1.00 \text{ C}^\circ$. $\sum Q = 0$ so $mL_v + m_{\text{man}}c\Delta T$ and

$$m = -\frac{m_{\text{man}}c\Delta T}{L_v} = -\frac{(70.0 \text{ kg})(3480 \text{ J/kg} \cdot \text{K})(-1.00 \text{ C}^\circ)}{2.42 \times 10^6 \text{ J/kg}} = 0.101 \text{ kg} = 101 \text{ g}$$

$$(b) V = \frac{m}{\rho} = \frac{0.101 \text{ kg}}{1000 \text{ kg/m}^3} = 1.01 \times 10^{-4} \text{ m}^3 = 101 \text{ cm}^3. \text{ This is about 28\% of the volume of a soft-drink can.}$$

EVALUATE: Fluid loss by evaporation from the skin can be significant.

17.55. IDENTIFY: Use $Q = Mc\Delta T$ to find Q for a temperature rise from 34.0°C to 40.0°C . Set this equal to

$Q = mL_v$ and solve for m , where m is the mass of water the camel would have to drink.

SET UP: $c = 3480 \text{ J/kg} \cdot \text{K}$ and $L_v = 2.42 \times 10^6 \text{ J/kg}$. For water, 1.00 kg has a volume 1.00 L . $M = 400 \text{ kg}$ is the mass of the camel.

$$\text{EXECUTE: The mass of water that the camel saves is } m = \frac{Mc\Delta T}{L_v} = \frac{(400 \text{ kg})(3480 \text{ J/kg} \cdot \text{K})(6.0 \text{ K})}{(2.42 \times 10^6 \text{ J/kg})} = 3.45 \text{ kg}$$

which is a volume of 3.45 L .

EVALUATE: This is nearly a gallon of water, so it is an appreciable savings.

17.56. IDENTIFY: The asteroid's kinetic energy is $K = \frac{1}{2}mv^2$. To boil the water, its temperature must be raised to

100.0°C and the heat needed for the phase change must be added to the water.

SET UP: For water, $c = 4190 \text{ J/kg} \cdot \text{K}$ and $L_v = 2256 \times 10^3 \text{ J/kg}$.

EXECUTE: $K = \frac{1}{2}(2.60 \times 10^{15} \text{ kg})(32.0 \times 10^3 \text{ m/s})^2 = 1.33 \times 10^{24} \text{ J}$. $Q = mc\Delta T + mL_v$.

$$m = \frac{Q}{c\Delta T + L_v} = \frac{1.33 \times 10^{24} \text{ J}}{(4190 \text{ J/kg} \cdot \text{K})(90.0 \text{ K}) + 2256 \times 10^3 \text{ J/kg}} = 5.05 \times 10^{15} \text{ kg}$$

EVALUATE: The mass of water boiled is 2.5 times the mass of water in Lake Superior.

17.57. IDENTIFY: Apply $Q = mc\Delta T$ to the air in the refrigerator and to the turkey.

SET UP: For the air $m_{\text{air}} = \rho V$

EXECUTE: $m_{\text{air}} = (1.20 \text{ kg/m}^3)(1.50 \text{ m}^3) = 1.80 \text{ kg}$. $Q = m_{\text{air}}c_{\text{air}}\Delta T + m_t c_t \Delta T$.

$$Q = [(1.80 \text{ kg})[1020 \text{ J/kg} \cdot \text{K}] + [10.0 \text{ kg}][3480 \text{ J/kg} \cdot \text{K}](-15.0 \text{ C}^\circ) = -5.50 \times 10^5 \text{ J}$$

EVALUATE: Q is negative because heat is removed. 5% of the heat removed comes from the air.

17.58. IDENTIFY: $Q = mc\Delta T$ for a temperature change. The net Q for the system (sample, can and water) is zero.

SET UP: For water, $c_w = 4.19 \times 10^3 \text{ J/kg} \cdot \text{K}$. For copper, $c_c = 390 \text{ J/kg} \cdot \text{K}$.

EXECUTE: For the water, $Q_w = m_w c_w \Delta T_w = (0.200 \text{ kg})(4.19 \times 10^3 \text{ J/kg} \cdot \text{K})(7.1 \text{ C}^\circ) = 5.95 \times 10^3 \text{ J}$.

For the copper can, $Q_c = m_c c_c \Delta T_c = (0.150 \text{ kg})(390 \text{ J/kg} \cdot \text{K})(7.1 \text{ C}^\circ) = 415 \text{ J}$.

For the sample, $Q_s = m_s c_s \Delta T_s = (0.085 \text{ kg})c_s(-73.9 \text{ C}^\circ)$.

$$\sum Q = 0 \text{ gives } (0.085 \text{ kg})(-73.9 \text{ C}^\circ)c_s + 415 \text{ J} + 5.95 \times 10^3 \text{ J} = 0. \quad c_s = 1.01 \times 10^3 \text{ J/kg} \cdot \text{K}.$$

EVALUATE: Heat comes out of the sample and goes into the water and the can. The value of c_s we calculated is consistent with the values in Table 17.3.

- 17.59. IDENTIFY and SET UP:** Heat flows out of the water and into the ice. The net heat flow for the system is zero. The ice warms 0°C , melts, and then the water from the melted ice warms from 0°C to the final temperature.

EXECUTE: $Q_{\text{system}} = 0$; calculate Q for each component of the system: (Beaker has small mass says that

$Q = mc\Delta T$ for beaker can be neglected.)

0.250 kg of water (cools from 75.0°C to 30.0°C)

$$Q_{\text{water}} = mc\Delta T = (0.250 \text{ kg})(4190 \text{ J/kg} \cdot \text{K})(30.0^\circ\text{C} - 75.0^\circ\text{C}) = -4.714 \times 10^4 \text{ J}$$

ice (warms to 0°C ; melts; water from melted ice warms to 30.0°C)

$$Q_{\text{ice}} = mc_{\text{ice}}\Delta T + mL_f + mc_{\text{water}}\Delta T$$

$$Q_{\text{ice}} = m[(2100 \text{ J/kg} \cdot \text{K})(0^\circ\text{C} - (-20.0^\circ\text{C})) + 334 \times 10^3 \text{ J/kg} + (4190 \text{ J/kg} \cdot \text{K})(30.0^\circ\text{C} - 0^\circ\text{C})]$$

$$Q_{\text{ice}} = (5.017 \times 10^5 \text{ J/kg})m$$

$$Q_{\text{system}} = 0 \text{ says } Q_{\text{water}} + Q_{\text{ice}} = 0$$

$$-4.714 \times 10^4 \text{ J} + (5.017 \times 10^5 \text{ J/kg})m = 0$$

$$m = \frac{4.714 \times 10^4 \text{ J}}{5.017 \times 10^5 \text{ J/kg}} = 0.0940 \text{ kg}$$

EVALUATE: Since the final temperature is 30.0°C we know that all the ice melts and the final system is all liquid water. The mass of ice added is much less than the mass of the 75°C water; the ice requires a large heat input for the phase change.

- 17.60. IDENTIFY:** For a temperature change $Q = mc\Delta T$. For a melting phase transition $Q = mL_f$. The net Q for the system (sample, vial and ice) is zero.

SET UP: Ice remains, so the final temperature is 0.0°C . For water, $L_f = 3.34 \times 10^5 \text{ J/kg}$.

EXECUTE: For the sample, $Q_s = m_s c_s \Delta T_s = (16.0 \times 10^{-3} \text{ kg})(2250 \text{ J/kg} \cdot \text{K})(-19.5 \text{ C}^\circ) = -702 \text{ J}$. For the vial,

$Q_v = m_v c_v \Delta T_v = (6.0 \times 10^{-3} \text{ kg})(2800 \text{ J/kg} \cdot \text{K})(-19.5 \text{ C}^\circ) = -328 \text{ J}$. For the ice that melts, $Q_i = mL_f$. $\sum Q = 0$ gives $mL_f - 702 \text{ J} - 328 \text{ J} = 0$ and $m = 3.08 \times 10^{-3} \text{ kg} = 3.08 \text{ g}$.

EVALUATE: Only a small fraction of the ice melts. The water for the melted ice remains at 0°C and has no heat flow.

- 17.61. IDENTIFY and SET UP:** Large block of ice implies that ice is left, so $T_2 = 0^\circ\text{C}$ (final temperature). Heat comes out of the ingot and into the ice. The net heat flow is zero. The ingot has a temperature change and the ice has a phase change.

EXECUTE: $Q_{\text{system}} = 0$; calculate Q for each component of the system:

ingot

$$Q_{\text{ingot}} = mc\Delta T = (4.00 \text{ kg})(234 \text{ J/kg} \cdot \text{K})(0^\circ\text{C} - 750^\circ\text{C}) = -7.02 \times 10^5 \text{ J}$$

ice

$$Q_{\text{ice}} = +mL_f, \text{ where } m \text{ is the mass of the ice that changes phase (melts)}$$

$$Q_{\text{system}} = 0 \text{ says } Q_{\text{ingot}} + Q_{\text{ice}} = 0$$

$$-7.02 \times 10^5 \text{ J} + m(334 \times 10^3 \text{ J/kg}) = 0$$

$$m = \frac{7.02 \times 10^5 \text{ J}}{334 \times 10^3 \text{ J/kg}} = 2.10 \text{ kg}$$

EVALUATE: The liquid produced by the phase change remains at 0°C since it is in contact with ice.

- 17.62. IDENTIFY:** The initial temperature of the ice and water mixture is 0.0°C . Assume all the ice melts. We will know that assumption is incorrect if the final temperature we calculate is less than 0.0°C . The net Q for the system (can, water, ice and lead) is zero.

SET UP: For copper, $c_c = 390 \text{ J/kg} \cdot \text{K}$. For lead, $c_l = 130 \text{ J/kg} \cdot \text{K}$. For water, $c_w = 4.19 \times 10^3 \text{ J/kg} \cdot \text{K}$ and

$$L_f = 3.34 \times 10^5 \text{ J/kg}.$$

EXECUTE: For the copper can, $Q_c = m_c c_c \Delta T_c = (0.100 \text{ kg})(390 \text{ J/kg} \cdot \text{K})(T - 0.0^\circ\text{C}) = (39.0 \text{ J/K})T$.

For the water, $Q_w = m_w c_w \Delta T_w = (0.160 \text{ kg})(4.19 \times 10^3 \text{ J/kg} \cdot \text{K})(T - 0.0^\circ\text{C}) = (670.4 \text{ J/K})T$.

For the ice, $Q_i = m_i L_f + m_i c_w \Delta T_w$

$Q_i = (0.018 \text{ kg})(3.34 \times 10^5 \text{ J/kg} \cdot \text{K}) + (0.018 \text{ kg})(4.19 \times 10^3 \text{ J/kg} \cdot \text{K})(T - 0.0^\circ\text{C}) = 6012 \text{ J} + (75.4 \text{ J/K})T$

For the lead, $Q_l = m_l c_l \Delta T_l = (0.750 \text{ kg})(130 \text{ J/kg} \cdot \text{K})(T - 255^\circ\text{C}) = (97.5 \text{ J/K})T - 2.486 \times 10^4 \text{ J}$

$\sum Q = 0$ gives $(39.0 \text{ J/K})T + (670.4 \text{ J/K})T + 6012 \text{ J} + (75.4 \text{ J/K})T + (97.5 \text{ J/K})T - 2.486 \times 10^4 \text{ J} = 0$.

$$T = \frac{1.885 \times 10^4 \text{ J}}{882.3 \text{ J/K}} = 21.4^\circ\text{C}.$$

EVALUATE: $T > 0.0^\circ\text{C}$, which confirms that all the ice melts.

- 17.63. IDENTIFY:** Set $Q_{\text{system}} = 0$, for the system of water, ice and steam. $Q = mc\Delta T$ for a temperature change and $Q = \pm mL$ for a phase transition.

SET UP: For water, $c = 4190 \text{ J/kg} \cdot \text{K}$, $L_f = 334 \times 10^3 \text{ J/kg}$ and $L_v = 2256 \times 10^3 \text{ J/kg}$.

EXECUTE: The steam both condenses and cools, and the ice melts and heats up along with the original water.

$m_i L_f + m_i c(28.0^\circ\text{C}) + m_w c(28.0^\circ\text{C}) - m_{\text{steam}} L_v + m_{\text{steam}} c(-72.0^\circ\text{C}) = 0$. The mass of steam needed is

$$m_{\text{steam}} = \frac{(0.450 \text{ kg})(334 \times 10^3 \text{ J/kg}) + (2.85 \text{ kg})(4190 \text{ J/kg} \cdot \text{K})(28.0^\circ\text{C})}{2256 \times 10^3 \text{ J/kg} + (4190 \text{ J/kg} \cdot \text{K})(72.0^\circ\text{C})} = 0.190 \text{ kg}.$$

EVALUATE: Since the final temperature is greater than 0.0°C , we know that all the ice melts.

- 17.64. IDENTIFY:** $H = kA\Delta T/L$ and $k = \frac{HL}{A\Delta T}$.

SET UP: The SI units of H are watts, the units of area are m^2 , the temperature difference is in K, the length is in meters, so the SI units for thermal conductivity are $\frac{[\text{W}][\text{m}]}{[\text{m}^2][\text{K}]} = \frac{\text{W}}{\text{m} \cdot \text{K}}$.

EVALUATE: An equivalent way to express the units of k is $\text{J}/(\text{s} \cdot \text{m} \cdot \text{K})$.

- 17.65. IDENTIFY and SET UP:** The temperature gradient is $(T_H - T_C)/L$ and can be calculated directly. Use Eq.(17.21) to calculate the heat current H . In part (c) use H from part (b) and apply Eq.(17.21) to the 12.0-cm section of the left end of the rod. $T_2 = T_H$ and $T_1 = T$, the target variable.

EXECUTE: (a) temperature gradient $= (T_H - T_C)/L = (100.0^\circ\text{C} - 0.0^\circ\text{C})/0.450 \text{ m} = 222 \text{ C}^\circ/\text{m} = 222 \text{ K/m}$

(b) $H = kA(T_H - T_C)/L$. From Table 17.5, $k = 385 \text{ W/m} \cdot \text{K}$, so

$$H = (385 \text{ W/m} \cdot \text{K})(1.25 \times 10^{-4} \text{ m}^2)(222 \text{ K/m}) = 10.7 \text{ W}$$

(c) $H = 10.7 \text{ W}$ for all sections of the rod.

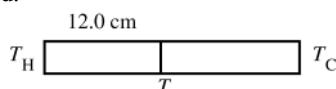


Figure 17.65

Apply $H = kA\Delta T/L$ to the 12.0 cm section (Figure 17.65): $T_H - T = LH/kA$ and

$$T = T_H - LH/kA = 100.0^\circ\text{C} - \frac{(0.120 \text{ m})(10.7 \text{ W})}{(1.25 \times 10^{-4} \text{ m}^2)(385 \text{ W/m} \cdot \text{K})} = 73.3^\circ\text{C}$$

EVALUATE: H is the same at all points along the rod, so $\Delta T/\Delta x$ is the same for any section of the rod with length Δx . Thus $(T_H - T)/(12.0 \text{ cm}) = (T_H - T_C)/(45.0 \text{ cm})$ gives that $T_H = T = 26.7^\circ\text{C}$ and $T = 73.3^\circ\text{C}$, as we already calculated.

- 17.66. IDENTIFY:** For a melting phase transition, $Q = mL_f$. The rate of heat conduction is $\frac{Q}{t} = \frac{kA(T_H - T_C)}{L}$.

SET UP: For water, $L_f = 3.34 \times 10^5 \text{ J/kg}$.

EXECUTE: The heat conducted by the rod in 10.0 min is

$$Q = mL_f = (8.50 \times 10^{-3} \text{ kg})(3.34 \times 10^5 \text{ J/kg}) = 2.84 \times 10^3 \text{ J}. \quad \frac{Q}{t} = \frac{2.84 \times 10^3 \text{ J}}{600 \text{ s}} = 4.73 \text{ W}.$$

$$k = \frac{(Q/t)L}{A(T_H - T_C)} = \frac{(4.73 \text{ W})(0.600 \text{ m})}{(1.25 \times 10^{-4} \text{ m}^2)(100^\circ\text{C})} = 227 \text{ W/m} \cdot \text{K}.$$

EVALUATE: The heat conducted by the rod is the heat that enters the ice and produces the phase change.

- 17.67. IDENTIFY and SET UP:** Call the temperature at the interface between the wood and the styrofoam T . The heat current in each material is given by $H = kA(T_H - T_C)/L$.

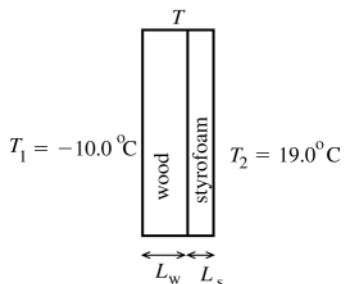


Figure 17.67

See Figure 17.67

Heat current through the wood: $H_w = k_w A(T - T_1)L_w$

Heat current through the styrofoam: $H_s = k_s A(T_2 - T)/L_s$

In steady-state heat does not accumulate in either material. The same heat has to pass through both materials in succession, so $H_w = H_s$.

EXECUTE: (a) This implies $k_w A(T - T_1)/L_w = k_s A(T_2 - T)/L_s$

$$k_w L_s (T - T_1) = k_s L_w (T_2 - T)$$

$$T = \frac{k_w L_s T_1 + k_s L_w T_2}{k_w L_s + k_s L_w} = \frac{-0.0176 \text{ W} \cdot \text{°C/K} + 0.0057 \text{ W} \cdot \text{°C/K}}{0.00206 \text{ W/K}} = -5.8^\circ\text{C}$$

EVALUATE: The temperature at the junction is much closer in value to T_1 than to T_2 . The styrofoam has a very large k , so a larger temperature gradient is required for than for wood to establish the same heat current.

(b) **IDENTIFY and SET UP:** Heat flow per square meter is $\frac{H}{A} = k \left(\frac{T_H - T_C}{L} \right)$. We can calculate this either for the wood or for the styrofoam; the results must be the same.

EXECUTE: wood

$$\frac{H_w}{A} = k_w \frac{T - T_1}{L_w} = (0.080 \text{ W/m} \cdot \text{K}) \frac{(-5.8^\circ\text{C} - (-10.0^\circ\text{C}))}{0.030 \text{ m}} = 11 \text{ W/m}^2.$$

styrofoam

$$\frac{H_s}{A} = k_s \frac{T_2 - T}{L_s} = (0.010 \text{ W/m} \cdot \text{K}) \frac{(19.0^\circ\text{C} - (-5.8^\circ\text{C}))}{0.022 \text{ m}} = 11 \text{ W/m}^2.$$

EVALUATE: H must be the same for both materials and our numerical results show this. Both materials are good insulators and the heat flow is very small.

- 17.68. IDENTIFY:** $\frac{Q}{t} = \frac{kA(T_H - T_C)}{L}$

SET UP: $T_H - T_C = 175^\circ\text{C} - 35^\circ\text{C}$. $1 \text{ K} = 1 \text{ C}^\circ$, so there is no need to convert the temperatures to kelvins.

EXECUTE: (a) $\frac{Q}{t} = \frac{(0.040 \text{ W/m} \cdot \text{K})(1.40 \text{ m}^2)(175^\circ\text{C} - 35^\circ\text{C})}{4.0 \times 10^{-2} \text{ m}} = 196 \text{ W}$.

(b) The power input must be 196 W, to replace the heat conducted through the walls.

EVALUATE: The heat current is small because k is small for fiberglass.

- 17.69. IDENTIFY:** Apply Eq.(17.23). $Q = Ht$.

SET UP: $1 \text{ Btu} = 1055 \text{ J}$

EXECUTE: The energy that flows in time t is $Q = Ht = \frac{A\Delta T}{R}t = \frac{(125 \text{ ft}^2)(34 \text{ F}^\circ)}{(30 \text{ ft}^2 \cdot \text{F}^\circ \cdot \text{h/Btu})}(5.0 \text{ h}) = 708 \text{ Btu} = 7.5 \times 10^5 \text{ J}$.

EVALUATE: With the given units of R , we can use A in ft^2 , ΔT in F° and t in h, and the calculation then gives Q in Btu.

- 17.70. 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.

- 17.71. 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.

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

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

Then $H = kA(T_H - T_C)/L$ 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.

- 17.72. IDENTIFY:** Apply Eq.(17.21) and solve for A .

SET UP: The area of each circular end of a cylinder is related to the diameter D by $A = \pi R^2 = \pi(D/2)^2$. For steel, $k = 50.2 \text{ W/m} \cdot \text{K}$. The boiling water has $T = 100^\circ\text{C}$, so $\Delta T = 300 \text{ K}$.

EXECUTE: $\frac{Q}{t} = kA \frac{\Delta T}{L}$ and $150 \text{ J/s} = (50.2 \text{ W/m} \cdot \text{K})A \left(\frac{300 \text{ K}}{0.500 \text{ m}} \right)$. This gives $A = 4.98 \times 10^{-3} \text{ m}^2$, and

$D = \sqrt{4A/\pi} = \sqrt{4(4.98 \times 10^{-3} \text{ m}^2)/\pi} = 8.0 \times 10^{-2} \text{ m} = 8.0 \text{ cm}$.

EVALUATE: H increases when A increases.

- 17.73. IDENTIFY:** Assume the temperatures of the surfaces of the window are the outside and inside temperatures. Use the concept of thermal resistance. For part (b) use the fact that when insulating materials are in layers, the R values are additive.

SET UP: From Table 17.5, $k = 0.8 \text{ W/m} \cdot \text{K}$ for glass. $R = L/k$.

EXECUTE: (a) For the glass, $R_{\text{glass}} = \frac{5.20 \times 10^{-3} \text{ m}}{0.8 \text{ W/m} \cdot \text{K}} = 6.50 \times 10^{-3} \text{ m}^2 \cdot \text{K/W}$.

$H = \frac{A(T_H - T_C)}{R} = \frac{(1.40 \text{ m})(2.50 \text{ m})(39.5 \text{ K})}{6.50 \times 10^{-3} \text{ m}^2 \cdot \text{K/W}} = 2.1 \times 10^4 \text{ W}$

(b) For the paper, $R_{\text{paper}} = \frac{0.750 \times 10^{-3} \text{ m}}{0.05 \text{ W/m} \cdot \text{K}} = 0.015 \text{ m}^2 \cdot \text{K/W}$. The total R is $R = R_{\text{glass}} + R_{\text{paper}} = 0.0215 \text{ m}^2 \cdot \text{K/W}$.

$H = \frac{A(T_H - T_C)}{R} = \frac{(1.40 \text{ m})(2.50 \text{ m})(39.5 \text{ K})}{0.0215 \text{ m}^2 \cdot \text{K/W}} = 6.4 \times 10^3 \text{ W}$.

EVALUATE: The layer of paper decreases the rate of heat loss by a factor of about 3.

- 17.74. IDENTIFY:** The rate of energy radiated per unit area is $\frac{H}{A} = e\sigma T^4$.

SET UP: A blackbody has $e = 1$.

EXECUTE: (a) $\frac{H}{A} = (1)(5.67 \times 10^{-8} \text{ W/m}^2 \cdot \text{K}^4)(273 \text{ K})^4 = 315 \text{ W/m}^2$

(b) $\frac{H}{A} = (1)(5.67 \times 10^{-8} \text{ W/m}^2 \cdot \text{K}^4)(2730 \text{ K})^4 = 3.15 \times 10^6 \text{ W/m}^2$

EVALUATE: When the Kelvin temperature increases by a factor of 10 the rate of energy radiation increases by a factor of 10^4 .

- 17.75. IDENTIFY:** Use Eq.(17.26) to calculate H_{net} .

SET UP: $H_{\text{net}} = Ae\sigma(T^4 - T_s^4)$ (Eq.(17.26); T must be in kelvins)

Example 17.16 gives $A = 1.2 \text{ m}^2$, $e = 1.0$, and $T = 30^\circ\text{C} = 303 \text{ K}$ (body surface temperature)

$T_s = 5.0^\circ\text{C} = 278 \text{ K}$

EXECUTE: $H_{\text{net}} = 573.5 \text{ W} - 406.4 \text{ W} = 167 \text{ W}$

EVALUATE: Note that this is larger than H_{net} calculated in Example 17.16. The lower temperature of the surroundings increases the rate of heat loss by radiation.

- 17.76. IDENTIFY:** The net heat current is $H = Ae\sigma(T^4 - T_s^4)$. A power input equal to H is required to maintain constant temperature of the sphere.

SET UP: The surface area of a sphere is $4\pi r^2$.

EXECUTE: $H = 4\pi(0.0150 \text{ m})^2(0.35)(5.67 \times 10^{-8} \text{ W/m}^2 \cdot \text{K}^4)([3000 \text{ K}]^4 - [290 \text{ K}]^4) = 4.54 \times 10^4 \text{ W}$

EVALUATE: Since $3000 \text{ K} > 290 \text{ K}$ and H is proportional to T^4 , the rate of emission of heat energy is much greater than the rate of absorption of heat energy from the surroundings.

17.77. IDENTIFY: Use Eq.(17.26) to calculate A .

SET UP: $H = Ae\sigma T^4$ so $A = H/e\sigma T^4$

150-W and all electrical energy consumed is radiated says $H = 150$ W

EXECUTE: $A = \frac{150 \text{ W}}{(0.35)(5.67 \times 10^{-8} \text{ W/m}^2 \cdot \text{K}^4)(2450 \text{ K})^4} = 2.1 \times 10^{-4} \text{ m}^2 (1 \times 10^4 \text{ cm}^2/1 \text{ m}^2) = 2.1 \text{ cm}^2$

EVALUATE: Light bulb filaments are often in the shape of a tightly wound coil to increase the surface area; larger A means a larger radiated power H .

17.78. 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

$R_E = 6.38 \times 10^6$ m, the radius of the sun is $R_{\text{sun}} = 6.96 \times 10^8$ m, and the distance between the earth and the sun is $r = 1.50 \times 10^{11}$ m.

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

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

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

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.

17.79. IDENTIFY and SET UP: Use the temperature difference in M° and in C° between the melting and boiling points of mercury to relate M° to C° . Also adjust for the different zero points on the two scales to get an equation for T_M in terms of T_C .

(a) **EXECUTE:** normal melting point of mercury: $-39^\circ\text{C} = 0.0^\circ\text{M}$

normal boiling point of mercury: $357^\circ\text{C} = 100.0^\circ\text{M}$

$100.0^\circ\text{M} = 396 \text{ C}^\circ$ so $1 \text{ M}^\circ = 3.96 \text{ C}^\circ$

Zero on the M scale is -39 on the C scale, so to obtain T_C multiply T_M by 3.96 and then subtract 39° :

$$T_C = 3.96T_M - 39^\circ$$

Solving for T_M gives $T_M = \frac{1}{3.96}(T_C + 39^\circ)$

The normal boiling point of water is 100°C ; $T_M = \frac{1}{3.96}(100^\circ + 39^\circ) = 35.1^\circ\text{M}$

(b) $10.0 \text{ M}^\circ = 39.6 \text{ C}^\circ$

EVALUATE: A M° is larger than a C° since it takes fewer of them to express the difference between the boiling and melting points for mercury.

17.80. IDENTIFY: Apply $\Delta L = L_0\alpha\Delta T$ to the radius of the hoop. The thickness of the space equals the increase in radius of the hoop.

SET UP: The earth has radius $R_E = 6.38 \times 10^6$ m and this is the initial radius R_0 of the hoop. For steel,

$\alpha = 1.2 \times 10^{-5} \text{ K}^{-1}$. $1 \text{ K} = 1 \text{ C}^\circ$.

EXECUTE: The increase in the radius of the hoop would be

$$\Delta R = R\alpha\Delta T = (6.38 \times 10^6 \text{ m})(1.2 \times 10^{-5} \text{ K}^{-1})(0.5 \text{ K}) = 38 \text{ m}.$$

EVALUATE: Even though ΔR is large, the fractional change in radius, $\Delta R/R_0$, is very small.

17.81. IDENTIFY: The volume increases by $\Delta V = V_0\beta\Delta T$ and the mass is constant. $\rho = m/V$.

SET UP: Copper has density $\rho_0 = 8.9 \times 10^3 \text{ kg/m}^3$ and coefficient of volume expansion $\beta = 5.1 \times 10^{-5} (\text{C}^\circ)^{-1}$. The tube is initially at temperature T_0 , has sides of length L_0 , volume V_0 , density ρ_0 , and coefficient of volume expansion β .

EXECUTE: (a) When the temperature increase to $T_0 + \Delta T$, the volume changes by an amount ΔV , where

$\Delta V = \beta V_0 \Delta T$. Then, $\rho = \frac{m}{V_0 + \Delta V}$, or eliminating ΔV , $\rho = \frac{m}{V_0 + \beta V_0 \Delta T}$. Divide the top and bottom by V_0 and

substitute $\rho_0 = m/V_0$. Then $\rho = \frac{\rho_0}{1 + \beta\Delta T}$. This can be rewritten as $\rho = \rho_0(1 + \beta\Delta T)^{-1}$. Then using the expression

$(1+x)^n \approx 1+nx$, where $n = -1$, $\rho = \rho_0(1 - \beta\Delta T)$. This is accurate when $\beta\Delta T$ is small, which is the case if

$\Delta T \ll 1/\beta$. $1/\beta$ is on the order of 10^4 C° and ΔT is typically about 10^2 C° or less, so this approximation is accurate.

(b) The copper cube has sides of length $1.25 \text{ cm} = 0.0125 \text{ m}$ and $\Delta T = 70.0^\circ\text{C} - 20.0^\circ\text{C} = 50.0 \text{ C}^\circ$.

$$\Delta V = \beta V_0 \Delta T = (5.1 \times 10^{-5} \text{ (C}^\circ)^{-1})(0.0125 \text{ m})^3 (50.0 \text{ C}^\circ) = 5 \times 10^{-9} \text{ m}^3. \text{ Similarly,}$$

$$\rho = (8.9 \times 10^3 \text{ kg/m}^3)(1 - (5.1 \times 10^{-5} \text{ (C}^\circ)^{-1})(50.0 \text{ C}^\circ)) = 8.877 \times 10^3 \text{ kg/m}^3. \text{ Therefore, } \Delta \rho = -23 \text{ kg/m}^3.$$

EVALUATE: When the temperature increases, the volume decreases and the density increases.

17.82. IDENTIFY: $v = \sqrt{F/\mu} = \sqrt{FL/m}$. For the fundamental, $\lambda = 2L$ and $f = \frac{v}{\lambda} = \frac{1}{2} \sqrt{\frac{F}{mL}}$. F , v and λ change when T changes because L changes. $\Delta L = L\alpha\Delta T$, where L is the original length.

SET UP: For copper, $\alpha = 1.7 \times 10^{-5} \text{ (C}^\circ)^{-1}$.

EXECUTE: (a) We can use differentials to find the frequency change because all length changes are small percents.

$$\Delta f \approx \frac{\partial f}{\partial L} \Delta L \text{ (only } L \text{ changes due to heating). } \Delta f = \frac{1}{2} (F/mL)^{-1/2} (F/m) (-1/L^2) \Delta L = \frac{1}{2} \left(\frac{1}{2} \sqrt{\frac{F}{mL}} \right) \frac{\Delta L}{L} = \frac{1}{2} f \frac{\Delta L}{L}.$$

$\Delta f = -\frac{1}{2} (\alpha \Delta T) f = -\frac{1}{2} (1.7 \times 10^{-5} \text{ (C}^\circ)^{-1})(40 \text{ C}^\circ)(440 \text{ Hz}) = -0.15 \text{ Hz}$. The frequency decreases since the length increases.

$$\text{(b) } \Delta v = \frac{\partial v}{\partial L} \Delta L. \quad \frac{\Delta v}{v} = \frac{\frac{1}{2} (FL/m)^{-1/2} (F/m) \Delta L}{\sqrt{FL/m}} = \frac{\Delta L}{2L} = \frac{\alpha \Delta T}{2} = \frac{1}{2} (1.7 \times 10^{-5} \text{ (C}^\circ)^{-1})(40 \text{ C}^\circ) = 3.4 \times 10^{-4} = 0.034\%.$$

$$\text{(d) } \lambda = 2L \text{ so } \Delta \lambda = 2\Delta L \rightarrow \frac{\Delta \lambda}{\lambda} = \frac{2\Delta L}{2L} = \frac{\Delta L}{L} = \alpha \Delta T. \quad \frac{\Delta \lambda}{\lambda} = (1.7 \times 10^{-5} \text{ (C}^\circ)^{-1})(40 \text{ C}^\circ) = 6.8 \times 10^{-4} = 0.068\%.$$

λ increases.

EVALUATE: The wave speed and wavelength increase when the length increases and the frequency decreases. The percentage change in the frequency is -0.034% . The fractional change in all these quantities is very small.

17.83. IDENTIFY and SET UP: Use Eq.(17.8) for the volume expansion of the oil and of the cup. Both the volume of the cup and the volume of the olive oil increase when the temperature increases, but β is larger for the oil so it expands more. When the oil starts to overflow, $\Delta V_{\text{oil}} = \Delta V_{\text{glass}} + (1.00 \times 10^{-3} \text{ m})A$, where A is the cross-sectional area of the cup.

$$\text{EXECUTE: } \Delta V_{\text{oil}} = V_{0,\text{oil}} \beta_{\text{oil}} \Delta T = (9.9 \text{ cm})A \beta_{\text{oil}} \Delta T$$

$$\Delta V_{\text{glass}} = V_{0,\text{glass}} \beta_{\text{glass}} \Delta T = (10.0 \text{ cm})A \beta_{\text{glass}} \Delta T$$

$$(9.9 \text{ cm})A \beta_{\text{oil}} \Delta T - (10.0 \text{ cm})A \beta_{\text{glass}} \Delta T + (1.00 \times 10^{-3} \text{ m})A$$

The A divides out. Solving for ΔT gives $\Delta T = 15.5 \text{ C}^\circ$

$$T_2 = T_1 + \Delta T = 37.5^\circ\text{C}$$

EVALUATE: If the expansion of the cup is neglected, the olive oil will have expanded to fill the cup when $(0.100 \text{ cm})A = (9.9 \text{ cm})A \beta_{\text{oil}} \Delta T$, so $\Delta T = 15.0 \text{ C}^\circ$ and $T_2 = 37.0^\circ\text{C}$. Our result is slightly higher than this. The cup also expands but not very much since $\beta_{\text{glass}} \ll \beta_{\text{oil}}$.

17.84. IDENTIFY: Volume expansion: $dV = \beta V dT$. $\beta = \frac{dV/dT}{V}$.

SET UP: dV/dT is the slope of the graph of V versus T , the graph given in Figure 17.12 in the textbook.

EXECUTE: $\beta = \frac{\text{Slope of graph}}{V}$. Construct the tangent to the graph at 2°C and 8°C and measure the slope of this line.

At 22°C : Slope $\approx -\frac{0.10 \text{ cm}^3}{3 \text{ C}^\circ}$ and $V \approx 1000 \text{ cm}^3$. $\beta \approx -\frac{0.10 \text{ cm}^3/3 \text{ C}^\circ}{1000 \text{ cm}^3} \approx -3 \times 10^{-5} \text{ (C}^\circ)^{-1}$. The slope is negative, as the

water contracts or it is heated. At 8°C : slope $\approx \frac{0.24 \text{ cm}^3}{4 \text{ C}^\circ}$ and $V \approx 1000 \text{ cm}^3$. $\beta \approx \frac{0.24 \text{ cm}^3/4 \text{ C}^\circ}{1000 \text{ cm}^3} \approx 6 \times 10^{-5} \text{ (C}^\circ)^{-1}$.

The water now expands when heated.

EVALUATE: $\beta > 0$ when the material expands when heated and $\beta < 0$ when the material contracts when it is heated. The minimum volume is at about 4°C and β has opposite signs above and below this temperature.

17.85. IDENTIFY: Use Eq.(17.6) to find the change in diameter of the sphere and the change in length of the cable. Set the sum of these two increases in length equal to 2.00 mm .

SET UP: $\alpha_{\text{brass}} = 2.0 \times 10^{-5} \text{ K}^{-1}$ and $\alpha_{\text{steel}} = 1.2 \times 10^{-5} \text{ K}^{-1}$.

EXECUTE: $\Delta L = (\alpha_{\text{brass}} L_{0,\text{brass}} + \alpha_{\text{steel}} L_{0,\text{steel}}) \Delta T$.

$$\Delta T = \frac{2.00 \times 10^{-3} \text{ m}}{(2.0 \times 10^{-5} \text{ K}^{-1})(0.350 \text{ m}) + (1.2 \times 10^{-5} \text{ K}^{-1})(10.5 \text{ m})} = 15.0 \text{ C}^\circ. \quad T_2 = T_1 + \Delta T = 35.0^\circ\text{C}.$$

EVALUATE: The change in diameter of the brass sphere is 0.10 mm . This is small, but should not be neglected.

17.86. IDENTIFY: Conservation of energy says $Q_e + Q_c = 0$, where Q_e and Q_c are the heat changes for the ethanol and cylinder. To find the volume of ethanol that overflows calculate ΔV for the ethanol and for the cylinder.

SET UP: For ethanol, $c_e = 2428 \text{ J/kg} \cdot \text{K}$ and $\beta_e = 75 \times 10^{-5} \text{ K}^{-1}$.

EXECUTE: (a) $Q_e + Q_c = 0$ gives $m_e c_e (T_f - [-10.0^\circ\text{C}]) + m_c c_c (T_f - 20.0^\circ\text{C}) = 0$.

$$T_f = \frac{(20.0^\circ\text{C})m_e c_e - (10.0^\circ\text{C})m_c c_c}{m_e c_e + m_c c_c} = \frac{(20.0^\circ\text{C})(0.110 \text{ kg})(840 \text{ J/kg} \cdot \text{K}) - (10.0^\circ\text{C})(0.0873 \text{ kg})(2428 \text{ J/kg} \cdot \text{K})}{(0.0873 \text{ kg})(2428 \text{ J/kg} \cdot \text{K}) + (0.110 \text{ kg})(840 \text{ J/kg} \cdot \text{K})}$$

$$T_f = \frac{-271.6^\circ\text{C}}{304.4} = -0.892^\circ\text{C}.$$

(b) $\Delta V_e = \beta_e V_e \Delta T = (75 \times 10^{-5} \text{ K}^{-1})(108 \text{ cm}^3)(-0.892^\circ\text{C} - [-10.0^\circ\text{C}]) = +0.738 \text{ cm}^3$.

$\Delta V_c = \beta_c V_c \Delta T = (1.2 \times 10^{-5} \text{ K}^{-1})(108 \text{ cm}^3)(-0.892^\circ\text{C} - 20.0^\circ\text{C}) = -0.0271 \text{ cm}^3$. The volume that overflows is $0.738 \text{ cm}^3 - (-0.0271 \text{ cm}^3) = 0.765 \text{ cm}^3$.

EVALUATE: The cylinder cools so its volume decreases. The ethanol warms, so its volume increases. The sum of the magnitudes of the two volume changes gives the volume that overflows.

17.87. IDENTIFY and SET UP: Call the metals A and B. Use the data given to calculate α for each metal.

EXECUTE: $\Delta L = L_0 \alpha \Delta T$ so $\alpha = \Delta L / (L_0 \Delta T)$

$$\text{metal A: } \alpha_A = \frac{\Delta L}{L_0 \Delta T} = \frac{0.0650 \text{ cm}}{(30.0 \text{ cm})(100 \text{ C}^\circ)} = 2.167 \times 10^{-5} (\text{C}^\circ)^{-1}$$

$$\text{metal B: } \alpha_B = \frac{\Delta L}{L_0 \Delta T} = \frac{0.0350 \text{ cm}}{(30.0 \text{ cm})(100 \text{ C}^\circ)} = 1.167 \times 10^{-5} (\text{C}^\circ)^{-1}$$

EVALUATE: L_0 and ΔT are the same, so the rod that expands the most has the larger α .

IDENTIFY and SET UP: Now consider the composite rod (Figure 17.87). Apply Eq.(17.6). The target variables are L_A and L_B , the lengths of the metals A and B in the composite rod.



Figure 17.87

EXECUTE: $\Delta L = \Delta L_A + \Delta L_B = (\alpha_A L_A + \alpha_B L_B) \Delta T$

$$\Delta L / \Delta T = \alpha_A L_A + \alpha_B (0.300 \text{ m} - L_A)$$

$$L_A = \frac{\Delta L / \Delta T - (0.300 \text{ m}) \alpha_B}{\alpha_A - \alpha_B} = \frac{(0.058 \times 10^{-2} \text{ m} / 100 \text{ C}^\circ) - (0.300 \text{ m})(1.167 \times 10^{-5} (\text{C}^\circ)^{-1})}{1.00 \times 10^{-5} (\text{C}^\circ)^{-1}}$$

$$L_B = 30.0 \text{ cm} - L_A = 30.0 \text{ cm} - 23.0 \text{ m} = 7.0 \text{ cm}$$

EVALUATE: The expansion of the composite rod is similar to that of rod A, so the composite rod is mostly metal A.

17.88. IDENTIFY: Apply $\Delta V = V_0 \beta \Delta T$ to the gasoline and to the volume of the tank.

SET UP: For aluminum, $\beta = 7.2 \times 10^{-5} \text{ K}^{-1}$. $1 \text{ L} = 10^{-3} \text{ m}^3$.

EXECUTE: (a) The lost volume, 2.6 L, is the difference between the expanded volume of the fuel and the tanks, and the maximum temperature difference is

$$\Delta T = \frac{\Delta V}{(\beta_{\text{fuel}} - \beta_{\text{Al}}) V_0} = \frac{(2.6 \times 10^{-3} \text{ m}^3)}{(9.5 \times 10^{-4} (\text{C}^\circ)^{-1} - 7.2 \times 10^{-5} (\text{C}^\circ)^{-1})(106.0 \times 10^{-3} \text{ m}^3)} = 28 \text{ C}^\circ.$$

The maximum temperature was 32°C .

(b) No fuel can spill if the tanks are filled just before takeoff.

EVALUATE: Both the volume of the gasoline and the capacity of the tanks increased when T increased. But β is larger for gasoline than for aluminum so the volume of the gasoline increased more. When the tanks have returned to 4.0°C on Sunday morning there is 2.6 L of air space in the tanks.

17.89. IDENTIFY: The change in length due to heating is $\Delta L_T = L_0 \alpha \Delta T$ and this need not equal ΔL . The change in

length due to the tension is $\Delta L_F = \frac{F L_0}{A Y}$. Set $\Delta L = \Delta L_F + \Delta L_T$.

SET UP: $\alpha_{\text{brass}} = 2.0 \times 10^{-5} (\text{C}^\circ)^{-1}$. $\alpha_{\text{steel}} = 1.5 \times 10^{-5} (\text{C}^\circ)^{-1}$. $Y_{\text{steel}} = 20 \times 10^{10} \text{ Pa}$.

EXECUTE: (a) The change in length is due to the tension and heating. $\frac{\Delta L}{L_0} = \frac{F}{A Y} + \alpha \Delta T$. Solving for F/A ,

$$\frac{F}{A} = Y \left(\frac{\Delta L}{L_0} - \alpha \Delta T \right).$$

(b) The brass bar is given as “heavy” and the wires are given as “fine,” so it may be assumed that the stress in the bar due to the fine wires does not affect the amount by which the bar expands due to the temperature increase. This means that ΔL is not zero, but is the amount $\alpha_{\text{brass}}L_0\Delta T$ that the brass expands, and so

$$\frac{F}{A} = Y_{\text{steel}}(\alpha_{\text{brass}} - \alpha_{\text{steel}})\Delta T = (20 \times 10^{10} \text{ Pa})(2.0 \times 10^{-5} (\text{C}^\circ)^{-1} - 1.2 \times 10^{-5} (\text{C}^\circ)^{-1})(120 \text{ C}^\circ) = 1.92 \times 10^8 \text{ Pa}.$$

EVALUATE: The length of the brass bar increases more than the length of the steel wires. The wires remain taut and are under tension when the temperature of the system is raised above 20°C .

17.90. IDENTIFY: Apply the equation derived in part (a) of Problem 17.89 to the steel and aluminum sections. The sum of the ΔL values of the two sections must be zero.

SET UP: For steel, $Y = 20 \times 10^{10} \text{ Pa}$ and $\alpha = 1.2 \times 10^{-5} (\text{C}^\circ)^{-1}$. For aluminum, $Y = 7.0 \times 10^{10} \text{ Pa}$ and $\alpha = 2.4 \times 10^{-5} (\text{C}^\circ)^{-1}$.

EXECUTE: In deriving Eq.(17.12), it was assumed that $\Delta L = 0$; if this is not the case when there are both thermal

and tensile stresses, Eq. (17.12) becomes $\Delta L = L_0 \left(\alpha \Delta T + \frac{F}{AY} \right)$. (See Problem 17.89.) For the situation in this

problem, there are two length changes which must sum to zero, and so Eq.(17.12) may be extended to two

materials a and b in the form $L_{0a} \left(\alpha_a \Delta T + \frac{F}{AY_a} \right) + L_{0b} \left(\alpha_b \Delta T + \frac{F}{AY_b} \right) = 0$. Note that in the above, ΔT , F and A are

the same for the two rods. Solving for the stress F/A , $\frac{F}{A} = -\frac{\alpha_a L_{0a} + \alpha_b L_{0b}}{((L_{0a}/Y_a) + (L_{0b}/Y_b))} \Delta T$.

$$\frac{F}{A} = \frac{(1.2 \times 10^{-5} (\text{C}^\circ)^{-1})(0.350 \text{ m}) + (2.4 \times 10^{-5} (\text{C}^\circ)^{-1})(0.250 \text{ m})}{((0.350 \text{ m}/20 \times 10^{10} \text{ Pa}) + (0.250 \text{ m}/7 \times 10^{10} \text{ Pa}))} (60.0 \text{ C}^\circ) = -1.2 \times 10^8 \text{ Pa}.$$

EVALUATE: F/A is negative and the stress is compressive. If the steel rod was considered alone and its length was held fixed, the stress would be $-Y_{\text{steel}}\alpha_{\text{steel}}\Delta T = -1.4 \times 10^8 \text{ Pa}$. For the aluminum rod alone the stress would be $-Y_{\text{aluminum}}\alpha_{\text{aluminum}}\Delta T = -1.0 \times 10^8 \text{ Pa}$. The stress for the combined rod is the average of these two values.

17.91. (a) IDENTIFY and SET UP: The diameter of the ring undergoes linear expansion (increases with T) just like a solid steel disk of the same diameter as the hole in the ring. Heat the ring to make its diameter equal to 2.5020 in.

EXECUTE: $\Delta L = \alpha L_0 \Delta T$ so $\Delta T = \frac{\Delta L}{L_0 \alpha} = \frac{0.0020 \text{ in.}}{(2.5000 \text{ in.})(1.2 \times 10^{-5} (\text{C}^\circ)^{-1})} = 66.7 \text{ C}^\circ$

$$T = T_0 + \Delta T = 20.0^\circ\text{C} + 66.7 \text{ C}^\circ = 87^\circ\text{C}$$

(b) **IDENTIFY and SET UP:** Apply the linear expansion equation to the diameter of the brass shaft and to the diameter of the hole in the steel ring.

EXECUTE: $L = L_0(1 + \alpha \Delta T)$

Want L_s (steel) = L_b (brass) for the same ΔT for both materials: $L_{0s}(1 + \alpha_s \Delta T) = L_{0b}(1 + \alpha_b \Delta T)$ so

$$L_{0s} + L_{0s}\alpha_s \Delta T = L_{0b} + L_{0b}\alpha_b \Delta T$$

$$\Delta T = \frac{L_{0b} - L_{0s}}{L_{0s}\alpha_s - L_{0b}\alpha_b} = \frac{2.5020 \text{ in.} - 2.5000 \text{ in.}}{(2.5000 \text{ in.})(1.2 \times 10^{-5} (\text{C}^\circ)^{-1}) - (2.5050 \text{ in.})(2.0 \times 10^{-5} (\text{C}^\circ)^{-1})}$$

$$\Delta T = \frac{0.0020}{3.00 \times 10^{-5} - 5.00 \times 10^{-5}} \text{ C}^\circ = -100 \text{ C}^\circ$$

$$T = T_0 + \Delta T = 20.0^\circ\text{C} - 100 \text{ C}^\circ = -80^\circ\text{C}$$

EVALUATE: Both diameters decrease when the temperature is lowered but the diameter of the brass shaft decreases more since $\alpha_b > \alpha_s$; $|\Delta L_b| - |\Delta L_s| = 0.0020 \text{ in.}$

17.92. IDENTIFY: Follow the derivation of Eq.(17.12).

SET UP: For steel, the bulk modulus is $B = 1.6 \times 10^{11} \text{ Pa}$ and the volume expansion coefficient is

$$\beta = 3.0 \times 10^{-5} \text{ K}^{-1}.$$

EXECUTE: (a) The change in volume due to the temperature increase is $\beta V \Delta T$, and the change in volume due to the pressure increase is $-\frac{V}{B} \Delta p$. Setting the net change equal to zero, $\beta V \Delta T = V \frac{\Delta p}{B}$, or $\Delta p = B \beta \Delta T$.

(b) From the above, $\Delta p = (1.6 \times 10^{11} \text{ Pa})(3.0 \times 10^{-5} \text{ K}^{-1})(15.0 \text{ K}) = 8.6 \times 10^7 \text{ Pa}$.

EVALUATE: Δp in part (b) is about 850 atm. A small temperature increase corresponds to a very large pressure increase.

17.93. IDENTIFY: Apply Eq.(11.14) to the volume increase of the liquid due to the pressure decrease. Eq.(17.8) gives the volume decrease of the cylinder and liquid when they are cooled. Can think of the liquid expanding when the pressure is reduced and then contracting to the new volume of the cylinder when the temperature is reduced.

SET UP: Let β_l and β_m be the coefficients of volume expansion for the liquid and for the metal. Let ΔT be the (negative) change in temperature when the system is cooled to the new temperature.

EXECUTE: Change in volume of cylinder when cool: $\Delta V_m = \beta_m V_0 \Delta T$ (negative)

Change in volume of liquid when cool: $\Delta V_l = \beta_l V_0 \Delta T$ (negative)

The difference $\Delta V_l = \Delta V_m$ must be equal to the negative volume change due to the increase in pressure, which is $-\Delta p V_0 / B = -k \Delta p V_0$. Thus $\Delta V_l - \Delta V_m = -k \Delta p V_0$.

$$\Delta T = -\frac{k \Delta p}{\beta_l - \beta_m}$$

$$\Delta T = -\frac{(8.50 \times 10^{-10} \text{ Pa}^{-1})(50.0 \text{ atm})(1.013 \times 10^5 \text{ Pa/1 atm})}{4.80 \times 10^{-4} \text{ K}^{-1} - 3.90 \times 10^{-5} \text{ K}^{-1}} = -9.8 \text{ C}^\circ$$

$$T = T_0 + \Delta T = 30.0^\circ\text{C} - 9.8 \text{ C}^\circ = 20.2^\circ\text{C}.$$

EVALUATE: A modest temperature change produces the same volume change as a large change in pressure; $B \gg \beta$ for the liquid.

17.94. IDENTIFY: $Q_{\text{system}} = 0$. Assume that the normal melting point of iron is above 745°C , so the iron initially is solid.

SET UP: For water, $c = 4190 \text{ J/kg} \cdot \text{K}$ and $L_v = 2256 \times 10^3 \text{ J/kg}$. For solid iron, $c = 470 \text{ J/kg} \cdot \text{K}$.

EXECUTE: The heat released when the iron slug cools to 100°C is

$$Q = mc\Delta T = (0.1000 \text{ kg})(470 \text{ J/kg} \cdot \text{K})(645 \text{ K}) = 3.03 \times 10^4 \text{ J}.$$

The heat absorbed when the temperature of the water is raised to 100°C is $Q = mc\Delta T = (0.0750 \text{ kg})(4190 \text{ J/kg} \cdot \text{K})(80.0 \text{ K}) = 2.51 \times 10^4 \text{ J}$. This is less than the heat

released from the iron and $3.03 \times 10^4 \text{ J} - 2.51 \times 10^4 \text{ J} = 5.20 \times 10^3 \text{ J}$ of heat is available for converting some of the

liquid water at 100°C to vapor. The mass m of water that boils is $m = \frac{5.20 \times 10^3 \text{ J}}{2256 \times 10^3 \text{ J/kg}} = 2.30 \times 10^{-3} \text{ kg} = 2.3 \text{ g}$

(a) The final temperature is 100°C .

(b) There is $75.0 \text{ g} - 2.3 \text{ g} = 72.7 \text{ g}$ of liquid water remaining, so the final mass of the iron and remaining water is 172.7 g .

EVALUATE: If we ignore the phase change of the water and write

$m_{\text{iron}} c_{\text{iron}} (T - 745^\circ\text{C}) + m_{\text{water}} c_{\text{water}} (T - 200^\circ\text{C}) = 0$, when we solve for T we will get a value larger than 100°C . That result is unphysical and tells us that some of the water changes phase.

17.95. (a) IDENTIFY: Calculate K/Q . We don't know the mass m of the spacecraft, but it divides out of the ratio.

SET UP: The kinetic energy is $K = \frac{1}{2}mv^2$. The heat required to raise its temperature by 600 C° (but not to melt it) is $Q = mc\Delta T$.

EXECUTE: The ratio is $\frac{K}{Q} = \frac{\frac{1}{2}mv^2}{mc\Delta T} = \frac{v^2}{2c\Delta T} = \frac{(7700 \text{ m/s})^2}{2(910 \text{ J/kg} \cdot \text{K})(600 \text{ C}^\circ)} = 54.3$.

(b) **EVALUATE:** The heat generated when friction work (due to friction force exerted by the air) removes the kinetic energy of the spacecraft during reentry is very large, and could melt the spacecraft. Manned space vehicles must have heat shields made of very high melting temperature materials, and reentry must be made slowly.

17.96. IDENTIFY: The rate at which thermal energy is being generated equals the rate at which the net torque due to the rope is doing work. The energy input associated with a temperature change is $Q = mc\Delta T$.

SET UP: The rate at which work is being done is $P = \tau\omega$. For iron, $c = 470 \text{ J/kg} \cdot \text{K}$. $1 \text{ C}^\circ = 1 \text{ K}$

EXECUTE: (a) The net torque that the rope exerts on the capstan, and hence the net torque that the capstan exerts on the rope, is the difference between the forces of the ends of the rope times the radius of the capstan. The capstan

is doing work on the rope at a rate $P = \tau\omega = F_{\text{net}} r \frac{2\pi \text{ rad}}{T} = (520 \text{ N})(5.0 \times 10^{-2} \text{ m}) \frac{2\pi \text{ rad}}{(0.90 \text{ s})} = 182 \text{ W}$, or 180 W to

two figures. A larger number of turns might increase the force, but for given forces, the torque is independent of the number of turns.

(b) $\frac{\Delta T}{t} = \frac{Q/t}{mc} = \frac{P}{mc} = \frac{(182 \text{ W})}{(6.00 \text{ kg})(470 \text{ J/kg} \cdot \text{K})} = 0.064 \text{ C}^\circ/\text{s}$.

EVALUATE: The rate of temperature rise is proportional to the difference in tension between the ends of the rope and to the rate at which the capstan is rotating.

17.97. IDENTIFY and SET UP: To calculate Q , use Eq.(17.18) in the form $dQ = nC dT$ and integrate, using $C(T)$ given in the problem. C_{av} is obtained from Eq.(17.19) using the finite temperature range instead of an infinitesimal dT .

EXECUTE: (a) $dQ = mc dT$

$$Q = n \int_{T_1}^{T_2} C dT = n \int_{T_1}^{T_2} k(T^3/\Theta^3) dT = (nk/\Theta^3) \int_{T_1}^{T_2} T^3 dt = (nk/\Theta^3) \left(\frac{1}{4} T^4 \Big|_{T_1}^{T_2} \right)$$

$$Q = \frac{nk}{4\Theta^3} (T_2^4 - T_1^4) = \frac{(1.50 \text{ mol})(1940 \text{ J/mol} \cdot \text{K})}{4(281 \text{ K})^3} ((40.0 \text{ K})^4 - (10.0 \text{ K})^4) = 83.6 \text{ J}$$

$$(b) C_{av} = \frac{1}{n} \frac{\Delta Q}{\Delta T} = \frac{1}{1.50 \text{ mol}} \left(\frac{83.6 \text{ J}}{40.0 \text{ K} - 10.0 \text{ K}} \right) = 1.86 \text{ J/mol} \cdot \text{K}$$

$$(c) C = k(t/\Theta)^3 = (1940 \text{ J/mol} \cdot \text{K})(40.0 \text{ K}/281 \text{ K})^3 = 5.60 \text{ J/mol} \cdot \text{K}$$

EVALUATE: C is increasing with T , so C at the upper end of the temperature integral is larger than its average value over the interval.

17.98. IDENTIFY: For a temperature change, $Q = mc\Delta T$, and for the liquid \rightarrow solid phase change, $Q = -mL_f$.

SET UP: The volume V_w of the water determines its mass. $m_w = \rho_w V_w$. For water, $\rho_w = 1000 \text{ kg/m}^3$, $c = 4190 \text{ J/kg} \cdot \text{K}$ and $L_f = 334 \times 10^3 \text{ J/kg}$.

EXECUTE: Set the heat energy that flows into the water equal to the final gravitational potential energy. $L_f \rho_w V_w + c_w \rho_w V_w \Delta T = mgh$. Solving for h , and inserting numbers:

$$h = \frac{(1000 \text{ kg/m}^3)(1.9 \times 0.8 \times 0.1 \text{ m}^3) [334 \times 10^3 \text{ J/kg} + (4190 \text{ J/kg} \cdot \text{K})(37 \text{ C}^\circ)]}{(70 \text{ kg})(9.8 \text{ m/s}^2)}$$

$$h = 1.08 \times 10^5 \text{ m} = 108 \text{ km.}$$

EVALUATE: The heat associated with temperature and phase changes corresponds to a large amount of mechanical energy.

17.99. IDENTIFY: Apply $Q = mc\Delta T$ to the air in the room.

SET UP: The mass of air in the room is $m = \rho V = (1.20 \text{ kg/m}^3)(3200 \text{ m}^3) = 3840 \text{ kg}$. $1 \text{ W} = 1 \text{ J/s}$.

EXECUTE: (a) $Q = (3000 \text{ s})(90 \text{ students})(100 \text{ J/s} \cdot \text{student}) = 2.70 \times 10^7 \text{ J}$.

$$(b) Q = mc\Delta T. \Delta T = \frac{Q}{mc} = \frac{2.70 \times 10^7 \text{ J}}{(3840 \text{ kg})(1020 \text{ J/kg} \cdot \text{K})} = 6.89 \text{ C}^\circ$$

$$(c) \Delta T = (6.89 \text{ C}^\circ) \left(\frac{280 \text{ W}}{100 \text{ W}} \right) = 19.3 \text{ C}^\circ.$$

EVALUATE: In the absence of a cooling mechanism for the air, the air temperature would rise significantly.

17.100. IDENTIFY: $dQ = nC dT$ so for the temperature change $T_1 \rightarrow T_2$, $Q = n \int_{T_1}^{T_2} C(T) dT$.

SET UP: $\int dT = T$ and $\int T dT = \frac{1}{2} T^2$. Express T_1 and T_2 in kelvins: $T_1 = 300 \text{ K}$, $T_2 = 500 \text{ K}$.

EXECUTE: Denoting C by $C = a + bT$, a and b independent of temperature, integration gives

$$Q = n \left(a(T_2 - T_1) + \frac{b}{2} (T_2^2 - T_1^2) \right).$$

$$Q = (3.00 \text{ mol})(29.5 \text{ J/mol} \cdot \text{K})(500 \text{ K} - 300 \text{ K}) + (4.10 \times 10^{-3} \text{ J/mol} \cdot \text{K}^2)((500 \text{ K})^2 - (300 \text{ K})^2).$$

$$Q = 1.97 \times 10^4 \text{ J.}$$

EVALUATE: If C is assumed to have the constant value $29.5 \text{ J/mol} \cdot \text{K}$, then $Q = 1.77 \times 10^4 \text{ J}$ for this temperature change. At $T_1 = 300 \text{ K}$, $C = 32.0 \text{ J/mol} \cdot \text{K}$ and at $T_2 = 500 \text{ K}$, $C = 33.6 \text{ J/mol} \cdot \text{K}$. The average value of C is $32.8 \text{ J/mol} \cdot \text{K}$. If C is assumed to be constant and to have this average value, then $Q = 2.02 \times 10^4 \text{ J}$, which is within 3% of the correct value.

17.101. IDENTIFY: Use $Q = mL_f$ to find the heat that goes into the ice to melt it. This amount of heat must be conducted through the walls of the box; $Q = Ht$. Assume the surfaces of the styrofoam have temperatures of 5.00°C and 21.0°C .

SET UP: For water $L_f = 334 \times 10^3 \text{ J/kg}$. For Styrofoam $k = 0.01 \text{ W/m} \cdot \text{K}$. One week is $6.048 \times 10^5 \text{ s}$. The surface area of the box is $4(0.500 \text{ m})(0.800 \text{ m}) + 2(0.500 \text{ m})^2 = 2.10 \text{ m}^2$.

EXECUTE: $Q = mL_f = (25.0 \text{ kg})(334 \times 10^3 \text{ J/kg}) = 8.016 \times 10^6 \text{ J}$. $H = kA \frac{T_H - T_C}{L}$. $Q = Ht$ gives

$$L = \frac{tkA(T_H - T_C)}{Q} = \frac{(6.048 \times 10^5 \text{ s})(0.01 \text{ W/m} \cdot \text{K})(2.10 \text{ m}^2)(21.0^\circ\text{C} - 5.00^\circ\text{C})}{8.016 \times 10^6 \text{ J}} = 2.5 \text{ cm}$$

EVALUATE: We have assumed that the liquid water that is produced by melting the ice remains in thermal equilibrium with the ice so has a temperature of 0°C . The interior of the box and the ice are not in thermal equilibrium, since they have different temperatures.

- 17.102. IDENTIFY:** For a temperature change $Q = mc\Delta T$. For the vapor \rightarrow liquid phase transition, $Q = -mL_v$.

SET UP: For water, $c = 4190 \text{ J/kg}\cdot\text{K}$ and $L_v = 2256 \times 10^3 \text{ J/kg}$.

EXECUTE: The requirement that the heat supplied in each case is the same gives $m_w c_w \Delta T_w = m_s (c_w \Delta T_s + L_v)$, where $\Delta T_w = 42.0 \text{ K}$ and $\Delta T_s = 65.0 \text{ K}$. The ratio of the masses is

$$\frac{m_s}{m_w} = \frac{c_w \Delta T_w}{c_w \Delta T_s + L_v} = \frac{(4190 \text{ J/kg}\cdot\text{K})(42.0 \text{ K})}{(4190 \text{ J/kg}\cdot\text{K})(65.0 \text{ K}) + 2256 \times 10^3 \text{ J/kg}} = 0.0696,$$

so 0.0696 kg of steam supplies the same heat as 1.00 kg of water.

EVALUATE: Note the heat capacity of water is used to find the heat lost by the condensed steam, since the phase transition produces liquid water at an initial temperature of 100°C .

- 17.103. (a) IDENTIFY and SET UP:** Assume that all the ice melts and that all the steam condenses. If we calculate a final temperature T that is outside the range 0°C to 100°C then we know that this assumption is incorrect. Calculate Q for each piece of the system and then set the total $Q_{\text{system}} = 0$.

EXECUTE: copper can (changes temperature from 0.0° to T ; no phase change)

$$Q_{\text{can}} = mc\Delta T = (0.446 \text{ kg})(390 \text{ J/kg}\cdot\text{K})(T - 0.0^\circ\text{C}) = (173.9 \text{ J/K})T$$

ice (melting phase change and then the water produced warms to T)

$$Q_{\text{ice}} = +mL_f + mc\Delta T = (0.0950 \text{ kg})(334 \times 10^3 \text{ J/kg}) + (0.0950 \text{ kg})(4190 \text{ J/kg}\cdot\text{K})(T - 0.0^\circ\text{C})$$

$$Q_{\text{ice}} = 3.173 \times 10^4 \text{ J} + (398.0 \text{ J/K})T.$$

steam (condenses to liquid and then water produced cools to T)

$$Q_{\text{steam}} = -mL_v + mc\Delta T = -(0.0350 \text{ kg})(2256 \times 10^3 \text{ J/kg}) + (0.0350 \text{ kg})(4190 \text{ J/kg}\cdot\text{K})(T - 100.0^\circ\text{C})$$

$$Q_{\text{steam}} = -7.896 \times 10^4 \text{ J} + (146.6 \text{ J/K})T - 1.466 \times 10^4 \text{ J} = -9.362 \times 10^4 \text{ J} + (146.6 \text{ J/K})T$$

$$Q_{\text{system}} = 0 \text{ implies } Q_{\text{can}} + Q_{\text{ice}} + Q_{\text{steam}} = 0.$$

$$(173.9 \text{ J/K})T + 3.173 \times 10^4 \text{ J} + (398.0 \text{ J/K})T - 9.362 \times 10^4 \text{ J} + (146.6 \text{ J/K})T = 0$$

$$(718.5 \text{ J/K})T = 6.189 \times 10^4 \text{ J}$$

$$T = \frac{6.189 \times 10^4 \text{ J}}{718.5 \text{ J/K}} = 86.1^\circ\text{C}$$

EVALUATE: This is between 0°C and 100°C so our assumptions about the phase changes being complete were correct.

(b) No ice, no steam $0.0950 \text{ kg} + 0.0350 \text{ kg} = 0.130 \text{ kg}$ of liquid water.

- 17.104. IDENTIFY:** The final amount of ice is less than the initial mass of water, so water remains and the final temperature is 0°C . The ice added warms to 0°C and heat comes out of water to convert it to ice. Conservation of energy says $Q_i + Q_w = 0$, where Q_i and Q_w are the heat flows for the ice that is added and for the water that freezes.

SET UP: Let m_i be the mass of ice that is added and m_w is the mass of water that freezes. The mass of ice increases by 0.328 kg , so $m_i + m_w = 0.328 \text{ kg}$. For water, $L_f = 334 \times 10^3 \text{ J/kg}$ and for ice $c_i = 2100 \text{ J/kg}\cdot\text{K}$. Heat comes out of the water when it freezes, so $Q_w = -mL_f$

EXECUTE: $Q_i + Q_w = 0$ gives $m_i c_i (15.0^\circ\text{C}) + (-m_w L_f) = 0$, $m_w = 0.328 \text{ kg} - m_i$, so

$$m_i c_i (15.0^\circ\text{C}) + (-0.328 + m_i)L_f = 0. \quad m_i = \frac{(0.328 \text{ kg})L_f}{c_i(15.0^\circ\text{C}) + L_f} = \frac{(0.328 \text{ kg})(334 \times 10^3 \text{ J/kg})}{(2100 \text{ J/kg}\cdot\text{K})(15.0 \text{ K}) + 334 \times 10^3 \text{ J/kg}} = 0.300 \text{ kg}.$$

0.300 kg of ice was added.

EVALUATE: The mass of water that froze when the ice at -15.0°C was added was $0.778 \text{ kg} - 0.450 \text{ kg} - 0.300 \text{ kg} = 0.028 \text{ kg}$.

- 17.105. IDENTIFY and SET UP:** Heat comes out of the steam when it changes phase and heat goes into the water and causes its temperature to rise. $Q_{\text{system}} = 0$. First determine what phases are present after the system has come to a uniform final temperature.

(a) EXECUTE: Heat that must be removed from steam if all of it condenses is

$$Q = -mL_v = -(0.0400 \text{ kg})(2256 \times 10^3 \text{ J/kg}) = -9.02 \times 10^4 \text{ J}$$

Heat absorbed by the water if it heats all the way to the boiling point of 100°C :

$$Q = mc\Delta T = (0.200 \text{ kg})(4190 \text{ J/kg}\cdot\text{K})(50.0^\circ\text{C}) = 4.19 \times 10^4 \text{ J}$$

EVALUATE: The water can't absorb enough heat for all the steam to condense. Steam is left and the final temperature then must be 100°C .

(b) EXECUTE: Mass of steam that condenses is $m = Q/L_v = 4.19 \times 10^4 \text{ J} / 2256 \times 10^3 \text{ J/kg} = 0.0186 \text{ kg}$

Thus there is $0.0400 \text{ kg} - 0.0186 \text{ kg} = 0.0214 \text{ kg}$ of steam left. The amount of liquid water is

$$0.0186 \text{ kg} + 0.200 \text{ kg} = 0.219 \text{ kg}.$$

17.106. IDENTIFY: $Q_{\text{system}} = 0$.

SET UP: The mass of the system increases by $0.525 \text{ kg} - 0.490 \text{ kg} = 0.035 \text{ kg}$, so the mass of the steam that condensed is 0.035 kg .

EVALUATE: The heat lost by the steam as it condenses and cools is $(0.035 \text{ kg})L_v + (0.035 \text{ kg})(4190 \text{ J/kg} \cdot \text{K})(29.0 \text{ K})$, and the heat gained by the original water and calorimeter is $((0.150 \text{ kg})(420 \text{ J/kg} \cdot \text{K}) + (0.340 \text{ kg})(4190 \text{ J/kg} \cdot \text{K}))(56.0 \text{ K}) = 8.33 \times 10^4 \text{ J}$. Setting the heat lost equal to the heat gained and solving for L_v gives $2.26 \times 10^6 \text{ J/kg}$, or $2.3 \times 10^6 \text{ J/kg}$ to two figures (the mass of steam condensed is known to only two figures).

EVALUATE: $Q_{\text{system}} = 0$ means the magnitude of the heat that flows out of the 0.035 kg of steam as it condenses and cools equals the heat that flows into the calorimeter and 0.340 kg of water as their temperature increases. To the accuracy of the calculation, our result agrees with the value of L_v given in Table 17.4.

17.107. IDENTIFY: Heat Q_1 comes out of the lead when it solidifies and the solid lead cools to T_f . If mass m_s of steam is produced, the final temperature is $T_f = 100^\circ\text{C}$ and the heat that goes into the water is

$Q_w = m_w c_w (25.0 \text{ C}^\circ) + m_s L_{v,w}$, where $m_w = 0.5000 \text{ kg}$. Conservation of energy says $Q_1 + Q_w = 0$. Solve for m_s . The mass that remains is $1.250 \text{ kg} + 0.5000 \text{ kg} - m_s$.

SET UP: For lead, $L_{f,l} = 24.5 \times 10^3 \text{ J/kg}$, $c_l = 130 \text{ J/kg} \cdot \text{K}$ and the normal melting point of lead is 327.3°C . For water, $c_w = 4190 \text{ J/kg} \cdot \text{K}$ and $L_{v,w} = 2256 \times 10^3 \text{ J/kg}$.

EXECUTE: $Q_1 + Q_w = 0$. $-m_l L_{f,l} + m_l c_l (-227.3 \text{ C}^\circ) + m_w c_w (25.0 \text{ C}^\circ) + m_s L_{v,w} = 0$.

$$m_s = \frac{m_l L_{f,l} + m_l c_l (+227.3 \text{ C}^\circ) - m_w c_w (25.0 \text{ C}^\circ)}{L_{v,w}}.$$

$$m_s = \frac{+(1.250 \text{ kg})(24.5 \times 10^3 \text{ J/kg}) + (1.250 \text{ kg})(130 \text{ J/kg} \cdot \text{K})(227.3 \text{ K}) - (0.5000 \text{ kg})(4190 \text{ J/kg} \cdot \text{K})(25.0 \text{ K})}{2256 \times 10^3 \text{ J/kg}}$$

$$m_s = \frac{1.519 \times 10^4 \text{ J}}{2256 \times 10^3 \text{ J/kg}} = 0.0067 \text{ kg}.$$

The mass of water and lead that remains is 1.743 kg .

EVALUATE: The magnitude of heat that comes out of the lead when it goes from liquid at 327.3°C to solid at 100.0°C is $6.76 \times 10^4 \text{ J}$. The heat that goes into the water to warm it to 100°C is $5.24 \times 10^4 \text{ J}$. The additional heat that goes into the water, $6.76 \times 10^4 \text{ J} - 5.24 \times 10^4 \text{ J} = 1.52 \times 10^4 \text{ J}$ converts 0.0067 kg of water at 100°C to steam.

17.108. IDENTIFY: Apply $H = kA \frac{\Delta T}{L}$ and solve for k .

SET UP: H equals the power input required to maintain a constant interior temperature

$$\text{EXECUTE: } k = H \frac{L}{A \Delta T} = (180 \text{ W}) \frac{(3.9 \times 10^{-2} \text{ m})}{(2.18 \text{ m}^2)(65.0 \text{ K})} = 5.0 \times 10^{-2} \text{ W/m} \cdot \text{K}.$$

EVALUATE: Our result is consistent with the values for insulating solids in Table 17.5.

17.109. IDENTIFY: Apply $H = kA \frac{\Delta T}{L}$.

SET UP: For the glass use $L = 12.45 \text{ cm}$, to account for the thermal resistance of the air films on either side of the glass.

$$\text{EXECUTE: (a) } H = (0.120 \text{ J/mol} \cdot \text{K}) (2.00 \times 0.95 \text{ m}^2) \left(\frac{28.0 \text{ C}^\circ}{5.0 \times 10^{-2} \text{ m} + 1.8 \times 10^{-2} \text{ m}} \right) = 93.9 \text{ W}.$$

(b) The heat flow through the wood part of the door is reduced by a factor of $1 - \frac{(0.50)^2}{(2.00 \times 0.95)} = 0.868$, so it

becomes 81.5 W . The heat flow through the glass is $H_{\text{glass}} = (0.80 \text{ J/mol} \cdot \text{K})(0.50 \text{ m}^2) \left(\frac{28.0 \text{ C}^\circ}{12.45 \times 10^{-2} \text{ m}} \right) = 45.0 \text{ W}$,

and so the ratio is $\frac{81.5 + 45.0}{93.9} = 1.35$.

EVALUATE: The single-pane window produces a significant increase in heat loss through the door. (See Problem 17.111).

17.110. IDENTIFY: Apply Eq.(17.23).

SET UP: Let $\Delta T_1 = \frac{HR_1}{A}$ be the temperature difference across the wood and let $\Delta T_2 = \frac{HR_2}{A}$ be the temperature difference across the insulation. The temperature difference across the combination is $\Delta T = \Delta T_1 + \Delta T_2$. The effective thermal resistance R of the combination is defined by $\Delta T = \frac{HR}{A}$.

EXECUTE: $\Delta T = \Delta T_1 + \Delta T_2$ gives $\frac{H}{A}(R_1 + R_2) = \frac{H}{A}R$, and $R = R_1 + R_2$.

EVALUATE: A good insulator has a large value of R . R for the combination is larger than the R for any one of the layers.

17.111. IDENTIFY and SET UP: Use H written in terms of the thermal resistance R : $H = A\Delta T/R$, where $R = L/k$ and $R = R_1 + R_2 + \dots$ (additive).

EXECUTE: single pane $R_s = R_{\text{glass}} + R_{\text{film}}$, where $R_{\text{film}} = 0.15 \text{ m}^2 \cdot \text{K}/\text{W}$ is the combined thermal resistance of the air films on the room and outdoor surfaces of the window.

$$R_{\text{glass}} = L/k = (4.2 \times 10^{-3} \text{ m})/(0.80 \text{ W/m} \cdot \text{K}) = 0.00525 \text{ m}^2 \cdot \text{K}/\text{W}$$

$$\text{Thus } R_s = 0.00525 \text{ m}^2 \cdot \text{K}/\text{W} + .15 \text{ m}^2 \cdot \text{K}/\text{W} = 0.1553 \text{ m}^2 \cdot \text{K}/\text{W}.$$

double pane $R_d = 2R_{\text{glass}} + R_{\text{air}} + R_{\text{film}}$, where R_{air} is the thermal resistance of the air space between the panes.

$$R_{\text{air}} = L/k = (7.0 \times 10^{-3} \text{ m})/(0.024 \text{ W/m} \cdot \text{K}) = 0.2917 \text{ m}^2 \cdot \text{K}/\text{W}$$

$$\text{Thus } R_d = 2(0.00525 \text{ m}^2 \cdot \text{K}/\text{W}) + 0.2917 \text{ m}^2 \cdot \text{K}/\text{W} + 0.15 \text{ m}^2 \cdot \text{K}/\text{W} = 0.4522 \text{ m}^2 \cdot \text{K}/\text{W}$$

$$H_s = A\Delta T/R_s, H_d = A\Delta T/R_d, \text{ so } H_s/H_d = R_d/R_s \text{ (since } A \text{ and } \Delta T \text{ are same for both)}$$

$$H_s/H_d = (0.4522 \text{ m}^2 \cdot \text{K}/\text{W})/(0.1553 \text{ m}^2 \cdot \text{K}/\text{W}) = 2.9$$

EVALUATE: The heat loss is about a factor of 3 less for the double-pane window. The increase in R for a double-pane is due mostly to the thermal resistance of the air space between the panes.

17.112. IDENTIFY: $H = \frac{kA\Delta T}{L}$ to each rod. Conservation of energy requires that the heat current through the copper equals the sum of the heat currents through the brass and the steel.

SET UP: Denote the quantities for copper, brass and steel by 1, 2 and 3, respectively, and denote the temperature at the junction by T_0 .

EXECUTE: (a) $H_1 = H_2 + H_3$. Using Eq.(17.21) and dividing by the common area gives,

$$\frac{k_1}{L_1}(100^\circ\text{C} - T_0) = \frac{k_2}{L_2}T_0 + \frac{k_3}{L_3}T_0. \text{ Solving for } T_0 \text{ gives } T_0 = \frac{(k_1/L_1)}{(k_1/L_1) + (k_2/L_2) + (k_3/L_3)}(100^\circ\text{C}). \text{ Substitution of}$$

numerical values gives $T_0 = 78.4^\circ\text{C}$.

(b) Using $H = \frac{kA}{L}\Delta T$ for each rod, with $\Delta T_1 = 21.6 \text{ C}^\circ$, $\Delta T_2 = \Delta T_3 = 78.4 \text{ C}^\circ$ gives $H_1 = 12.8 \text{ W}$, $H_2 = 9.50 \text{ W}$ and $H_3 = 3.30 \text{ W}$.

EVALUATE: In part (b), H_1 is seen to be the sum of H_2 and H_3 .

17.113. (a) EXECUTE: Heat must be conducted from the water to cool it to 0°C and to cause the phase transition. The entire volume of water is not at the phase transition temperature, just the upper surface that is in contact with the ice sheet.

(b) **IDENTIFY:** The heat that must leave the water in order for it to freeze must be conducted through the layer of ice that has already been formed.

SET UP: Consider a section of ice that has area A . At time t let the thickness be h . Consider a short time interval t to $t + dt$. Let the thickness that freezes in this time be dh . The mass of the section that freezes in the time interval dt is $dm = \rho dV = \rho A dh$. The heat that must be conducted away from this mass of water to freeze it is

$$dQ = dmL_f = (\rho AL_f)dh. H = dQ/dt = kA(\Delta T/h), \text{ so the heat } dQ \text{ conducted in time } dt \text{ throughout the thickness } h$$

that is already there is $dQ = kA\left(\frac{T_H - T_C}{h}\right)dt$. Solve for dh in terms of dt and integrate to get an expression relating h and t .

EXECUTE: Equate these expressions for dQ .

$$\rho A L_f dh = kA \left(\frac{T_H - T_C}{h} \right) dt$$

$$h dh = \left(\frac{k(T_H - T_C)}{\rho L_f} \right) dt$$

Integrate from $t = 0$ to time t . At $t = 0$ the thickness h is zero.

$$\int_0^h h dh = [k(T_H - T_C)\rho L_f] \int_0^t dt$$

$$\frac{1}{2}h^2 = \frac{k(T_H - T_C)}{\rho L_f} t \quad \text{and} \quad h = \sqrt{\frac{2k(T_H - T_C)}{\rho L_f} t}$$

The thickness after time t is proportional to \sqrt{t} .

(c) The expression in part (b) gives $t = \frac{h^2 \rho L_f}{2k(T_H - T_C)} = \frac{(0.25 \text{ m})^2 (920 \text{ kg/m}^3)(334 \times 10^3 \text{ J/kg})}{2(1.6 \text{ W/m} \cdot \text{K})(0^\circ\text{C} - (-10^\circ\text{C}))} = 6.0 \times 10^5 \text{ s}$

$$t = 170 \text{ h.}$$

(d) Find t for $h = 40 \text{ m}$. t is proportional to h^2 , so $t = (40 \text{ m}/0.25 \text{ m})^2 (6.0 \times 10^5 \text{ s}) = 1.5 \times 10^{10} \text{ s}$. This is about 500 years. With our current climate this will not happen.

EVALUATE: As the ice sheet gets thicker, the rate of heat conduction through it decreases. Part (d) shows that it takes a very long time for a moderately deep lake to totally freeze.

17.114. IDENTIFY: Apply Eq.(17.22) at each end of the short element. In part (b) use the fact that the net heat current into the element provides the Q for the temperature increase, according to $Q = mc\Delta T$.

SET UP: dT/dx is the temperature gradient.

EXECUTE: (a) $H = (380 \text{ W/m} \cdot \text{K})(2.50 \times 10^{-4} \text{ m}^2)(140 \text{ C}^\circ/\text{m}) = 13.3 \text{ W}$.

(b) Denoting the two ends of the element as 1 and 2, $H_2 - H_1 = \frac{Q}{t} = mc \frac{\Delta T}{t}$, where $\frac{\Delta T}{t} = 0.250 \text{ C}^\circ/\text{s}$.

$$kA \left. \frac{dT}{dx} \right|_2 - kA \left. \frac{dT}{dx} \right|_1 = mc \left(\frac{\Delta T}{t} \right). \quad \text{The mass } m \text{ is } \rho A \Delta x, \text{ so } kA \left. \frac{dT}{dx} \right|_2 = kA \left. \frac{dT}{dx} \right|_1 + \frac{\rho c \Delta x}{k} \left(\frac{\Delta T}{t} \right).$$

$$kA \left. \frac{dT}{dx} \right|_2 = 140 \text{ C}^\circ/\text{m} + \frac{(1.00 \times 10^4 \text{ kg/m}^3)(520 \text{ J/kg} \cdot \text{K})(1.00 \times 10^{-2} \text{ m})(0.250 \text{ C}^\circ/\text{s})}{380 \text{ W/m} \cdot \text{K}} = 174 \text{ C}^\circ/\text{m}.$$

EVALUATE: At steady-state temperature of the short element is no longer changing and $H_1 = H_2$.

17.115. IDENTIFY: The rate of heat conduction through the walls is 1.25 kW. Use the concept of thermal resistance and the fact that when insulating materials are in layers, the R values are additive.

SET UP: The total area of the four walls is $2(3.50 \text{ m})(2.50 \text{ m}) + 2(3.00 \text{ m})(2.50 \text{ m}) = 32.5 \text{ m}^2$

EXECUTE: $H = A \frac{T_H - T_C}{R}$ gives $R = \frac{A(T_H - T_C)}{H} = \frac{(32.5 \text{ m}^2)(17.0 \text{ K})}{1.25 \times 10^3 \text{ W}} = 0.442 \text{ m}^2 \cdot \text{K}/\text{W}$. For the wood,

$$R_w = \frac{L}{k} = \frac{1.80 \times 10^{-2} \text{ m}}{0.060 \text{ W/m} \cdot \text{K}} = 0.300 \text{ m}^2 \cdot \text{K}/\text{W}. \quad \text{For the insulating material, } R_{in} = R - R_w = 0.142 \text{ m}^2 \cdot \text{K}/\text{W}.$$

$$R_{in} = \frac{L_{in}}{k_{in}} \quad \text{and} \quad k_{in} = \frac{L_{in}}{R_{in}} = \frac{1.50 \times 10^{-2} \text{ m}}{0.142 \text{ m}^2 \cdot \text{K}/\text{W}} = 0.106 \text{ W/m} \cdot \text{K}.$$

EVALUATE: The thermal conductivity of the insulating material is larger than that of the wood, the thickness of the insulating material is less than that of the wood, and the thermal resistance of the wood is about three times that of the insulating material.

17.116. IDENTIFY: $I_1 r_1^2 = I_2 r_2^2$. Apply $H = Ae\sigma T^4$ (Eq.17.25) to the sun.

SET UP: $I_1 = 1.50 \times 10^3 \text{ W/m}^2$ when $r = 1.50 \times 10^{11} \text{ m}$.

EXECUTE: (a) The energy flux at the surface of the sun is

$$I_2 = (1.50 \times 10^3 \text{ W/m}^2) \left(\frac{1.50 \times 10^{11} \text{ m}}{6.96 \times 10^8 \text{ m}} \right)^2 = 6.97 \times 10^7 \text{ W/m}^2.$$

(b) Solving Eq.(17.25) with $e = 1$, $T = \left[\frac{H}{A \sigma} \right]^{\frac{1}{4}} = \left[\frac{6.97 \times 10^7 \text{ W/m}^2}{5.67 \times 10^{-8} \text{ W/m}^2 \cdot \text{K}^4} \right]^{\frac{1}{4}} = 5920 \text{ K}$.

EVALUATE: The total power output of the sun is $P = 4\pi r_2^2 I_2 = 2.0 \times 10^{31} \text{ W}$.

- 17.117. IDENTIFY and SET UP:** Use Eq.(17.26) to find the net heat current into the can due to radiation. Use $Q = Ht$ to find the heat that goes into the liquid helium, set this equal to mL and solve for the mass m of helium that changes phase.
EXECUTE: Calculate the net rate of radiation of heat from the can. $H_{\text{net}} = Ae\sigma(T^4 - T_s^4)$.

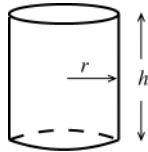


Figure 17.117

The surface area of the cylindrical can is
 $A = 2\pi rh + 2\pi r^2$. (See Figure 17.117.)

$$A = 2\pi r(h + r) = 2\pi(0.045 \text{ m})(0.250 \text{ m} + 0.045 \text{ m}) = 0.08341 \text{ m}^2.$$

$$H_{\text{net}} = (0.08341 \text{ m}^2)(0.200)(5.67 \times 10^{-8} \text{ W/m}^2 \cdot \text{K}^4)((4.22 \text{ K})^4 - (77.3 \text{ K})^4)$$

$H_{\text{net}} = -0.0338 \text{ W}$ (the minus sign says that the net heat current is into the can). The heat that is put into the can by radiation in one hour is $Q = -(H_{\text{net}})t = (0.0338 \text{ W})(3600 \text{ s}) = 121.7 \text{ J}$. This heat boils a mass m of helium according

$$\text{to the equation } Q = mL_f, \text{ so } m = \frac{Q}{L_f} = \frac{121.7 \text{ J}}{2.09 \times 10^4 \text{ J/kg}} = 5.82 \times 10^{-3} \text{ kg} = 5.82 \text{ g}.$$

EVALUATE: In the expression for the net heat current into the can the temperature of the surroundings is raised to the fourth power. The rate at which the helium boils away increases by about a factor of $(293/77)^4 = 210$ if the walls surrounding the can are at room temperature rather than at the temperature of the liquid nitrogen.

- 17.118. IDENTIFY:** The coefficient of volume expansion β is defined by $\Delta V = V_0\beta\Delta T$.

SET UP: For copper, $\beta = 5.1 \times 10^{-5} \text{ K}^{-1}$.

EXECUTE: (a) With $\Delta p = 0$, $p\Delta V = nR\Delta T = \frac{pV}{T}\Delta T$, or $\frac{\Delta V}{V} = \frac{\Delta T}{T}$, and $\beta = \frac{1}{T}$.

$$\text{(b) } \frac{\beta_{\text{air}}}{\beta_{\text{copper}}} = \frac{1}{(293 \text{ K})(5.1 \times 10^{-5} \text{ K}^{-1})} = 67.$$

EVALUATE: The coefficient of volume expansion for air is much greater than that for copper. For a given ΔT , gases expand much more than solids do.

- 17.119. IDENTIFY:** For the water, $Q = mc\Delta T$.

SET UP: For water, $c = 4190 \text{ J/kg} \cdot \text{K}$.

EXECUTE: (a) At steady state, the input power all goes into heating the water, so $P = \frac{Q}{t} = \frac{mc\Delta T}{t}$ and

$$\Delta T = \frac{Pt}{cm} = \frac{(1800 \text{ W})(60 \text{ s/min})}{(4190 \text{ J/kg} \cdot \text{K})(0.500 \text{ kg/min})} = 51.6 \text{ K}, \text{ and the output temperature is } 18.0^\circ\text{C} + 51.6^\circ\text{C} = 69.6^\circ\text{C}.$$

EVALUATE: (b) At steady state, the temperature of the apparatus is constant and the apparatus will neither remove heat from nor add heat to the water.

- 17.120. IDENTIFY:** For the air the heat input is related to the temperature change by $Q = mc\Delta T$.

SET UP: The rate P at which heat energy is generated is related to the rate P_0 at which food energy is consumed by the hamster by $P = 0.10P_0$.

EXECUTE: (a) The heat generated by the hamster is the heat added to the box;

$$P = \frac{Q}{t} = mc \frac{\Delta T}{t} = (1.20 \text{ kg/m}^3)(0.0500 \text{ m}^3)(1020 \text{ J/kg} \cdot \text{K})(1.60 \text{ C}^\circ/\text{h}) = 97.9 \text{ J/h}.$$

(b) Taking the efficiency into account, the mass M of seed that must be eaten in time t is

$$\frac{M}{t} = \frac{P_0}{L_c} = \frac{P/(10\%)}{L_c} = \frac{97.9 \text{ J/h}}{24 \text{ J/g}} = 40.8 \text{ g/h}.$$

EVALUATE: This is about 1.5 ounces of seed consumed in one hour.

- 17.121. IDENTIFY:** Heat Q_i goes into the ice when it warms to 0°C , melts, and the resulting water warms to the final temperature T_f . Heat Q_{ow} comes out of the ocean water when it cools to T_f . Conservation of energy gives

$$Q_i + Q_{\text{ow}} = 0.$$

SET UP: For ice, $c_i = 2100 \text{ J/kg} \cdot \text{K}$. For water, $L_f = 334 \times 10^3 \text{ J/kg}$ and $c_w = 4190 \text{ J/kg} \cdot \text{K}$. Let m be the total mass of the water on the earth's surface. So $m_i = 0.0175m$ and $m_{\text{ow}} = 0.975m$.

EXECUTE: $Q_i + Q_{ow} = 0$ gives $m_i c_i (30\text{ C}^\circ) + m_i L_f + m_i c_w T_f + m_{ow} c_w (T_f - 5.00^\circ\text{C}) = 0$.

$$T_f = \frac{-m_i c_i (30\text{ C}^\circ) - m_i L_f + m_{ow} c_w (5.00\text{ C}^\circ)}{(m_i + m_{ow}) c_w}$$

$$T_f = \frac{-(0.0175m)(2100\text{ J/kg}\cdot\text{K})(30\text{ K}) - (0.0175m)(334\times 10^3\text{ J/kg}) + (0.975m)(4190\text{ J/kg}\cdot\text{K})(5.00\text{ K})}{(0.0175m + 0.975m)(4190\text{ J/kg}\cdot\text{K})}$$

$$T_f = \frac{1.348\times 10^4\text{ J/kg}}{4.159\times 10^3\text{ J/kg}\cdot\text{K}} = 3.24^\circ\text{C}. \text{ The temperature decrease is } 1.76\text{ C}^\circ.$$

EVALUATE: The mass of ice in the icecaps is much less than the mass of the water in the oceans, but much more heat is required to change the phase of 1 kg of ice than to change the temperature of 1 kg of water 1 C° , so the lowering of the temperature of the oceans would be appreciable.

17.122. IDENTIFY: Apply Eq.(17.21). For a spherical or cylindrical surface, the area A in Eq.(17.21) is not constant, and the material must be considered to consist of shells with thickness dr and a temperature difference between the inside and outside of the shell dT . The heat current will be a constant, and must be found by integrating a differential equation.

SET UP: The surface area of a sphere is $4\pi r^2$. The surface area of the curved side of a cylinder is $2\pi r l$. $\ln(1 + \varepsilon) \approx \varepsilon$ when $\varepsilon \ll 1$.

(a) Equation (17.21) becomes $H = k(4\pi r^2) \frac{dT}{dr}$ or $\frac{H dr}{4\pi r^2} = k dT$. Integrating both sides between the appropriate

limits, $\frac{H}{4\pi} \left(\frac{1}{a} - \frac{1}{b} \right) = k(T_2 - T_1)$. In this case the ‘‘appropriate limits’’ have been chosen so that if the inner

temperature T_2 is at the higher temperature T_1 , the heat flows outward; that is, $\frac{dT}{dr} < 0$. Solving for the heat

$$\text{current, } H = \frac{k4\pi ab(T_2 - T_1)}{b - a}.$$

(b) The rate of change of temperature with radius is of the form $\frac{dT}{dr} = \frac{B}{r^2}$, with B a constant. Integrating from

$r = a$ to r and from $r = a$ to $r = b$ gives $T(r) - T_2 = B \left(\frac{1}{a} - \frac{1}{r} \right)$ and $T_1 - T_2 = B \left(\frac{1}{a} - \frac{1}{b} \right)$. Using the second of these

to eliminate B and solving for $T(r)$ gives $T(r) = T_2 - (T_2 - T_1) \left(\frac{r - a}{b - a} \right) \left(\frac{b}{r} \right)$. There are, of course, many equivalent

forms. As a check, note that at $r = a$, $T = T_2$ and at $r = b$, $T = T_1$.

(c) As in part (a), the expression for the heat current is $H = k(2\pi r l) \frac{dT}{dr}$ or $\frac{H}{2\pi r} = kLdT$, which integrates, with

the same condition on the limits, to $\frac{H}{2\pi} \ln(b/a) = kL(T_2 - T_1)$, or $H = \frac{2\pi kL(T_2 - T_1)}{\ln(b/a)}$.

(d) A method similar to that used in part (b) gives $T(r) = T_2 + (T_1 - T_2) \frac{\ln(r/a)}{\ln(b/a)}$.

EVALUATE: (e) For the sphere: Let $b - a = l$, and approximate $b \sim a$, with a the common radius. Then the surface area of the sphere is $A = 4\pi a^2$, and the expression for H is that of Eq. (17.21) (with l instead of L , which has

another use in this problem). For the cylinder: with the same notation, consider $\ln \left(\frac{b}{a} \right) = \ln \left(1 + \frac{l}{a} \right) \sim \frac{l}{a}$,

where the approximation for $\ln(1 + \varepsilon)$ for small ε has been used. The expression for H then reduces to

$k(2\pi La)(\Delta T/l)$, which is Eq. (17.21) with $A = 2\pi La$.

17.123. IDENTIFY: From the result of Problem 17.122, the heat current through each of the jackets is related to the temperature difference by $H = \frac{2\pi k l}{\ln(b/a)} \Delta T$, where l is the length of the cylinder and b and a are the inner and outer radii of the cylinder.

SET UP: Let the temperature across the cork be ΔT_1 and the temperature across the styrofoam be ΔT_2 , with similar notation for the thermal conductivities and heat currents.

EXECUTE: (a) $\Delta T_1 + \Delta T_2 = \Delta T = 125\text{ C}^\circ$. Setting $H_1 = H_2 = H$ and canceling the common factors,

$\frac{\Delta T_1 k_1}{\ln 2} = \frac{\Delta T_2 k_2}{\ln 1.5}$. Eliminating ΔT_2 and solving for ΔT_1 gives $\Delta T_1 = \Delta T \left(1 + \frac{k_1 \ln 1.5}{k_2 \ln 2} \right)^{-1}$. Substitution of numerical

values gives $\Delta T_1 = 37\text{ C}^\circ$, and the temperature at the radius where the layers meet is $140^\circ\text{C} - 37^\circ\text{C} = 103^\circ\text{C}$.

(b) Substitution of this value for ΔT_1 into the above expression for $H_1 = H$ gives

$$H = \frac{2\pi(2.00\text{ m})(0.0400\text{ W/m}\cdot\text{K})}{\ln 2}(37\text{ C}^\circ) = 27\text{ W}.$$

EVALUATE: $\Delta T = 103^\circ\text{C} - 15^\circ\text{C} = 88\text{ C}^\circ$. $H_2 = \frac{2\pi(2.00\text{ m})(0.0100\text{ W/m}\cdot\text{K})}{\ln(6.00/4.00)}(88\text{ C}^\circ) = 27\text{ W}$. This is the same

as H_1 , as it should be.

17.124. IDENTIFY: Apply Eq.(17.22) to different points along the rod, where $\frac{dT}{dx}$ is the temperature gradient at each point.

SET UP: For copper, $k = 385\text{ W/m}\cdot\text{K}$.

EXECUTE: (a) The initial temperature distribution, $T = (100^\circ\text{C})\sin\pi x/L$, is shown in Figure 17.124a.

(b) After a very long time, no heat will flow, and the entire rod will be at a uniform temperature which must be that of the ends, 0°C .

(c) The temperature distribution at successively greater times $T_1 < T_2 < T_3$ is sketched in Figure 17.124b.

(d) $\frac{dT}{dx} = (100^\circ\text{C})(\pi/L)\cos\pi x/L$. At the ends, $x = 0$ and $x = L$, the cosine is ± 1 and the temperature gradient is $\pm(100^\circ\text{C})(\pi/0.100\text{ m}) = \pm 3.14 \times 10^3\text{ C}^\circ/\text{m}$.

(e) Taking the phrase “into the rod” to mean an absolute value, the heat current will be

$$kA\frac{dT}{dx} = (385.0\text{ W/m}\cdot\text{K})(1.00 \times 10^{-4}\text{ m}^2)(3.14 \times 10^3\text{ C}^\circ/\text{m}) = 121\text{ W}.$$

(f) Either by evaluating $\frac{dT}{dx}$ at the center of the rod, where $\pi x/L = \pi/2$ and $\cos(\pi/2) = 0$, or by checking the

figure in part (a), the temperature gradient is zero, and no heat flows through the center; this is consistent with the symmetry of the situation. There will not be any heat current at the center of the rod at any later time.

(g) $\frac{k}{\rho c} = \frac{(385\text{ W/m}\cdot\text{K})}{(8.9 \times 10^3\text{ kg/m}^3)(390\text{ J/kg}\cdot\text{K})} = 1.1 \times 10^{-4}\text{ m}^2/\text{s}$.

(h) Although there is no net heat current, the temperature of the center of the rod is decreasing; by considering the heat current at points just to either side of the center, where there is a non-zero temperature gradient, there must be a net flow of heat out of the region around the center. Specifically,

$$H((L/2) + \Delta x) - H((L/2) - \Delta x) = \rho A(\Delta x)c \frac{\partial T}{\partial t} = kA \left(\left. \frac{\partial T}{\partial x} \right|_{(L/2)+\Delta x} - \left. \frac{\partial T}{\partial x} \right|_{(L/2)-\Delta x} \right) = kA \frac{\partial^2 T}{\partial x^2} \Delta x, \text{ from which the Heat}$$

Equation, $\frac{\partial T}{\partial t} = \frac{k}{\rho c} \frac{\partial^2 T}{\partial x^2}$ is obtained. At the center of the rod, $\frac{\partial^2 T}{\partial x^2} = -(100\text{ C}^\circ)(\pi/L)^2$, and so

$$\frac{\partial T}{\partial t} = -(1.11 \times 10^{-4}\text{ m}^2/\text{s})(100\text{ C}^\circ) \left(\frac{\pi}{0.100\text{ m}} \right)^2 = -10.9\text{ C}^\circ/\text{s}, \text{ or } -11\text{C}^\circ/\text{s} \text{ to two figures.}$$

(i) $\frac{100\text{ C}^\circ}{10.9\text{ C}^\circ/\text{s}} = 9.17\text{ s}$

(j) Decrease (that is, become less negative), since as T decreases, $\frac{\partial^2 T}{\partial x^2}$ decreases. This is consistent with the graphs, which correspond to equal time intervals.

(k) At the point halfway between the end and the center, at any given time $\frac{\partial^2 T}{\partial x^2}$ is a factor of $\sin(\pi/4) = 1/\sqrt{2}$ less than at the center, and so the initial rate of change of temperature is $-7.71\text{C}^\circ/\text{s}$.

EVALUATE: A plot of temperature as a function of both position and time for $0 \leq t \leq 50$ s is shown in Figure 17.124c.

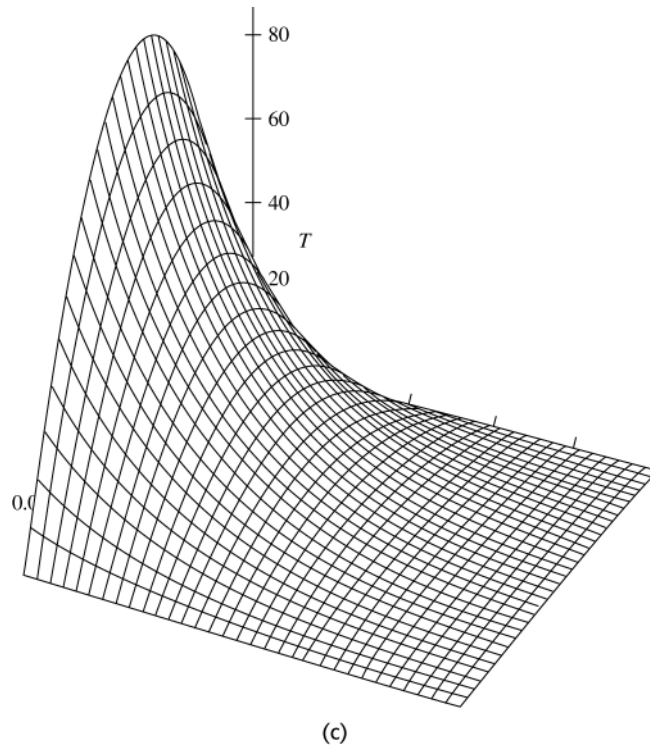
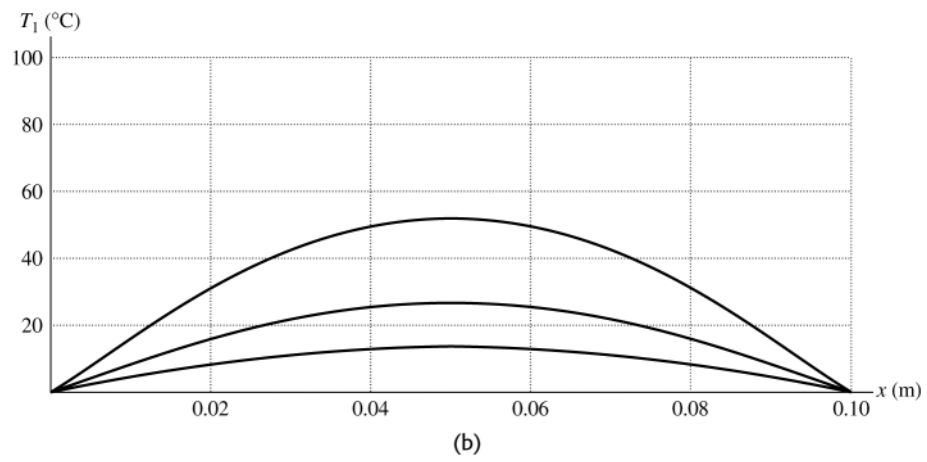
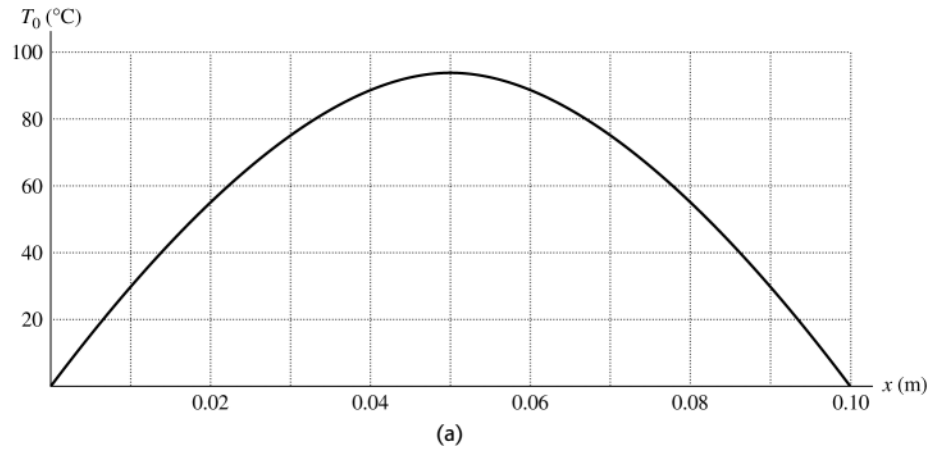


Figure 17.124

17.125. IDENTIFY: Apply the concept of thermal expansion. In part (b) the object can be treated as a simple pendulum.

SET UP: For steel $\alpha = 1.2 \times 10^{-5} \text{ (C}^\circ\text{)}^{-1}$. $1 \text{ yr} = 86,400 \text{ s}$.

EXECUTE: (a) In hot weather, the moment of inertia I and the length d in Eq.(13.39) will both increase by the same factor, and so the period will be longer and the clock will run slow (lose time). Similarly, the clock will run fast (gain time) in cold weather.

(b) $\frac{\Delta L}{L_0} = \alpha \Delta T = (1.2 \times 10^{-5} \text{ (C}^\circ\text{)}^{-1})(10.0 \text{ C}^\circ) = 1.2 \times 10^{-4}$.

(c) See Problem 13.98. To avoid possible confusion, denote the pendulum period by τ . For this problem, $\frac{\Delta \tau}{\tau} = \frac{1}{2} \frac{\Delta L}{L} = 6.0 \times 10^{-5}$ so in one day the clock will gain $(86,400 \text{ s})(6.0 \times 10^{-5}) = 5.2 \text{ s}$.

(d) $\left| \frac{\Delta \tau}{\tau} \right| = \frac{1}{2} \alpha \Delta T$. $\left| \frac{\Delta \tau}{\tau} \right| = \frac{1.0 \text{ s}}{86,400 \text{ s}}$ gives $\Delta T = 2[(1.2 \times 10^{-5} \text{ (C}^\circ\text{)}^{-1})(86,400)]^{-1} = 1.9 \text{ C}^\circ$. T must be controlled to within 1.9 C° .

EVALUATE: In part (d) the answer does not depend on the period of the pendulum. It depends only on the fractional change in the period.

17.126. IDENTIFY: The rate at which heat is absorbed at the blackened end is the heat current in the rod,

$$Ae\sigma(T_s^4 - T_2^4) = \frac{kA}{L}(T_2 - T_1) \text{ where } T_1 = 20.00 \text{ K and } T_2 \text{ is the temperature of the blackened end of the rod.}$$

SET UP: Since the end is blackened, $e = 1$. $T_s = 500.0 \text{ K}$.

EXECUTE: If the equation were to be solved exactly for T_2 , the equation would be a quartic, very likely not worth the trouble. Following the hint, approximate T_2 on the left side of the above expression as T_1 to obtain

$$T_2 = T_1 + \frac{\sigma L}{k}(T_s^4 - T_1^4) = T_1 + (6.79 \times 10^{-12} \text{ K}^{-3})(T_s^4 - T_1^4) = T_1 + 0.424 \text{ K} = 20.42 \text{ K}.$$

EVALUATE: This approximation for T_2 is indeed only slightly than T_1 , and is a good estimate of the temperature. Using this for T_2 in the original expression to find a better value of ΔT gives the same ΔT to eight figures, and further iterations are not worthwhile.

17.127. IDENTIFY: The rate in (iv) is given by Eq.(17.26), with $T = 309 \text{ K}$ and $T_s = 320 \text{ K}$. The heat absorbed in the evaporation of water is $Q = mL$.

SET UP: $m = \rho V$, so $\frac{m}{V} = \rho$.

EXECUTE: (a) The rates are: (i) 280 W,

(ii) $(54 \text{ J/h} \cdot \text{C}^\circ \cdot \text{m}^2)(1.5 \text{ m}^2)(11 \text{ C}^\circ)/(3600 \text{ s/h}) = 0.248 \text{ W}$,

(iii) $(1400 \text{ W/m}^2)(1.5 \text{ m}^2) = 2.10 \times 10^3 \text{ W}$,

(iv) $(5.67 \times 10^{-8} \text{ W/m}^2 \cdot \text{K}^4)(1.5 \text{ m}^2)((320 \text{ K})^4 - (309 \text{ K})^4) = 116 \text{ W}$.

The total is 2.50 kW, with the largest portion due to radiation from the sun.

(b) $\frac{P}{\rho L_v} = \frac{2.50 \times 10^3 \text{ W}}{(1000 \text{ kg/m}^3)(2.42 \times 10^6 \text{ J/kg} \cdot \text{K})} = 1.03 \times 10^{-6} \text{ m}^3/\text{s}$. This is equal to $= 3.72 \text{ L/h}$.

(c) Redoing the above calculations with $e = 0$ and the decreased area gives a power of 945 W and a corresponding evaporation rate of 1.4 L/h. Wearing reflective clothing helps a good deal. Large areas of loose weave clothing also facilitate evaporation.

EVALUATE: The radiant energy from the sun absorbed by the area covered by clothing is assumed to be zero, since $e \approx 0$ for the clothing and the clothing reflects almost all the radiant energy incident on it. For the same reason, the exposed skin area is the area used in Eq.(17.26).