Chapter 19

1. We take p_3 to be 80 kPa for both thermometers. According to Fig. 19-6, the nitrogen thermometer gives 373.35 K for the boiling point of water. Use Eq. 19-5 to compute the pressure:

$$p_{\mathrm{N}} = \frac{T}{273.16\,\mathrm{K}} p_3 = \left(\frac{373.35\,\mathrm{K}}{273.16\,\mathrm{K}}\right)(80\,\mathrm{kPa}) = 109.343\ \mathrm{kPa}\ .$$

The hydrogen thermometer gives 373.16 K for the boiling point of water and

$$p_{\mathrm{H}} = \left(\frac{373.16\,\mathrm{K}}{273.16\,\mathrm{K}}\right)(80\,\mathrm{kPa}) = 109.287\ \mathrm{kPa}\ .$$

The pressure in the nitrogen thermometer is higher than the pressure in the hydrogen thermometer by 0.056 kPa.

2. From Eq. 19-6, we see that the limiting value of the pressure ratio is the same as the absolute temperature ratio: $(373.15\,\mathrm{K})/(273.16\,\mathrm{K}) = 1.366$.

3. Let T_L be the temperature and p_L be the pressure in the left-hand thermometer. Similarly, let T_R be the temperature and p_R be the pressure in the right-hand thermometer. According to the problem statement, the pressure is the same in the two thermometers when they are both at the triple point of water. We take this pressure to be p_3. Writing Eq. 19-5 for each thermometer,

$$T_L = (273.16\,\mathrm{K})\left(\frac{p_L}{p_3}\right) \qquad \text{and} \quad T_R = (273.16\,\mathrm{K})\left(\frac{p_R}{p_3}\right)\ ,$$

we subtract the second equation from the first to obtain

$$T_L - T_R = (273.16\,\mathrm{K})\left(\frac{p_L - p_R}{p_3}\right)\ .$$

First, we take $T_L = 373.125\,\mathrm{K}$ (the boiling point of water) and $T_R = 273.16\,\mathrm{K}$ (the triple point of water). Then, $p_L - p_R = 120\,\mathrm{torr}$. We solve

$$373.125\,\mathrm{K} - 273.16\,\mathrm{K} = (273.16\,\mathrm{K})\left(\frac{120\,\mathrm{torr}}{p_3}\right)$$

for p_3. The result is $p_3 = 328\,\mathrm{torr}$. Now, we let $T_L = 273.16\,\mathrm{K}$ (the triple point of water) and T_R be the unknown temperature. The pressure difference is $p_L - p_R = 90.0\,\mathrm{torr}$. Solving

$$273.16\,\mathrm{K} - T_R = (273.16\,\mathrm{K})\left(\frac{90.0\,\mathrm{torr}}{328\,\mathrm{torr}}\right)$$

for the unknown temperature, we obtain $T_R = 348\,\mathrm{K}$.

4. (a) Let the reading on the Celsius scale be x and the reading on the Fahrenheit scale be y. Then $y = \frac{9}{5}x + 32$. If we require $y = 2x$, then we have

$$2x = \frac{9}{5}x + 32 \implies x = (5)(32) = 160°\text{C}$$

which yields $y = 2x = 320°$F.

(b) In this case, we require $y = \frac{1}{2}x$ and find

$$\frac{1}{2}x = \frac{9}{5}x + 32 \implies x = -\frac{(10)(32)}{13} \approx -24.6°\text{C}$$

which yields $y = x/2 = -12.3°$F.

5. (a) Fahrenheit and Celsius temperatures are related by $T_F = (9/5)T_C + 32°$. T_F is numerically equal to T_C if $T_F = (9/5)T_F + 32°$. The solution to this equation is $T_F = -(5/4)(32°) = -40°$F.

(b) Fahrenheit and Kelvin temperatures are related by $T_F = (9/5)T_C + 32° = (9/5)(T - 273.15) + 32°$. The Fahrenheit temperature T_F is numerically equal to the Kelvin temperature T if $T_F = (9/5)(T_F - 273.15) + 32°$. The solution to this equation is

$$T_F = \frac{5}{4}\left(\frac{9}{5} \times 273.15 - 32°\right) = 575°\text{F} .$$

(c) Since $T_C = T - 273.15$ the Kelvin and Celsius temperatures can never have the same numerical value.

6. (a) Let the reading on the Celsius scale be x and the reading on the Fahrenheit scale be y. Then $y = \frac{9}{5}x + 32$. For $x = -71$, this gives $y = -96$.

(b) The relationship between y and x may be inverted to yield $x = \frac{5}{9}(y - 32)$. Thus, for $y = 134$ we find $x \approx 56.7$ on the Celsius scale.

7. (a) Changes in temperature take place by means of radiation, conduction, and convection. The constant A can be reduced by placing the object in isolation, by surrounding it with a vacuum jacket, for example. This reduces conduction and convection. Absorption of radiation can be reduced by polishing the surface to a mirror finish. We note that A depends on the condition of the surface and on the ability of the environment to conduct or convect energy to or from the object. A has the dimensions of reciprocal time.

(b) We rearrange the equation to obtain

$$\frac{1}{\Delta T}\frac{d\Delta T}{dt} = -A .$$

Now, we integrate with respect to time and recognize that

$$\int \frac{1}{\Delta T}\frac{d\,\Delta T}{dt}\,dt = \int \frac{1}{\Delta T}\,d(\Delta T) .$$

Thus,

$$\int_{\Delta T_0}^{\Delta T} \frac{1}{\Delta T}\,d(\Delta T) = -\int_0^t A\,dt .$$

The integral on the right side yields $-At$ and the integral on the left yields $\ln \Delta T|_{\Delta T_0}^{\Delta T} = \ln(\Delta T) - \ln(\Delta T_0) = \ln(\Delta T/\Delta T_0)$, so

$$\ln \frac{\Delta T}{\Delta T_0} = -At .$$

We use each side as the exponent of e, the base of the natural logarithms, to obtain

$$\frac{\Delta T}{\Delta T_0} = e^{-At}$$

or

$$\Delta T = \Delta T_0\, e^{-At} \ .$$

8. From $\Delta T = \Delta T_0 e^{-At}$, we have $\Delta T/\Delta T_0 = e^{-A_1 t_1}$ (before insulation) and $\Delta T/\Delta T_0 = e^{-A_2 t_2}$ (after insulation). Thus the ratio is given by $A_2/A_1 = t_1/t_2 = 1/2$.

9. We assume scale X is a linear scale in the sense that if its reading is x then it is related to a reading y on the Kelvin scale by a linear relationship $y = mx + b$. We determine the constants m and b by solving the simultaneous equations:

$$\begin{aligned} 373.15 &= m(-53.5) + b \\ 273.15 &= m(-170) + b \end{aligned}$$

which yield the solutions $m = 100/(170 - 53.5) = 0.858$ and $b = 419$. With these values, we find x for $y = 340$:

$$x = \frac{y - b}{m} = \frac{340 - 419}{0.858} = -92.1^\circ X \ .$$

10. The change in length for the aluminum pole is

$$\Delta\ell = \ell_0 \alpha_{\mathrm{Al}} \Delta T = (33\,\mathrm{m})(23 \times 10^{-6}/\mathrm{C}^\circ)(15\mathrm{C}^\circ) = 0.011 \text{ m} \ .$$

11. When the temperature changes from T to $T + \Delta T$ the diameter of the mirror changes from D to $D + \Delta D$, where $\Delta D = \alpha D\, \Delta T$. Here α is the coefficient of linear expansion for Pyrex glass ($3.2 \times 10^{-6}/\mathrm{C}^\circ$, according to Table 19–2). The range of values for the diameters can be found by setting ΔT equal to the temperature range. Thus $\Delta D = (3.2 \times 10^{-6}/\mathrm{C}^\circ)(200\,\mathrm{in.})(60\,\mathrm{C}^\circ) = 3.84 \times 10^{-2}\,\mathrm{in.}$ Since 1 in. = $2.50\,\mathrm{cm} = 2.50 \times 10^4\,\mu\mathrm{m}$, this is $960\,\mu\mathrm{m}$.

12. (a) The coefficient of linear expansion α for the alloy is

$$\alpha = \Delta L/L\Delta T = \frac{10.015\,\mathrm{cm} - 10.000\,\mathrm{cm}}{(10.01\,\mathrm{cm})(100^\circ\mathrm{C} - 20.000^\circ\mathrm{C})} = 1.88 \times 10^{-5}/\mathrm{C}^\circ \ .$$

Thus, from 100°C to 0°C we have

$$\Delta L = L\alpha\Delta T = (10.015\,\mathrm{cm})\left(1.88 \times 10^{-5}/\mathrm{C}^\circ\right)(0^\circ\mathrm{C} - 100^\circ\mathrm{C}) = -1.88 \times 10^{-2} \text{ cm} \ .$$

The length at 0°C is therefore $L' = L + \Delta L = 10.015\,\mathrm{cm} - 0.0188\,\mathrm{cm} = 9.996\,\mathrm{cm}$.

(b) Let the temperature be T_x. Then from 20°C to T_x we have

$$\Delta L = 10.009\,\mathrm{cm} - 10.000\,\mathrm{cm} = \alpha L \Delta T = (1.88 \times 10^{-5}/\mathrm{C}^\circ)(10.000\,\mathrm{cm})\Delta T \ ,$$

giving $\Delta T = 48\,\mathrm{C}^\circ$. Thus, $T_x = 20^\circ\mathrm{C} + 48\,\mathrm{C}^\circ = 68^\circ\mathrm{C}$.

13. The new diameter is

$$\begin{aligned} D &= D_0(1 + \alpha_{\mathrm{Al}}\Delta T) \\ &= (2.725\,\mathrm{cm})[1 + (23 \times 10^{-6}/\mathrm{C}^\circ)(100.0^\circ\mathrm{C} - 0.000^\circ\mathrm{C})] = 2.731 \text{ cm} \ . \end{aligned}$$

14. The volume at 30°C is given by

$$\begin{aligned} V' &= V(1 + \beta\Delta T) = V(1 + 3\alpha\Delta T) \\ &= (50\,\mathrm{cm}^3)[1 + 3(29 \times 10^{-6}/\mathrm{C}^\circ)(30^\circ\mathrm{C} - 60^\circ\mathrm{C})] = 49.87 \text{ cm}^3 \ . \end{aligned}$$

where we have used $\beta = 3\alpha$.

15. Since a volume is the product of three lengths, the change in volume due to a temperature change ΔT is given by $\Delta V = 3\alpha V\,\Delta T$, where V is the original volume and α is the coefficient of linear expansion. See Eq. 19–11. Since $V = (4\pi/3)R^3$, where R is the original radius of the sphere, then

$$\Delta V = 3\alpha\left(\frac{4\pi}{3}R^3\right)\Delta T = (23\times10^{-6}\,/\mathrm{C}^\circ)(4\pi)(10\,\mathrm{cm})^3(100\,\mathrm{C}^\circ) = 29\,\mathrm{cm}^3\ .$$

The value for the coefficient of linear expansion is found in Table 19-2.

16. The change in area for the plate is

$$\Delta A = (a+\Delta a)(b+\Delta b) - ab \approx a\Delta b + b\Delta a = 2ab\alpha\Delta T = 2\alpha A\Delta T\ .$$

17. If V_c is the original volume of the cup, α_a is the coefficient of linear expansion of aluminum, and ΔT is the temperature increase, then the change in the volume of the cup is $\Delta V_c = 3\alpha_a V_c\,\Delta T$. See Eq. 19–11. If β is the coefficient of volume expansion for glycerin then the change in the volume of glycerin is $\Delta V_g = \beta V_c\,\Delta T$. Note that the original volume of glycerin is the same as the original volume of the cup. The volume of glycerin that spills is

$$\begin{aligned}\Delta V_g - \Delta V_c &= (\beta - 3\alpha_a)\,V_c\,\Delta T\\ &= \left[\left(5.1\times10^{-4}\,/\mathrm{C}^\circ\right) - 3\left(23\times10^{-6}\,/\mathrm{C}^\circ\right)\right]\left(100\,\mathrm{cm}^3\right)(6\,\mathrm{C}^\circ)\\ &= 0.26\ \mathrm{cm}^3\ .\end{aligned}$$

18. The change in length for the section of the steel ruler between its 20.05 cm mark and 20.11 cm mark is

$$\Delta L_s = L_s\alpha_s\Delta T = (20.11\,\mathrm{cm})(11\times10^{-6}/\mathrm{C}^\circ)(270^\circ\mathrm{C} - 20^\circ\mathrm{C}) = 0.055\ \mathrm{cm}\ .$$

Thus, the actual change in length for the rod is $\Delta L = (20.11\,\mathrm{cm} - 20.05\,\mathrm{cm}) + 0.055\,\mathrm{cm} = 0.115\,\mathrm{cm}$. The coefficient of thermal expansion for the material of which the rod is made of is then

$$\alpha = \frac{\Delta L}{\Delta T} = \frac{0.115\,\mathrm{cm}}{270^\circ\mathrm{C} - 20^\circ\mathrm{C}} = 23\times10^{-6}/\mathrm{C}^\circ\ .$$

19. After the change in temperature the diameter of the steel rod is $D_s = D_{s0} + \alpha_s D_{s0}\,\Delta T$ and the diameter of the brass ring is $D_b = D_{b0} + \alpha_b D_{b0}\,\Delta T$, where D_{s0} and D_{b0} are the original diameters, α_s and α_b are the coefficients of linear expansion, and ΔT is the change in temperature. The rod just fits through the ring if $D_s = D_b$. This means $D_{s0} + \alpha_s D_{s0}\,\Delta T = D_{b0} + \alpha_b D_{b0}\,\Delta T$. Therefore,

$$\begin{aligned}\Delta T &= \frac{D_{s0} - D_{b0}}{\alpha_b D_{b0} - \alpha_s D_{s0}}\\ &= \frac{3.000\,\mathrm{cm} - 2.992\,\mathrm{cm}}{(19\times10^{-6}\,/\mathrm{C}^\circ)(2.992\,\mathrm{cm}) - (11\times10^{-6}\,/\mathrm{C}^\circ)(3.000\,\mathrm{cm})} = 335\,\mathrm{C}^\circ\ .\end{aligned}$$

The temperature is $T = 25^\circ\mathrm{C} + 335\,\mathrm{C}^\circ = 360^\circ\mathrm{C}$.

20. (a) We use $\rho = m/V$ and $\Delta\rho = \Delta(m/V) = m\Delta(1/V) \simeq -m\Delta V/V^2 = -\rho(\Delta V/V) = -3\rho(\Delta L/L)$. The percent change in density is

$$\frac{\Delta\rho}{\rho} = -3\frac{\Delta L}{L} = -3(0.23\%) = -0.69\%\ .$$

(b) Since $\alpha = \Delta L/(L\Delta T) = 0.23\times10^{-2}/(100^\circ\mathrm{C} - 0.0^\circ\mathrm{C}) = 23\times10^{-6}/\mathrm{C}^\circ$, the metal is aluminum (using Table 19-2).

21. The change in volume of the liquid is given by $\Delta V = \beta V\,\Delta T$. If A is the cross-sectional area of the tube and h is the height of the liquid, then $V = Ah$ is the original volume and $\Delta V = A\,\Delta h$ is the change in volume. Since the tube does not change the cross-sectional area of the liquid remains the same. Therefore, $A\,\Delta h = \beta Ah\,\Delta T$ or $\Delta h = \beta h\,\Delta T$.

22. (a) Since $A = \pi D^2/4$, we have the differential $dA = 2(\pi D/4)dD$. Dividing the latter relation by the former, we obtain $dA/A = 2\,dD/D$. In terms of Δ's, this reads

$$\frac{\Delta A}{A} = 2\frac{\Delta D}{D} \qquad \text{for} \quad \frac{\Delta D}{D} \ll 1 \; .$$

We can think of the factor of 2 as being due to the fact that area is a two-dimensional quantity. Therefore, the area increases by $2(0.18\%) = 0.36\%$.

(b) Assuming that all dimension are allowed to freely expand, then the thickness increases by 0.18%.

(c) The volume (a three-dimensional quantity) increases by $3(0.18\%) = 0.54\%$.

(d) The mass does not change.

(e) The coefficient of linear expansion is

$$\alpha = \frac{\Delta D}{D\Delta T} = \frac{0.18 \times 10^{-2}}{100°\text{C}} = 18 \times 10^{-6}/\text{C}° \; .$$

23. We note that if the pendulum shortens, its frequency of oscillation will increase, thereby causing it to record more units of time ("ticks") than have actually passed during an interval. Thus, as the pendulum contracts (this problem involves cooling the brass wire), the pendulum will "run fast." Since the "direction" of the error has now been discussed, the remaining calculations are understood to be in absolute value. The differential of the equation for the pendulum period in Chapter 16 is

$$dT = \frac{1}{2}(2\pi)\frac{dL}{\sqrt{gL}}$$

which we divide by the period equation $T = 2\pi\sqrt{L/g}$ (and replace differentials with $|\Delta|$'s) to obtain

$$\frac{|\Delta T|}{T} = \frac{1}{2}\frac{|\Delta L|}{L} = \frac{1}{2}\alpha|\Delta T|$$

where we use Eq. 19-9 (in absolute value) in the last step. Thus, the (unitless) fractional change in period is

$$\frac{|\Delta T|}{T} = \frac{1}{2}\left(19 \times 10^{-6}/\text{C}°\right)(20\,\text{C}°) = 1.9 \times 10^{-4}$$

using Table 19-2. We can express this in "mixed units" fashion by recalling that there are 3600 s in an hour. Thus, $(3600\,\text{s/h})(1.9 \times 10^{-4}) = 0.68$ s/h.

24. We divide Eq. 19-9 by the time increment Δt and equate it to the (constant) speed $v = 100 \times 10^{-9}$ m/s.

$$v = \alpha L_0 \frac{\Delta T}{\Delta t}$$

where $L_0 = 0.0200$ m and $\alpha = 23 \times 10^{-6}/\text{C}°$. Thus, we obtain

$$\frac{\Delta T}{\Delta t} = 0.217\,\frac{\text{C}°}{\text{s}} = 0.217\,\frac{\text{K}}{\text{s}} \; .$$

25. Consider half the bar. Its original length is $\ell_0 = L_0/2$ and its length after the temperature increase is $\ell = \ell_0 + \alpha\ell_0\,\Delta T$. The old position of the half-bar, its new position, and the distance x that one end is displaced form a right triangle, with a hypotenuse of length ℓ, one side of length ℓ_0, and the other side of length x. The Pythagorean theorem yields $x^2 = \ell^2 - \ell_0^2 = \ell_0^2(1 + \alpha\,\Delta T)^2 - \ell_0^2$. Since the change in length is small we may approximate $(1 + \alpha\,\Delta T)^2$ by $1 + 2\alpha\,\Delta T$, where the small term $(\alpha\,\Delta T)^2$ was neglected. Then,

$$x^2 = \ell_0^2 + 2\ell_0^2\alpha\,\Delta T - \ell_0^2 = 2\ell_0^2\alpha\,\Delta T$$

and

$$x = \ell_0\sqrt{2\alpha\,\Delta T} = \frac{3.77\,\text{m}}{2}\sqrt{2(25 \times 10^{-6}\,/\text{C}°)(32\,\text{C}°)} = 7.5 \times 10^{-2}\ \text{m} \; .$$

26. We use $Q = cm\Delta T$. The textbook notes that a nutritionist's "Calorie" is equivalent to 1000 cal. The mass m of the water that must be consumed is

$$m = \frac{Q}{c\Delta T} = \frac{3500 \times 10^3\,\text{cal}}{(1\,\text{g/cal}\cdot\text{C}^\circ)(37.0^\circ\text{C} - 0.0^\circ\text{C})} = 94.6 \times 10^4 \text{ g} ,$$

which is equivalent to $9.46 \times 10^4\,\text{g}/(1000\,\text{g/liter}) = 94.6\,\text{liters}$ of water. This is certainly too much to drink in a single day!

27. (a) The specific heat is given by $c = Q/m(T_f - T_i)$, where Q is the heat added, m is the mass of the sample, T_i is the initial temperature, and T_f is the final temperature. Thus, recalling that a change in Celsius degrees is equal to the corresponding change on the Kelvin scale,

$$c = \frac{314\,\text{J}}{(30.0 \times 10^{-3}\,\text{kg})(45.0^\circ\text{C} - 25.0^\circ\text{C})} = 523 \text{ J/kg}\cdot\text{K} .$$

(b) The molar specific heat is given by

$$c_m = \frac{Q}{N(T_f - T_i)} = \frac{314\,\text{J}}{(0.600\,\text{mol})(45.0^\circ\text{C} - 25.0^\circ\text{C})} = 26.2 \text{ J/mol}\cdot\text{K} .$$

(c) If N is the number of moles of the substance and M is the mass per mole, then $m = NM$, so

$$N = \frac{m}{M} = \frac{30.0 \times 10^{-3}\,\text{kg}}{50 \times 10^{-3}\,\text{kg/mol}} = 0.600 \text{ mol} .$$

28. The amount of water m which is frozen is

$$m = \frac{Q}{L_F} = \frac{50.2\,\text{kJ}}{333\,\text{kJ/kg}} = 0.151\,\text{kg} = 151\,\text{g} .$$

Therefore the amount of water which remains unfrozen is $260\,\text{g} - 151\,\text{g} = 109\,\text{g}$.

29. The melting point of silver is 1235 K, so the temperature of the silver must first be raised from 15.0°C (= 288 K) to 1235 K. This requires heat

$$Q = cm(T_f - T_i) = (236\,\text{J/kg}\cdot\text{K})(0.130\,\text{kg})(1235^\circ\text{C} - 288^\circ\text{C}) = 2.91 \times 10^4\,\text{J} .$$

Now the silver at its melting point must be melted. If L_F is the heat of fusion for silver this requires

$$Q = mL_F = (0.130\,\text{kg})(105 \times 10^3\,\text{J/kg}) = 1.36 \times 10^4\,\text{J} .$$

The total heat required is $2.91 \times 10^4\,\text{J} + 1.36 \times 10^4\,\text{J} = 4.27 \times 10^4\,\text{J}$.

30. Recalling that a Watt is a Joule-per-second, the heat Q which is added to the room in 1 h is

$$Q = 4(100\,\text{W})(0.90)(1.00\,\text{h})\left(\frac{3600\,\text{s}}{1.00\,\text{h}}\right) = 1.30 \times 10^6 \text{ J} .$$

31. The textbook notes that a nutritionist's "Calorie" is equivalent to 1000 cal. The athlete's rate of dissipating energy is

$$P = 4000\,\text{Cal/day} = \frac{(4000 \times 10^3\,\text{cal})(4.18\,\text{J/cal})}{(1\,\text{day})(86400\,\text{s/day})} = 194 \text{ W} ,$$

which is 1.9 times as much as the power of a 100 W light bulb.

32. The work the man has to do to climb to the top of Mt. Everest is given by $W = mgy = (73)(9.8)(8840) = 6.3 \times 10^6$ J. Thus, the amount of butter needed is

$$m = \frac{(6.3 \times 10^6\,\text{J})\left(\frac{1.00\,\text{cal}}{4.186\,\text{J}}\right)}{6000\,\text{cal/g}} \approx 250 \text{ g} .$$

33. (a) The heat generated is the power output of the drill multiplied by the time: $Q = Pt$. We use $1\,\text{hp} = 2545\,\text{Btu/h}$ to convert the given value of the power to Btu/h and $1\,\text{min} = (1/60)\,\text{h}$ to convert the given value of the time to hours. Then,

$$Q = \frac{(0.400\,\text{hp})(2545\,\text{Btu/h})(2.00\,\text{min})}{60\,\text{min/h}} = 33.9 \text{ Btu} .$$

(b) We use $0.75Q = cm\,\Delta T$ to compute the rise in temperature. Here c is the specific heat of copper and m is the mass of the copper block. Table 19-3 gives $c = 386\,\text{J/kg}\cdot\text{K}$. We use $1\,\text{J} = 9.481 \times 10^{-4}\,\text{Btu}$ and $1\,\text{kg} = 6.852 \times 10^{-2}\,\text{slug}$ (see Appendix D) to show that

$$c = \frac{(386\,\text{J/kg}\cdot\text{K})(9.481 \times 10^{-4}\,\text{Btu/J})}{6.852 \times 10^{-2}\,\text{slug/kg}} = 5.341 \text{ Btu/slug}\cdot\text{K} .$$

The mass of the block is its weight W divided by the gravitational acceleration (which is 32 ft/s^2 in customary units, which uses "slugs" for mass):

$$m = \frac{W}{g} = \frac{1.60\,\text{lb}}{32\,\text{ft/s}^2} = 0.0500 \text{ slug} .$$

Thus,

$$\Delta T = \frac{0.750Q}{cm} = \frac{(0.750)(33.9\,\text{Btu})}{(5.341\,\text{Btu/slug}\cdot\text{K})(0.0500\,\text{slug})} = 95.3\,\text{K} = 95.3\,\text{C}^\circ .$$

This is equivalent to $(9/5)(95.3) = 172\,\text{F}^\circ$.

34. (a) The water (of mass m) releases energy in two steps, first by lowering its temperature from 20°C to 0°C, and then by freezing into ice. Thus the total energy transferred from the water to the surroundings is

$$Q = c_w m\Delta T + L_F m = (4190\,\text{J/kg}\cdot\text{K})(125\,\text{kg})(20^\circ\text{C}) + (333\,\text{kJ/kg})(125\,\text{kg}) = 5.2 \times 10^7 \text{ J} .$$

(b) Before all the water freezes, the lowest temperature possible is 0°C, below which the water must have already turned into ice.

35. The mass $m = 0.100\,\text{kg}$ of water, with specific heat $c = 4190\,\text{J/kg}\cdot\text{K}$, is raised from an initial temperature $T_i = 23^\circ\text{C}$ to its boiling point $T_f = 100^\circ\text{C}$. The heat input is given by $Q = cm(T_f - T_i)$. This must be the power output of the heater P multiplied by the time t; $Q = Pt$. Thus,

$$t = \frac{Q}{P} = \frac{cm(T_f - T_i)}{P} = \frac{(4190\,\text{J/kg}\cdot\text{K})(0.100\,\text{kg})(100^\circ\text{C} - 23^\circ\text{C})}{200\,\text{J/s}} = 160 \text{ s} .$$

36. (a) Using Eq. 19-17, the heat transferred to the water is

$$\begin{aligned} Q_w &= c_w m_w \Delta T + L_V m_s \\ &= (1\,\text{cal/g}\cdot\text{C}^\circ)(220\,\text{g})(100^\circ\text{C} - 20.0^\circ\text{C}) + (539\,\text{cal/g})(5.00\,\text{g}) \\ &= 20.3\,\text{kcal} . \end{aligned}$$

(b) The heat transferred to the bowl is

$$Q_b = c_b m_b \Delta T = (0.0923\,\text{cal/g}\cdot\text{C}^\circ)(150\,\text{g})(100^\circ\text{C} - 20.0^\circ\text{C}) = 1.11 \text{ kcal} .$$

(c) If the original temperature of the cylinder be T_i, then $Q_w + Q_b = c_c m_c(T_i - T_f)$, which leads to

$$T_i = \frac{Q_w + Q_b}{c_c m_c} + T_f = \frac{20.3\,\text{kcal} + 1.11\,\text{kcal}}{(0.0923\,\text{cal/g}\cdot\text{C}^\circ)(300\,\text{g})} + 100^\circ\text{C} = 873^\circ\text{C} .$$

37. Mass m of water must be raised from an initial temperature $T_i = 59^\circ\text{F} = 15^\circ\text{C}$ to a final temperature $T_f = 100^\circ\text{C}$. If c is the specific heat of water then the energy required is $Q = cm(T_f - T_i)$. Each shake supplies energy mgh, where h is the distance moved during the downward stroke of the shake. If N is the total number of shakes then $Nmgh = Q$. If t is the time taken to raise the water to its boiling point then $(N/t)mgh = Q/t$. We note that N/t is the rate R of shaking (30 shakes/min). This leads to $Rmgh = Q/t$. The distance h is 1.0 ft = 0.3048 m. Consequently,

$$\begin{aligned} t &= \frac{Q}{Rmgh} = \frac{cm(T_f - T_i)}{Rmgh} = \frac{c(T_f - T_i)}{Rgh} \\ &= \frac{(4190\,\text{J/kg}\cdot\text{K})(100^\circ\text{C} - 15^\circ\text{C})}{(30\,\text{shakes/min})(9.8\,\text{m/s}^2)(0.3048\,\text{m})} \\ &= 3.97 \times 10^3\,\text{min} = 2.8\text{ days} . \end{aligned}$$

38. We note from Eq. 19-12 that 1 Btu = 252 cal. The heat relates to the power, and to the temperature change, through $Q = Pt = cm\Delta T$. Therefore, the time t required is

$$\begin{aligned} t &= \frac{cm\Delta T}{P} = \frac{(1000\,\text{cal/kg}\cdot\text{C}^\circ)(40\,\text{gal})(1000\,\text{kg}/264\,\text{gal})(100^\circ\text{F} - 70^\circ\text{F})(5\text{C}^\circ/9\text{F}^\circ)}{(2.0 \times 10^5\,\text{Btu/h})(252.0\,\text{cal/Btu})(1\,\text{h}/60\,\text{min})} \\ &= 3.0\text{ min} . \end{aligned}$$

The metric version proceeds similarly:

$$\begin{aligned} t &= \frac{c\rho V\Delta T}{P} = \frac{(4190\,\text{J/kg}\cdot\text{C}^\circ)(1000\,\text{kg/m}^3)(150\,\text{L})(1\,\text{m}^3/1000\,\text{L})(38^\circ\text{C} - 21^\circ\text{C})}{(59000\,\text{J/s})(60\,\text{s}/1\,\text{min})} \\ &= 3.0\text{ min} . \end{aligned}$$

39. To accomplish the phase change at 78°C, $Q = L_V\, m = (879)(0.510) = 448.29$ kJ must be removed. To cool the liquid to −114°C, $Q = cm|\Delta T| = (2.43)(0.510)(192) = 237.95$ kJ, must be removed. Finally, to accomplish the phase change at −114°C, $Q = L_F\, m = (109)(0.510) = 55.59$ kJ must be removed. The grand total of heat removed is therefore $448.29 + 237.95 + 55.59 = 742$ kJ.

40. The deceleration a of the car is given by $v_f^2 - v_i^2 = -v_i^2 = 2ad$, or

$$a = -\frac{[(90\,\text{km/h})(10^3\,\text{m/km})(1\,\text{h}/3600\,\text{s})]^2}{2(80\,\text{m})} = -3.9\text{ m/s}^2 .$$

The time t it takes for the car to stop is then

$$t = \frac{v_f - v_i}{a} = -\frac{(90\,\text{km/h})(10^3\,\text{m/km})(1\,\text{h}/3600\,\text{s})}{-3.9\,\text{m/s}^2} = 6.4\text{ s} .$$

The average rate at which thermal energy is produced is then

$$P = \frac{\frac{1}{2}mv_i^2}{t} = \frac{(1500\,\text{kg})[(90\,\text{km/h})(1000\,\text{m/km})(1\,\text{h}/3600\,\text{s})]^2}{2(6.4\,\text{s})} = 7.3 \times 10^4\text{ W} .$$

41. The heat needed is found by integrating the heat capacity:

$$\begin{aligned} Q &= \int_{T_i}^{T_f} cm\,dT = m\int_{T_i}^{T_f} c\,dT \\ &= (2.09)\int_{5.0^\circ\mathrm{C}}^{15.0^\circ\mathrm{C}} (0.20 + 0.14T + 0.023T^2)\,dT \\ &= (2.0)(0.20T + 0.070T^2 + 0.00767T^3)\Big|_{5.0}^{15.0}\ \text{(cal)} \\ &= 82\ \text{cal}\ . \end{aligned}$$

42. The power consumed by the system is

$$\begin{aligned} P &= \left(\frac{1}{20\%}\right)\frac{cm\Delta T}{t} \\ &= \left(\frac{1}{20\%}\right)\frac{(4.18\,\mathrm{J/g\cdot^\circ C})(200\times 10^3\,\mathrm{cm^3})(1\,\mathrm{g/cm^3})(40^\circ\mathrm{C} - 20^\circ\mathrm{C})}{(1.0\,\mathrm{h})(3600\,\mathrm{s/h})} \\ &= 2.3\times 10^4\ \mathrm{W}\ . \end{aligned}$$

The area needed is then

$$A = \frac{2.3\times 10^4\,\mathrm{W}}{700\,\mathrm{W/m^2}} = 33\ \mathrm{m^2}\ .$$

43. Let the mass of the steam be m_s and that of the ice be m_i. Then $L_F m_c + c_w m_c(T_f - 0.0^\circ\mathrm{C}) = L_s m_s + c_w m_s(100^\circ\mathrm{C} - T_f)$, where $T_f = 50^\circ\mathrm{C}$ is the final temperature. We solve for m_s:

$$\begin{aligned} m_s &= \frac{L_F m_c + c_w m_c(T_f - 0.0^\circ\mathrm{C})}{L_s + c_w(100^\circ\mathrm{C} - T_f)} \\ &= \frac{(79.7\,\mathrm{cal/g})(150\,\mathrm{g}) + (1\,\mathrm{cal/g\cdot^\circ C})(150\,\mathrm{g})(50^\circ\mathrm{C} - 0.0^\circ\mathrm{C})}{539\,\mathrm{cal/g} + (1\,\mathrm{cal/g\cdot C^\circ})(100^\circ\mathrm{C} - 50^\circ\mathrm{C})} \\ &= 33\ \mathrm{g}\ . \end{aligned}$$

44. We compute with Celsius temperature, which poses no difficulty for the J/kg·K values of specific heat capacity (see Table 19-3) since a change of Kelvin temperature is numerically equal to the corresponding change on the Celsius scale. If the equilibrium temperature is T_f then the energy absorbed as heat by the ice is $Q_I = L_F m_I + c_w m_I(T_f - 0^\circ\mathrm{C})$, while the energy transferred as heat from the water is $Q_w = c_w m_w(T_f - T_i)$. The system is insulated, so $Q_w + Q_I = 0$, and we solve for T_f:

$$T_f = \frac{c_w m_w T_i - L_F m_I}{(m_I + m_c)\,c_w}\ .$$

(a) Now $T_i = 90^\circ\mathrm{C}$ so

$$T_f = \frac{(4190\,\mathrm{J/kg\cdot C^\circ})(0.500\,\mathrm{kg})(90^\circ\mathrm{C}) - \left(333\times 10^3\,\mathrm{J/kg}\right)(0.500\,\mathrm{kg})}{(0.500\,\mathrm{kg} + 0.500\,\mathrm{kg})(4190\,\mathrm{J/kg\cdot C^\circ})} = 5.3^\circ\mathrm{C}\ .$$

(b) If we were to use the formula above with $T_i = 70^\circ\mathrm{C}$, we would get $T_f < 0$, which is impossible. In fact, not all the ice has melted in this case (and the equilibrium temperature is $0^\circ\mathrm{C}$) The amount of ice that melts is given by

$$m_I' = \frac{c_w m_w\,(T_i - 0^\circ\mathrm{C})}{L_F} = \frac{(4190\,\mathrm{J/kg\cdot C^\circ})\,(0.500\,\mathrm{kg})\,(70\,\mathrm{C^\circ})}{333\times 10^3\,\mathrm{J/kg}} = 0.440\ \mathrm{kg}\ .$$

Therefore, there amount of (solid) ice remaining is $\Delta m_I = m_I - m_I' = 500\,\mathrm{g} - 440\,\mathrm{g} = 60\,\mathrm{g}$, and (as mentioned) we have $T_f = 0^\circ\mathrm{C}$ (because the system is an ice-water mixture in thermal equilibrium).

45. (a) We work in Celsius temperature, which poses no difficulty for the J/kg·K values of specific heat capacity (see Table 19-3) since a change of Kelvin temperature is numerically equal to the corresponding change on the Celsius scale. There are three possibilities:

- None of the ice melts and the water-ice system reaches thermal equilibrium at a temperature that is at or below the melting point of ice.
- The system reaches thermal equilibrium at the melting point of ice, with some of the ice melted.
- All of the ice melts and the system reaches thermal equilibrium at a temperature at or above the melting point of ice.

First, we suppose that no ice melts. The temperature of the water decreases from $T_{Wi} = 25°\text{C}$ to some final temperature T_f and the temperature of the ice increases from $T_{Ii} = -15°\text{C}$ to T_f. If m_W is the mass of the water and c_W is its specific heat then the water rejects heat

$$|Q| = c_W m_W (T_{Wi} - T_f) \ .$$

If m_I is the mass of the ice and c_I is its specific heat then the ice absorbs heat

$$Q = c_I m_I (T_f - T_{Ii}) \ .$$

Since no energy is lost to the environment, these two heats (in absolute value) must be the same. Consequently,

$$c_W m_W (T_{Wi} - T_f) = c_I m_I (T_f - T_{Ii}) \ .$$

The solution for the equilibrium temperature is

$$\begin{aligned} T_f &= \frac{c_W m_W T_{Wi} + c_I m_I T_{Ii}}{c_W m_W + c_I m_I} \\ &= \frac{(4190\,\text{J/kg·K})(0.200\,\text{kg})(25°\text{C}) + (2220\,\text{J/kg·K})(0.100\,\text{kg})(-15°\text{C})}{(4190\,\text{J/kg·K})(0.200\,\text{kg}) + (2220\,\text{J/kg·K})(0.100\,\text{kg})} \\ &= 16.6°\text{C} \ . \end{aligned}$$

This is above the melting point of ice, which invalidates our assumption that no ice has melted. That is, the calculation just completed does not take into account the melting of the ice and is in error. Consequently, we start with a new assumption: that the water and ice reach thermal equilibrium at $T_f = 0°\text{C}$, with mass m ($< m_I$) of the ice melted. The magnitude of the heat rejected by the water is

$$|Q| = c_W m_W T_{Wi} \ ,$$

and the heat absorbed by the ice is

$$Q = c_I m_I (0 - T_{Ii}) + m L_F \ ,$$

where L_F is the heat of fusion for water. The first term is the energy required to warm all the ice from its initial temperature to 0°C and the second term is the energy required to melt mass m of the ice. The two heats are equal, so

$$c_W m_W T_{Wi} = -c_I m_I T_{Ii} + m L_F \ .$$

This equation can be solved for the mass m of ice melted:

$$\begin{aligned} m &= \frac{c_W m_W T_{Wi} + c_I m_I T_{Ii}}{L_F} \\ &= \frac{(4190\,\text{J/kg·K})(0.200\,\text{kg})(25°\text{C}) + (2220\,\text{J/kg·K})(0.100\,\text{kg})(-15°\text{C})}{333 \times 10^3\,\text{J/kg}} \\ &= 5.3 \times 10^{-2}\,\text{kg} = 53\ \text{g} \ . \end{aligned}$$

Since the total mass of ice present initially was 100 g, there *is* enough ice to bring the water temperature down to 0°C. This is then the solution: the ice and water reach thermal equilibrium at a temperature of 0°C with 53 g of ice melted.

(b) Now there is less than 53 g of ice present initially. All the ice melts and the final temperature is above the melting point of ice. The heat rejected by the water is

$$|Q| = c_W m_W (T_{Wi} - T_f)$$

and the heat absorbed by the ice and the water it becomes when it melts is

$$Q = c_I m_I (0 - T_{Ii}) + c_W m_I (T_f - 0) + m_I L_F \ .$$

The first term is the energy required to raise the temperature of the ice to 0°C, the second term is the energy required to raise the temperature of the melted ice from 0°C to T_f, and the third term is the energy required to melt all the ice. Since the two heats are equal,

$$c_W m_W (T_{Wi} - T_f) = c_I m_I (-T_{Ii}) + c_W m_I T_f + m_I L_F \ .$$

The solution for T_f is

$$T_f = \frac{c_W m_W T_{Wi} + c_I m_I T_{Ii} - m_I L_F}{c_W (m_W + m_I)} \ .$$

Inserting the given values, we obtain $T_f = 2.5$°C.

46. We denote the ice with subscript I and the coffee with c, respectively. Let the final temperature be T_f. The heat absorbed by the ice is $Q_I = \lambda_F m_I + m_I c_w \left(T_f - 0°\mathrm{C}\right)$, and the heat given away by the coffee is $|Q_c| = m_w c_w \left(T_I - T_f\right)$. Setting $Q_I = |Q_c|$, we solve for T_f:

$$\begin{aligned} T_f &= \frac{m_w c_w T_I - \lambda_F m_I}{(m_I + m_c) c_w} \\ &= \frac{(130\,\mathrm{g})\,(4190\,\mathrm{J/kg{\cdot}C°})\,(80.0°\mathrm{C}) - \left(333 \times 10^3\,\mathrm{J/g}\right)(12.0\,\mathrm{g})}{(12.0\,\mathrm{g} + 130\,\mathrm{g})\,(4190\,\mathrm{J/kg{\cdot}C°})} \\ &= 66.5°\mathrm{C} \ . \end{aligned}$$

Note that we work in Celsius temperature, which poses no difficulty for the J/kg·K values of specific heat capacity (see Table 19-3) since a change of Kelvin temperature is numerically equal to the corresponding change on the Celsius scale. Therefore, the temperature of the coffee will cool by $|\Delta T| = 80.0°\mathrm{C} - 66.5°\mathrm{C} = 13.5\mathrm{C}°$.

47. If the ring diameter at 0.000°C is D_{r0} then its diameter when the ring and sphere are in thermal equilibrium is

$$D_r = D_{r0}(1 + \alpha_c T_f) \, ,$$

where T_f is the final temperature and α_c is the coefficient of linear expansion for copper. Similarly, if the sphere diameter at T_i (= 100.0°C) is D_{s0} then its diameter at the final temperature is

$$D_s = D_{s0}[1 + \alpha_a (T_f - T_i)] \, ,$$

where α_a is the coefficient of linear expansion for aluminum. At equilibrium the two diameters are equal, so

$$D_{r0}(1 + \alpha_c T_f) = D_{s0}[1 + \alpha_a (T_f - T_i)] \ .$$

The solution for the final temperature is

$$\begin{aligned} T_f &= \frac{D_{r0} - D_{s0} + D_{s0}\alpha_a T_i}{D_{s0}\alpha_a - D_{r0}\alpha_c} \\ &= \frac{2.54000\,\mathrm{cm} - 2.54508\,\mathrm{cm} + (2.54508\,\mathrm{cm})\left(23 \times 10^{-6}/\mathrm{C°}\right)(100°\mathrm{C})}{(2.54508\,\mathrm{cm})\,(23 \times 10^{-6}/\mathrm{C°}) - (2.54000\,\mathrm{cm})\,(17 \times 10^{-6}/\mathrm{C°})} \\ &= 50.38°\mathrm{C} \ . \end{aligned}$$

The expansion coefficients are from Table 19-2 of the text. Since the initial temperature of the ring is 0°C, the heat it absorbs is

$$Q = c_c m_r T_f \ ,$$

where c_c is the specific heat of copper and m_r is the mass of the ring. The heat rejected up by the sphere is

$$|Q| = c_a m_s \left(T_i - T_f\right)$$

where c_a is the specific heat of aluminum and m_s is the mass of the sphere. Since these two heats are equal,

$$c_c m_r T_f = c_a m_s \left(T_i - T_f\right) \ ,$$

we use specific heat capacities from the textbook to obtain

$$m_s = \frac{c_c m_r T_f}{c_a \left(T_i - T_f\right)} = \frac{(386\,\mathrm{J/kg{\cdot}K})(0.0200\,\mathrm{kg})(50.38°\mathrm{C})}{(900\,\mathrm{J/kg{\cdot}K})(100°\mathrm{C} - 50.38°\mathrm{C})} = 8.71 \times 10^{-3}\ \mathrm{kg}\ .$$

48. (a) Since work is done *on* the system (perhaps to compress it) we write $W = -200\,\mathrm{J}$.

(b) Since heat leaves the system, we have $Q = -70.0\,\mathrm{cal} = -293\,\mathrm{J}$.

(c) The change in internal energy is $\Delta E_{\mathrm{int}} = Q - W = -293\,\mathrm{J} - (-200\,\mathrm{J}) = -93\,\mathrm{J}$.

49. One part of path A represents a constant pressure process. The volume changes from $1.0\,\mathrm{m}^3$ to $4.0\,\mathrm{m}^3$ while the pressure remains at 40 Pa. The work done is

$$W_A = p\,\Delta V = (40\,\mathrm{Pa})\left(4.0\,\mathrm{m}^3 - 1.0\,\mathrm{m}^3\right) = 120\ \mathrm{J}\ .$$

The other part of the path represents a constant volume process. No work is done during this process. The total work done over the entire path is 120 J. To find the work done over path B we need to know the pressure as a function of volume. Then, we can evaluate the integral $W = \int p\,dV$. According to the graph, the pressure is a linear function of the volume, so we may write $p = a + bV$, where a and b are constants. In order for the pressure to be 40 Pa when the volume is $1.0\,\mathrm{m}^3$ and 10 Pa when the volume is $4.00\,\mathrm{m}^3$ the values of the constants must be $a = 50\,\mathrm{Pa}$ and $b = -10\,\mathrm{Pa/m}^3$. Thus $p = 50\,\mathrm{Pa} - (10\,\mathrm{Pa/m}^3)V$ and

$$\begin{aligned} W_B &= \int_1^4 p\,dV = \int_1^4 (50 - 10V)\,dV = \left(50V - 5V^2\right)\Big|_1^4 \\ &= 200\,\mathrm{J} - 50\,\mathrm{J} - 80\,\mathrm{J} + 5\,\mathrm{J} = 75\ \mathrm{J}\ . \end{aligned}$$

One part of path C represents a constant pressure process in which the volume changes from $1.0\,\mathrm{m}^3$ to $4.0\,\mathrm{m}^3$ while p remains at 10 Pa. The work done is

$$W_C = p\,\Delta V = (10\,\mathrm{Pa})(4.0\,\mathrm{m}^3 - 1.0\,\mathrm{m}^3) = 30\ \mathrm{J}\ .$$

The other part of the process is at constant volume and no work is done. The total work is 30 J. We note that the work is different for different paths.

50. (a)
- During process $A \to B$, the system is expanding, doing work on its environment, so $W > 0$, and since $\Delta E_{\mathrm{int}} > 0$ is given then $Q = W + \Delta E_{\mathrm{int}}$ must also be positive.
- During process $B \to C$, the system is neither expanding nor contracting, so $W = 0$; therefore, the sign of ΔE_{int} must be the same (by the first law of thermodynamics) as that of Q (which is given as positive).
- During process $C \to A$, the system is contracting (the environment is doing work on the system), which implies $W < 0$. Also, $\Delta E_{\mathrm{int}} < 0$ because $\sum \Delta E_{\mathrm{int}} = 0$ (for the whole cycle) and the other values of ΔE_{int} (for the other processes) were positive. Therefore, $Q = W + \Delta E_{\mathrm{int}}$ must also be negative.

(b) The area of a triangle is $\frac{1}{2}$(base)(height). Applying this to the figure, we find $|W_{\text{net}}| = \frac{1}{2}(2.0\,\text{m}^3)(20\,\text{Pa}) = 20$ J. Since process $C \to A$ involves larger negative work (it occurs at higher average pressure) than the positive work done during process $A \to B$, then the net work done during the cycle must be negative. The answer is therefore $W_{\text{net}} = -20$ J.

51. Over a cycle, the internal energy is the same at the beginning and end, so the heat Q absorbed equals the work done: $Q = W$. Over the portion of the cycle from A to B the pressure p is a linear function of the volume V and we may write

$$p = \frac{10}{3}\,\text{Pa} + \left(\frac{20}{3}\,\text{Pa/m}^3\right) V\,,$$

where the coefficients were chosen so that $p = 10\,\text{Pa}$ when $V = 1.0\,\text{m}^3$ and $p = 30\,\text{Pa}$ when $V = 4.0\,\text{m}^3$. The work done by the gas during this portion of the cycle is

$$\begin{aligned} W_{AB} &= \int_1^4 p\,dV = \int_1^4 \left(\frac{10}{3} + \frac{20}{3}V\right) dV = \left(\frac{10}{3}V + \frac{10}{3}V^2\right)\Big|_1^4 \\ &= \frac{40}{3} + \frac{160}{3} - \frac{10}{3} - \frac{10}{3} = 60 \text{ J}\,. \end{aligned}$$

The BC portion of the cycle is at constant pressure and the work done by the gas is $W_{BC} = p\,\Delta V = (30\,\text{Pa})(1.0\,\text{m}^3 - 4.0\,\text{m}^3) = -90\,\text{J}$. The CA portion of the cycle is at constant volume, so no work is done. The total work done by the gas is $W = W_{AB} + W_{BC} + W_{CA} = 60\,\text{J} - 90\,\text{J} + 0 = -30\,\text{J}$ and the total heat absorbed is $Q = W = -30\,\text{J}$. This means the gas loses 30 J of energy in the form of heat.

52. Since the process is a complete cycle (beginning and ending in the same thermodynamic state) the change in the internal energy is zero and the heat absorbed by the gas is equal to the work done by the gas: $Q = W$. In terms of the contributions of the individual parts of the cycle $Q_{AB} + Q_{BC} + Q_{CA} = W$ and $Q_{CA} = W - Q_{AB} - Q_{BC} = +15.0\,\text{J} - 20.0\,\text{J} - 0 = -5.0\,\text{J}$. This means 5.0 J of energy leaves the gas in the form of heat.

53. (a) The change in internal energy ΔE_{int} is the same for path iaf and path ibf. According to the first law of thermodynamics, $\Delta E_{\text{int}} = Q - W$, where Q is the heat absorbed and W is the work done by the system. Along iaf $\Delta E_{\text{int}} = Q - W = 50\,\text{cal} - 20\,\text{cal} = 30\,\text{cal}$. Along ibf $W = Q - \Delta E_{\text{int}} = 36\,\text{cal} - 30\,\text{cal} = 6\,\text{cal}$.

(b) Since the curved path is traversed from f to i the change in internal energy is $-30\,\text{cal}$ and $Q = \Delta E_{\text{int}} + W = -30\,\text{cal} - 13\,\text{cal} = -43\,\text{cal}$.

(c) Let $\Delta E_{\text{int}} = E_{\text{int},\,f} - E_{\text{int},\,i}$. Then, $E_{\text{int},\,f} = \Delta E_{\text{int}} + E_{\text{int},\,i} = 30\,\text{cal} + 10\,\text{cal} = 40\,\text{cal}$.

(d) The work W_{bf} for the path bf is zero, so $Q_{bf} = E_{\text{int},\,f} - E_{\text{int},\,b} = 40\,\text{cal} - 22\,\text{cal} = 18\,\text{cal}$. For the path ibf $Q = 36\,\text{cal}$ so $Q_{ib} = Q - Q_{bf} = 36\,\text{cal} - 18\,\text{cal} = 18\,\text{cal}$.

54. We use $P_{\text{cond}} = kA(T_H - T_C)/L$. The temperature T_H at a depth of 35.0 km is

$$T_H = \frac{P_{\text{cond}}L}{kA} + T_C = \frac{(54.0 \times 10^{-3}\,\text{W/m}^2)(35.0 \times 10^3\,\text{m})}{2.50\,\text{W/m}\cdot\text{K}} + 10.0^\circ\text{C} = 766^\circ\text{C}\,.$$

55. We refer to the polyurethane foam with subscript p and silver with subscript s. We use Eq 19-32 to find $L = kR$.

(a) From Table 19-6 we find $k_p = 0.024\,\text{W/m}\cdot\text{K}$ so

$$\begin{aligned} L_p &= k_p R_p \\ &= (0.024\,\text{W/m}\cdot\text{K})(30\,\text{ft}^2\cdot\text{F}^\circ\cdot\text{h/Btu})(1\,\text{m}/3.281\,\text{ft})^2(5\text{C}^\circ/9\text{F}^\circ)(3600\,\text{s/h})(1\,\text{Btu}/1055\,\text{J}) \\ &= 0.13\text{ m}\,. \end{aligned}$$

(b) For silver $k_s = 428\,\mathrm{W/m{\cdot}K}$, so

$$L_s = k_s R_s = \left(\frac{k_s R_s}{k_p R_p}\right) L_p = \left[\frac{428(30)}{0.024(30)}\right](0.13\,\mathrm{m}) = 2.3\times 10^3\ \mathrm{m}\ .$$

56. (a) The rate of heat flow is

$$P_{\mathrm{cond}} = \frac{kA(T_H - T_C)}{L} = \frac{(0.040\,\mathrm{W/m{\cdot}K})(1.8\,\mathrm{m^2})(33^\circ\mathrm{C} - 1.0^\circ\mathrm{C})}{1.0\times 10^{-2}\,\mathrm{m}} = 2.3\times 10^2\ \mathrm{J/s}\ .$$

(b) The new rate of heat flow is

$$P'_{\mathrm{cond}} = \frac{k' P_{\mathrm{cond}}}{k} = \frac{(0.60\,\mathrm{W/m{\cdot}K})(230\,\mathrm{J/s})}{0.040\,\mathrm{W/m{\cdot}K}} = 3.5\times 10^3\ \mathrm{J/s}\ ,$$

which is about 15 times as fast as the original heat flow.

57. The rate of heat flow is given by

$$P_{\mathrm{cond}} = kA\,\frac{T_H - T_C}{L}\ ,$$

where k is the thermal conductivity of copper ($401\,\mathrm{W/m{\cdot}K}$), A is the cross-sectional area (in a plane perpendicular to the flow), L is the distance along the direction of flow between the points where the temperature is T_H and T_C. Thus,

$$P_{\mathrm{cond}} = \frac{(401\,\mathrm{W/m{\cdot}K})(90.0\times 10^{-4}\,\mathrm{m^2})(125^\circ\mathrm{C} - 10.0^\circ\mathrm{C})}{0.250\,\mathrm{m}} = 1.66\times 10^3\ \mathrm{J/s}\ .$$

The thermal conductivity is found in Table 19-6 of the text. Recall that a change in Kelvin temperature is numerically equivalent to a change on the Celsius scale.

58. (a) We estimate the surface area of the average human body to be about $2\,\mathrm{m^2}$ and the skin temperature to be about 300 K (somewhat less than the internal temperature of 310 K). Then from Eq. 19-37

$$P_r = \sigma\varepsilon A T^4 \approx \left(5.67\times 10^{-8}\,\mathrm{W/m^2{\cdot}K^4}\right)(0.9)\left(2.0\,\mathrm{m^2}\right)(300\,\mathrm{K})^4 = 8\times 10^2\ \mathrm{W}\ .$$

(b) The energy lost is given by

$$\Delta E = P_r \Delta t = (8\times 10^2\,\mathrm{W})(30\,\mathrm{s}) = 2\times 10^4\ \mathrm{J}\ .$$

59. (a) Recalling that a change in Kelvin temperature is numerically equivalent to a change on the Celsius scale, we find that the rate of heat conduction is

$$P_{\mathrm{cond}} = \frac{kA(T_H - T_C)}{L} = \frac{(401\,\mathrm{W/m{\cdot}K})(4.8\times 10^{-4}\,\mathrm{m^2})(100\,\mathrm{C^\circ})}{1.2\,\mathrm{m}} = 16\ \mathrm{J/s}\ .$$

(b) Using Table 19-4, the rate at which ice melts is

$$\left|\frac{dm}{dt}\right| = \frac{P_{\mathrm{cond}}}{L_F} = \frac{16\,\mathrm{J/s}}{333\,\mathrm{J/g}} = 0.048\ \mathrm{g/s}\ .$$

60. With arrangement (a), the rate of the heat flow is

$$\begin{aligned} P_{\mathrm{cond}\,a} &= P_{\mathrm{cond}\,1} + P_{\mathrm{cond}\,2} = \frac{Ak_1}{2L}(T_H - T_C) + \frac{Ak_2}{2L}(T_H - T_C) \\ &= \frac{A}{2L}k_a(T_H - T_C) \end{aligned}$$

where $k_a = 4K_1 + k_2$. With arrangement (b), we use Eq. 19-36 to find the rate of heat flow:

$$P_{\text{cond}\,b} = \frac{2A\,(T_H - T_C)}{(L/k_1) + (L/k_2)} = \frac{A}{2L} k_b\,(T_H - T_C)$$

where $k_b = fk_1k_2/(k_1 + k_2)$. Since $k_1 \neq k_2$, we see that $(k_1 - k_2)^2 = (k_1 + k_2)^2 - 4k_1k_2 > 0$, or

$$\frac{k_b}{k_a} = \frac{4k_1 + k_2}{(k_1 + k_2)^2} < 0 \;.$$

Therefore, $P_{\text{cond}\,b} < P_{\text{cond}\,a}$. That is, arrangement ($b$) would give the lower heat flow.

61. We use $P_{\text{cond}} = kA\Delta T/L \propto A/L$. Comparing cases ($a$) and ($b$) in Figure 19-40, we have

$$P_{\text{cond}\,b} = \left(\frac{A_bL_a}{A_aL_b}\right) P_{\text{cond}\,a} = 4P_{\text{cond}\,a} \quad .$$

Consequently, it would take $2.0\,\text{min}/4 = 0.5\,\text{min}$ for the same amount of heat to be conducted through the rods welded as shown in Fig. 19-42(b).

62. We use Eqs. 19-38 through 19-40. Note that the surface area of the sphere is given by $A = 4\pi r^2$, where $r = 0.500\,\text{m}$ is the radius.

(a) The temperature of the sphere is $T = 273.15 + 27.00 = 300.15\,\text{K}$. Thus

$$\begin{aligned} P_r &= \sigma\varepsilon AT^4 \\ &= \left(5.67 \times 10^{-8}\,\text{W/m}^2{\cdot}\text{K}^4\right)(0.850)(4\pi)(0.500\,\text{m})^2(300.15\,\text{K})^4 \\ &= 1.23 \times 10^3 \text{ W} \;. \end{aligned}$$

(b) Now, $T_{\text{env}} = 273.15 + 77.00 = 350.15\,\text{K}$ so

$$\begin{aligned} P_a &= \sigma\varepsilon AT_{\text{env}}^4 \\ &= \left(5.67 \times 10^{-8}\,\text{W/m}^2{\cdot}\text{K}^4\right)(0.850)(4\pi)(0.500\,\text{m})^2(350.15\,\text{K})^4 \\ &= 2.28 \times 10^3 \text{ W} \;. \end{aligned}$$

(c) From Eq. 19-40, we have

$$P_n = P_a - P_r = 2.28 \times 10^3\,\text{W} - 1.23 \times 10^3\,\text{W} = 1.05 \times 10^3 \text{ W} \;.$$

63. (a) We use

$$P_{\text{cond}} = kA\,\frac{T_H - T_C}{L}$$

with the conductivity of glass given in Table 19-6 as $1.0\,\text{W/m}{\cdot}\text{K}$. We choose to use the Celsius scale for the temperature: a temperature difference of

$$T_H - T_C = 72°\text{F} - (-20°\text{F}) = 92\,\text{F}°$$

is equivalent to $\frac{5}{9}(92) = 51.1\,\text{C}°$. This, in turn, is equal to 51.1 K since a change in Kelvin temperature is entirely equivalent to a Celsius change. Thus,

$$\frac{P_{\text{cond}}}{A} = k\,\frac{T_H - T_C}{L} = (1.0\,\text{W/m}{\cdot}\text{K})\left(\frac{51.1\,\text{C}°}{3.0 \times 10^{-3}\,\text{m}}\right) = 1.7 \times 10^4 \text{ W/m}^2 \;.$$

(b) The energy now passes in succession through 3 layers, one of air and two of glass. The heat transfer rate P is the same in each layer and is given by

$$P_{\text{cond}} = \frac{A\,(T_H - T_C)}{\sum L/k}$$

where the sum in the denominator is over the layers. If L_g is the thickness of a glass layer, L_a is the thickness of the air layer, k_g is the thermal conductivity of glass, and k_a is the thermal conductivity of air, then the denominator is

$$\sum \frac{L}{k} = \frac{2L_g}{k_g} + \frac{L_a}{k_a} = \frac{2L_g k_a + L_a k_g}{k_a k_g} \; .$$

Therefore, the heat conducted per unit area occurs at the following rate:

$$\begin{aligned} \frac{P_{\text{cond}}}{A} &= \frac{(T_H - T_C)k_a k_g}{2L_g k_a + L_a k_g} \\ &= \frac{(51.1\,\text{C}^\circ)\,(0.026\,\text{W/m}\cdot\text{K})(1.0\,\text{W/m}\cdot\text{K})}{2(3.0\times10^{-3}\,\text{m})(0.026\,\text{W/m}\cdot\text{K}) + (0.075\,\text{m})(1.0\,\text{W/m}\cdot\text{K})} \\ &= 18\ \text{W/m}^2 \; . \end{aligned}$$

64. We divide both sides of Eq. 19-32 by area A, which gives us the (uniform) rate of heat conduction per unit area:

$$\frac{P_{\text{cond}}}{A} = k_1\,\frac{T_H - T_1}{L_1} = k_4\,\frac{T - T_C}{L_4}$$

where $T_H = 30°\text{C}$, $T_1 = 25°\text{C}$ and $T_C = -10°\text{C}$. We solve for the unknown T.

$$T = T_C + \frac{k_1\,L_4}{k_4\,L_1}\,(T_H - T_1) = -4.2°\text{C} \; .$$

65. Let h be the thickness of the slab and A be its area. Then, the rate of heat flow through the slab is

$$P_{\text{cond}} = \frac{kA\,(T_H - T_C)}{h}$$

where k is the thermal conductivity of ice, T_H is the temperature of the water (0°C), and T_C is the temperature of the air above the ice (−10°C). The heat leaving the water freezes it, the heat required to freeze mass m of water being $Q = L_F m$, where L_F is the heat of fusion for water. Differentiate with respect to time and recognize that $dQ/dt = P_{\text{cond}}$ to obtain

$$P_{\text{cond}} = L_F\,\frac{dm}{dt} \; .$$

Now, the mass of the ice is given by $m = \rho A h$, where ρ is the density of ice and h is the thickness of the ice slab, so $dm/dt = \rho A(dh/dt)$ and

$$P_{\text{cond}} = L_F \rho A\,\frac{dh}{dt} \; .$$

We equate the two expressions for P_{cond} and solve for $dh/\text{d}t$:

$$\frac{dh}{dt} = \frac{k(T_H - T_C)}{L_F \rho h} \; .$$

Since $1\,\text{cal} = 4.186\,\text{J}$ and $1\,\text{cm} = 1\times10^{-2}\,\text{m}$, the thermal conductivity of ice has the SI value $k = (0.0040\,\text{cal/s}\cdot\text{cm}\cdot\text{K})(4.186\,\text{J/cal})/(1\times10^{-2}\,\text{m/cm}) = 1.674\,\text{W/m}\cdot\text{K}$. The density of ice is $\rho = 0.92\,\text{g/cm}^3 = 0.92\times10^3\,\text{kg/m}^3$. Thus,

$$\frac{dh}{dt} = \frac{(1.674\,\text{W/m}\cdot\text{K})(0°\text{C} + 10°\text{C})}{(333\times10^3\,\text{J/kg})(0.92\times10^3\,\text{kg/m}^3)(0.050\,\text{m})} = 1.1\times10^{-6}\,\text{m/s} = 0.40\ \text{cm/h} \; .$$

66. We assume (although this should be viewed as a "controversial" assumption) that the top surface of the ice is at $T_C = -5.0°\text{C}$. Less controversial are the assumptions that the bottom of the body of water is at $T_H = 4.0°\text{C}$ and the interface between the ice and the water is at $T_X = 0.0°\text{C}$. The primary mechanism for the heat transfer through the total distance $L = 1.4$ m is assumed to be conduction, and we use Eq. 19-34:

$$\begin{aligned} \frac{k_{\text{water}} A\,(T_H - T_X)}{L - L_{\text{ice}}} &= \frac{k_{\text{ice}} A\,(T_X - T_C)}{L_{\text{ice}}} \\ \frac{(0.12)A\,(4.0° - 0.0°)}{1.4 - L_{\text{ice}}} &= \frac{(0.40)A\,(0.0° + 5.0°)}{L_{\text{ice}}} \ . \end{aligned}$$

We cancel the area A and solve for thickness of the ice layer: $L_{\text{ice}} = 1.1$ m.

67. For a cylinder of height h, the surface area is $A_c = 2\pi r h$, and the area of a sphere is $A_o = 4\pi R^2$. The net radiative heat transfer is given by Eq. 19-40.

(a) We estimate the surface area A of the body as that of a cylinder of height 1.8 m and radius $r = 0.15$ m plus that of a sphere of radius $R = 0.10$ m. Thus, we have $A \approx A_c + A_o = 1.8\ \text{m}^2$. The emissivity $\varepsilon = 0.80$ is given in the problem, and the Stefan-Boltzmann constant is found in §19-11: $\sigma = 5.67 \times 10^{-8}\ \text{W/m}^2{\cdot}\text{K}^4$. The "environment" temperature is $T_{\text{env}} = 303$ K, and the skin temperature is $T = \frac{5}{9}(102 - 32) + 273 = 312$ K. Therefore,

$$P_{\text{net}} = \sigma\varepsilon A\left(T_{\text{env}}^4 - T^4\right) = -86\ \text{W} \ .$$

The corresponding sign convention is discussed in the textbook immediately after Eq. 19-40. We conclude that heat is being lost by the body at a rate of roughly 90 W.

(b) Half the body surface area is roughly $A = 1.8/2 = 0.9\ \text{m}^2$. Now, with $T_{\text{env}} = 248$ K, we find

$$|P_{\text{net}}| = \left|\sigma\varepsilon A\left(T_{\text{env}}^4 - T^4\right)\right| \approx 230\ \text{W} \ .$$

(c) Finally, with $T_{\text{env}} = 193$ K (and still with $A = 0.9\ \text{m}^2$) we obtain $|P_{\text{net}}| = 330$ W.

68. (a) The top surface area is that of a circle $A_o = \pi r^2$. Since the problem directs us to denote this as "a" then the radius is

$$r = \sqrt{\frac{a}{\pi}} \ .$$

The side surface of a cylinder of height h is $A_c = 2\pi r h$. Therefore, the total radiating surface area is

$$A = A_o + A_c = a + 2\pi\left(\sqrt{\frac{a}{\pi}}\right)h = a + 2h\sqrt{\pi a} \ .$$

Consequently, Eq. 19-38 leads to

$$P_i = \sigma\varepsilon A T^4 = \sigma\varepsilon T^4\left(a + 2h\sqrt{\pi a}\right) \ .$$

(b) Packing together N rigid cylinders as close as possible into a large cylinder-like arrangement can involve some subtle mathematics, which we will avoid by simply assuming that (perhaps due to the fact that these "cylinders" are certainly not rigid!) they somehow become a large-radius (R) cylinder of height h. With the top surface area being Na, the large radius is

$$R = \sqrt{\frac{Na}{\pi}} \ .$$

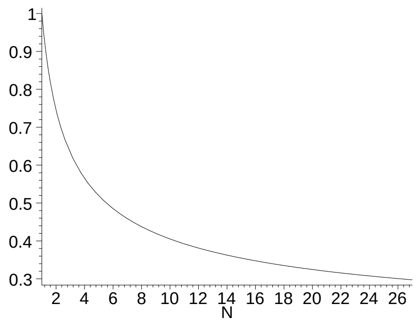
The side surface of the large-radius cylinder is $A_c = 2\pi R h$. Therefore, the total radiating surface area is

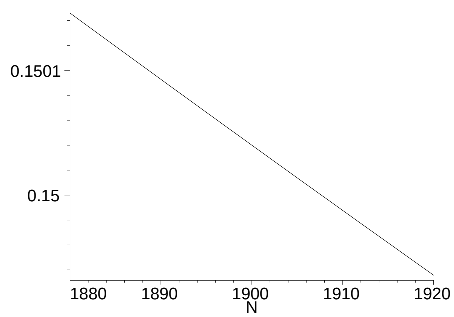
$$A = A_o + A_c = Na + 2\pi\left(\sqrt{\frac{Na}{\pi}}\right)h = Na + 2h\sqrt{N\pi a} \ .$$

Consequently, Eq. 19-38 leads to

$$P_h = \sigma\varepsilon A T^4 = \sigma\varepsilon T^4\left(Na + 2h\sqrt{N\pi a}\right) \ .$$

(c) The graphs below shows P_h/NP_i (vertical axis) versus the number of penguins N (horizontal axis).





(d) This can be estimated from the graph, in which case we $N \approx 5$, or algebraically solved for (in which case $N = 5.53$ which should be rounded to 5 or 6).

(e) From the graph, we estimate $N \approx 10$. If we algebraically solve for it, we get $N = 10.4$ which should be rounded to 10 or 11.

(f) From the graph, we estimate $N \approx 26$. If we algebraically solve for it, we get $N = 26.2$ which should be rounded to 26.

(g) A graph over the appropriate range is not shown above (but would be straightforward to generate). If we algebraically solve for it, we get $N = 154.8$ which should be rounded to 150 or 160.

(h) From the second graph above, we estimate N is slightly more than 1900. If we algebraically solve for it, we get $N = 1907.65$ which should be rounded to 1900.

(i) The $N \to \infty$ limit of the ratio

$$\frac{Na + 2h\sqrt{\pi N a}}{N(a + 2h\sqrt{\pi a})} \frac{a + 2h\sqrt{\pi a/N}}{a + 2h\sqrt{\pi a}} \ \to \ \frac{a}{a + 2h\sqrt{\pi a}}$$

is 0.13. We note that this value depends on the ratio of $h/\sqrt{a}$.

69. We denote $T_H = 100°\text{C}$, $T_C = 0°\text{C}$, the temperature of the copper-aluminum junction by T_1 and that of the aluminum-brass junction by T_2. Then,

$$P_{\text{cond}} = \frac{k_c A}{L}(T_H - T_1) = \frac{k_a A}{L}(T_1 - T_2) = \frac{k_b A}{L}(T_2 - T_c) \ .$$

We solve for T_1 and T_2 to obtain

$$\begin{aligned} T_1 &= T_H + \frac{T_C - T_H}{1 + k_c(k_a + k_b)/k_a k_b} \\ &= 100°\text{C} + \frac{0.00°\text{C} - 100°\text{C}}{1 + 401(235 + 109)/[(235)(109)]} = 84.3°\text{C} \end{aligned}$$

and

$$\begin{aligned} T_2 &= T_c + \frac{T_H - T_C}{1 + k_b(k_c + k_a)/k_c k_a} \\ &= 0.00°\text{C} + \frac{100°\text{C} - 0.00°\text{C}}{1 + 109(235 + 401)/[(235)(401)]} \\ &= 57.6°\text{C} \ . \end{aligned}$$

70. The heat conducted is

$$\begin{aligned} Q &= P_{\text{cond}}t = \frac{kAt\Delta T}{L} \\ &= \frac{(67\,\text{W/m}\cdot\text{K})(\pi/4)(1.7\,\text{m})^2(5.0\,\text{min})(60\,\text{s/min})(2.3\,\text{C}^\circ)}{5.2\times10^{-3}\,\text{m}} \\ &= 2.0\times10^7\ \text{J}\ . \end{aligned}$$

71. The problem asks for 0.5% of E, where $E = Pt$ with $t = 120$ s and P given by Eq. 19-38. Therefore, with $A = 4\pi r^2 = 5.0\times10^{-3}$ m^2, we obtain

$$(0.005)Pt = (0.005)\sigma\varepsilon AT^4t = 8.6\ \text{J}\ .$$

72. We denote the total mass M and the melted mass m. The problem tells us that Work$/M = p/\rho$, and that all the work is assumed to contribute to the phase change $Q = Lm$ where $L = 150\times10^3$ J/kg. Thus,

$$\frac{p}{\rho}M = Lm \implies m = \frac{5.5\times10^6}{1200}\,\frac{M}{150\times10^3}$$

which yields $m = 0.0306M$. Dividing this by 0.30M (the mass of the fats, which we are told is equal to 30% of the total mass), leads to a percentage $0.0306/0.30 = 10\%$.

73. The net work may be computed as a sum of works (for the individual processes involved) or as the "area" (with appropriate $\pm$ sign) inside the figure (representing the cycle). In this solution, we take the former approach (sum over the processes) and will need the following fact related to processes represented in pV diagrams:

$$\text{for straight line}\quad \text{Work} = \frac{p_i + p_f}{2}\,\Delta V$$

which is easily verified using the definition Eq. 19-25. The cycle represented by the "triangle" BC consists of three processes:

- "tilted" straight line from $(1.0\,\text{m}^3, 40\,\text{Pa})$ to $(4.0\,\text{m}^3, 10\,\text{Pa})$, with

$$\text{Work} = \frac{40\,\text{Pa} + 10\,\text{Pa}}{2}\left(4.0\,\text{m}^3 - 1.0\,\text{m}^3\right) = 75\ \text{J}$$

- horizontal line from $(4.0\,\text{m}^3, 10\,\text{Pa})$ to $(1.0\,\text{m}^3, 10\,\text{Pa})$, with

$$\text{Work} = (10\,\text{Pa})\left(1.0\,\text{m}^3 - 4.0\,\text{m}^3\right) = -30\ \text{J}$$

- vertical line from $(1.0\,\text{m}^3, 10\,\text{Pa})$ to $(1.0\,\text{m}^3, 40\,\text{Pa})$, with

$$\text{Work} = \frac{10\,\text{Pa} + 40\,\text{Pa}}{2}\left(1.0\,\text{m}^3 - 1.0\,\text{m}^3\right) = 0$$

Thus, the total work during the BC cycle is $75 - 30 = 45$ J. During the BA cycle, the "tilted" part is the same as before, and the main difference is that the horizontal portion is at higher pressure, with Work $= (40\,\text{Pa})(-3.0\,\text{m}^3) = -120$ J. Therefore, the total work during the BA cycle is $75 - 120 = -45$ J.

74. The work (the "area under the curve") for process 1 is $4p_iV_i$, so that $U_b - U_a = Q_1 - W_1 = 6p_iV_i$ by the First Law of Thermodynamics.

   (a) Path 2 involves more work than path 1 (note the triangle in the figure of area $\frac{1}{2}(4V_i)(p_i/2) = p_iV_i$). With $W_2 = 4p_iV_i + p_iV_i = 5p_iV_i$, we obtain

$$Q_2 = W_2 + U_b - U_a = 5p_iV_i + 6p_iV_i = 11p_iV_i\quad .$$

(b) Path 3 starts at a and ends at b so that $\Delta U = U_b - U_a = 6p_iV_i$.

75. We use $Q = -\lambda_F m_{ice} = W + \Delta E_{\text{int}}$. In this case $\Delta E_{\text{int}} = 0$. Since $\Delta T = 0$ for the idea gas, then the work done on the gas is

$$W' = -W = \lambda_F m_i = (333\,\text{J/g})(100\,\text{g}) = 33.3\text{ kJ} .$$

76. Consider the object of mass m_1 falling through a distance h. The loss of its mechanical energy is $\Delta E = m_1gh$. This amount of energy is then used to heat up the temperature of water of mass m_2: $\Delta E = m_1gh = Q = m_2c\Delta T$. Thus, the maximum possible rise in water temperature is

$$\begin{aligned} \Delta T &= \frac{m_1gh}{m_2c} \\ &= \frac{(6.00\,\text{kg})\left(9.8\,\text{m/s}^2\right)(50.0\,\text{m})}{(0.600\,\text{kg})\left(4190\,\text{J/kg}\cdot\text{C}^\circ\right)} \\ &= 1.17\text{ C}^\circ . \end{aligned}$$

77. The change in length of the rod is

$$\Delta L = L\alpha\Delta T = (20\,\text{cm})(11\times10^{-6}/\text{C}^\circ)(50^\circ\text{C} - 30^\circ\text{C}) = 4.4\times10^{-3}\text{ cm} .$$

78. The diameter of the brass disk in the dry ice is

$$\begin{aligned} D' &= D(1+\alpha\Delta T) \\ &= (80.00\,\text{mm})\left[1 + \left(19\times10^{-6}/\text{C}^\circ\right)(-57.00^\circ\text{C} - 43.00^\circ\text{C})\right] \\ &= 79.85\text{ mm} . \end{aligned}$$

79. The increase in the surface area of the brass cube (which has six faces), which had side length is L at 20°, is

$$\begin{aligned} \Delta A &= 6(L+\Delta L)^2 - 6L^2 \approx 12L\Delta L = 12\alpha_{\text{b}}L^2\Delta T \\ &= 12\left(19\times10^{-6}/\text{C}^\circ\right)(30\,\text{cm})^2(75^\circ\text{C} - 20^\circ\text{C}) \\ &= 11\text{ cm}^2 . \end{aligned}$$

80. No, the doctor is probably using the Kelvin scale, in which case your temperature is $310 - 273 = 37^\circ$C. This is equivalent to $\frac{9}{5}(37) + 32 = 98.6^\circ$F.

81. We use $T_C = T_K - 273 = (5/9)[T_F - 32]$. The results are:

(a) $T = 10000^\circ$F;

(b) $T = 37.0^\circ$C;

(c) $T = -57^\circ$C;

(d) $T = -297^\circ$F;

(e) $28^\circ\text{C} = 82^\circ\text{F}$ (for example).

82. The heat needed is

$$\begin{aligned} Q &= (10\%)mL_F \\ &= \left(\frac{1}{10}\right)(200,000\text{ metric tons})(1000\,\text{kg/metric ton})(333\,\text{kJ/kg}) \\ &= 6.7\times10^{12}\text{ J} . \end{aligned}$$

83. For isotropic materials, the coefficient of linear expansion α is related to that for volume expansion by $\alpha = \frac{1}{3}\beta$ (Eq. 19-11). The radius of Earth may be found in the Appendix. With these assumptions, the radius of the Earth should have increased by approximately

$$\begin{aligned} \Delta R_E &= R_E \alpha \Delta T \\ &= \left(6.4 \times 10^3\,\text{km}\right)\left(\frac{1}{3}\right)\left(3.0 \times 10^{-5}/\,\text{K}\right)(3000\,\text{K} - 300\,\text{K}) \\ &= 1.7 \times 10^3 \text{ km} . \end{aligned}$$

84. If the window is L_1 high and L_2 wide at the lower temperature and $L_1 + \Delta L_1$ high and $L_2 + \Delta L_2$ wide at the higher temperature then its area changes from $A_1 = L_1 L_2$ to

$$A_2 = (L_1 + \Delta L_1)(L_2 + \Delta L_2) \approx L_1 L_2 + L_1\,\Delta L_2 + L_2\,\Delta L_1$$

where the term $\Delta L_1\,\Delta L_2$ has been omitted because it is much smaller than the other terms, if the changes in the lengths are small. Consequently, the change in area is

$$\Delta A = A_2 - A_1 = L_1\,\Delta L_2 + L_2\,\Delta L_1 .$$

If ΔT is the change in temperature then $\Delta L_1 = \alpha L_1\,\Delta T$ and $\Delta L_2 = \alpha L_2\,\Delta T$, where α is the coefficient of linear expansion. Thus

$$\begin{aligned} \Delta A &= \alpha(L_1 L_2 + L_1 L_2)\,\Delta T = 2\alpha L_1 L_2\,\Delta T \\ &= 2\left(9 \times 10^{-6}/\text{C}^\circ\right)(30\,\text{cm})(20\,\text{cm})(30^\circ\text{C}) \\ &= 0.32 \text{ cm}^2 . \end{aligned}$$

85. (a) Recalling that a Watt is a Joule-per-second, and that a change in Celsius temperature is equivalent (numerically) to a change in Kelvin temperature, we convert the value of k to SI units, using Eq. 19-12.

$$\left(2.9 \times 10^{-3}\,\frac{\text{cal}}{\text{cm}\cdot\text{C}^\circ\cdot\text{s}}\right)\left(\frac{4.186\,\text{J}}{1\ \text{cal}}\right)\left(\frac{100\,\text{cm}}{1\ \text{m}}\right) = 1.2\ \frac{\text{W}}{\text{m}\cdot\text{K}} .$$

(b) Now, a change in Celsius is equivalent to five-ninths of a Fahrenheit change, so

$$\left(2.9 \times 10^{-3}\,\frac{\text{cal}}{\text{cm}\cdot\text{C}^\circ\cdot\text{s}}\right)\left(\frac{0.003969\,\text{Btu}}{1\ \text{cal}}\right)\left(\frac{5\,\text{C}^\circ}{9\,\text{F}^\circ}\right)\left(\frac{3600\,\text{s}}{1\ \text{h}}\right)\left(\frac{30.48\,\text{cm}}{1\ \text{ft}}\right) = 0.70\ \frac{\text{Btu}}{\text{ft}\cdot\text{F}^\circ\cdot\text{h}} .$$

(c) Using Eq. 19-33, we obtain

$$R = \frac{L}{k} = \frac{0.0064\,\text{m}}{1.2\,\text{W/m}\cdot\text{K}} = 0.0053\ \text{m}^2\cdot\text{K/W} .$$

86. Its initial volume is $5^3 = 125$ cm^3, and using Table 19-2, Eq. 19-10 and Eq. 19-11, we find

$$\Delta V = \left(125\,\text{m}^3\right)\left(3 \times 23 \times 10^{-6}/\text{C}^\circ\right)\left(50\,\text{C}^\circ\right) = 0.43\ \text{cm}^3 .$$

87. The cube has six faces, each of which has an area of $\left(6.0 \times 10^{-6}\,\text{m}\right)^2$. Using Kelvin temperatures and Eq. 19-40, we obtain

$$\begin{aligned} P_{\text{net}} &= \sigma\varepsilon A\left(T_{\text{env}}^4 - T^4\right) \\ &= \left(5.67 \times 10^{-8}\,\frac{\text{W}}{\text{m}^2\cdot\text{K}^4}\right)(0.75)\left(2.16 \times 10^{-10}\,\text{m}^2\right)\left((123.15\,\text{K})^4 - (173.15\,\text{K})^4\right) \\ &= -6.1 \times 10^{-9}\ \text{W} . \end{aligned}$$

88. We take absolute values of Eq. 19-9 and Eq. 13-25:

$$|\Delta L| = L\alpha|\Delta T| \qquad \text{and} \qquad \left|\frac{F}{A}\right| = E\left|\frac{\Delta L}{L}\right| \ .$$

The ultimate strength for steel is $(F/A)_{\text{rupture}} = S_u = 400 \times 10^6\,\text{N/m}^2$ from Table 13-1. Combining the above equations (eliminating the ratio $\Delta L/L$), we find the rod will rupture if the temperature change exceeds

$$|\Delta T| = \frac{S_u}{E\alpha} = \frac{400 \times 10^6\,\text{N/m}^2}{\left(200 \times 10^9\,\text{N/m}^2\right)(11 \times 10^{-6}/\text{C}^\circ)} = 182^\circ\text{C} \ .$$

Since we are dealing with a temperature decrease, then, the temperature at which the rod will rupture is $T = 25.0^\circ\text{C} - 182^\circ\text{C} = -157^\circ\text{C}$.

89. (a) At -40°F the tuning fork is shorter and takes less time to execute a "tick." The record of the clock assumes every "tick" corresponds to some standard unit of time – the net effect being that its time-record is "fast" or "ahead" of the correct time. We write the (absolute value of) relative error as

$$\left|\frac{t_{\text{fork}} - t_{\text{correct}}}{t_{\text{correct}}}\right| = \frac{T_{\text{fork}}}{T_{\text{correct}}} - 1 \ .$$

Using Eq. 16-28, this becomes

$$\left|\frac{\Delta t}{t_{\text{correct}}}\right| = \sqrt{\frac{L_{-40}}{L_{25}}} - 1 \ ,$$

where we have used the fact that the tuning fork would be accurate if the temperature were 25°F. Now, Eq. 19-9 tells us that $L_{-40} = L_{25}(1 + \alpha\Delta T)$, where $\Delta T = -65\,\text{F}^\circ$. Also, $\alpha = 5 \times 10^{-7}/\text{C}^\circ$ according to Table 19-2, which we convert to $\alpha = 2.8 \times 10^{-7}/\text{F}^\circ$ for the needed computations. Now, the above equation becomes

$$\left|\frac{\Delta t}{t_{\text{correct}}}\right| = \sqrt{1 + \alpha\Delta T} - 1 \ .$$

We can expand this with the binomial theorem (Appendix E) or compute it the "brute force" way; in any case we find $|\Delta t/t_{\text{correct}}| = 9 \times 10^{-6}$. Since the clock, as mentioned above, is "fast" we say the relative *gain* in time is 9×10^{-6}. *Note:* a more elegant approach to this problem in terms of differentials is as follows (with k some constant of proportionality).

$$\begin{aligned} t_{\text{fork}} &= k\sqrt{L} \qquad\qquad k = \text{constant} \\ dt_{\text{fork}} &= \frac{1}{2}kL^{-1/2}\,dL \\ dt_{\text{fork}} &= \frac{\alpha}{2}t_{\text{fork}}\,dT \\ \frac{dt_{\text{fork}}}{t_{\text{fork}}} &= \frac{\alpha}{2}\,dT \end{aligned}$$

At this point $dT \to \Delta T$ and the previous results are obtained.

(b) This proceeds very similarly to part (a), but with the tuning fork longer – and thus ticking more slowly, and with $\Delta T = 95\,\text{F}^\circ$. The result is a relative *loss* in time of magnitude 13×10^{-6}.

90. We require $\sum Q = 0$ (which amounts to assuming the system is isolated). There are both temperature changes (with $Q = cm\Delta T$) and phase changes ($Q = L_F\,m$). Masses are in kilograms and heat in Joules, with temperatures measured on the Celsius scale. We refer to the ice (which melts and becomes (liquid) water) as H_2O to avoid confusion; note that it involves *three* terms. The ice has mass m

and the tea has a 1.0 kg mass (the density of tea is taken to be the same as the density of water $\rho_w = 1000 \text{ kg/m}^3 = 1.0 \text{ kg/L}$).

$$\begin{aligned} Q_{H_2O} + Q_{tea} &= 0 \\ (2220)m\,(10^\circ) + (333000)m + (4190)m\,(10^\circ) + (4190)(1.0)\,(10^\circ - 90^\circ) &= 0 \\ 397100m - 335200 &= 0 \end{aligned}$$

Therefore, $m = 0.84$ kg which amounts to *forty-two* 20 g ice cubes.

91. We have $W = \int p\,dV$ (Eq. 19-24). Therefore,

$$W = a\int V^2\,dV = \frac{a}{3}\left(V_f^3 - V_i^3\right) = 23 \text{ J} .$$

92. (a) The length change of bar 1 is ΔL_1 and that of bar 2 is ΔL_2. The total length change is given by

$$\begin{aligned} \alpha L \Delta T &= \Delta L \\ &= \Delta L_1 + \Delta L_2 \\ &= \alpha_1 L_1 \Delta T + \alpha_2 L_2 \Delta T \end{aligned}$$

which leads to the desired expression after dividing through by ΔT and solving for α.

(b) Substituting $L_2 = L - L_1$ into the expression, we have

$$\alpha = \frac{\alpha_1 L_1 + \alpha_2 (L - L_1)}{L} \quad \Longrightarrow \quad L_1 = L\frac{\alpha - \alpha_2}{\alpha_1 - \alpha_2} .$$

Therefore, if $\alpha_1 = 19 \times 10^{-6}/\text{C}^\circ$ (brass, from Table 19-2), $\alpha_2 = 11 \times 10^{-6}/\text{C}^\circ$ (steel, also from Table 19-2), $L = 52.4$ cm and $\alpha = 13 \times 10^{-6}/\text{C}^\circ$, we obtain $L_1 = 13.1$ cm for the length of brass and $L_2 = L - L_1 = 39.3$ cm for the steel.

93. (a) The surface are of the cylinder is given by $A_1 = 2\pi r_1^2 + 2\pi r_1 h_1 = 2\pi(2.5 \times 10^{-2}\,\text{m})^2 + 2\pi(2.5 \times 10^{-2}\,\text{m})(5.0 \times 10^{-2}\,\text{m}) = 1.18 \times 10^{-2}\,\text{m}^2$, its temperature is $T_1 = 273 + 30 = 303\,\text{K}$, and the temperature of the environment is $T_{env} = 273 + 50 = 323\,\text{K}$. From Eq. 19-39 we have

$$\begin{aligned} P_1 &= \sigma\varepsilon A_1 (T_{env}^4 - T^4) \\ &= ()\,(0.85)(1.18 \times 10^{-2}\,\text{m}^2)\left((323\,\text{K})^4 - (303\,\text{K})^4\right) \\ &= 1.39\,\text{W} . \end{aligned}$$

(b) Let the new height of the cylinder be h_2. Since the volume V of the cylinder is fixed, we must have $V = \pi r_1^2 h_1 = \pi r_2^2 h_2$. We solve for h_2:

$$\begin{aligned} h_2 = \left(\frac{r_1}{r_2}\right)^2 h_1 \\ &= \left(\frac{2.5\,\text{cm}}{0.50\,\text{cm}}\right)^2 (5.0\,\text{cm}) \\ &= 125\,\text{cm} = 1.25 \text{ m} . \end{aligned}$$

The corresponding new surface area A_2 of the cylinder is

$$A_2 = 2\pi r_2^2 + 2\pi r_2 h_2 = 2\pi(0.50 \times 10^{-2}\,\text{m})^2 + 2\pi(0.50 \times 10^{-2}\,\text{m})(1.25\,\text{m}) = 3.94 \times 10^{-2} \text{ m}^2 .$$

Consequently,

$$\frac{P_2}{P_1} = \frac{A_2}{A_1} = \frac{3.94 \times 10^{-2}\,\text{m}^2}{1.18 \times 10^{-2}\,\text{m}^2} = 3.3 .$$

94. We denote the density of the liquid as ρ, the rate of liquid flowing in the calorimeter as μ, the specific heat of the liquid as c, the rate of heat flow as P, and the temperature change as ΔT. Consider a time duration dt, during this time interval, the amount of liquid being heated is $dm = \mu\rho dt$. The energy required for the heating is $dQ = Pdt = c(dm)\Delta T = c\mu\Delta T dt$. Thus,

$$c = \frac{P}{\rho\mu\Delta T} = \frac{250\,\mathrm{W}}{(8.0\times10^{-6}\,\mathrm{m^3/s})(0.85\times10^3\,\mathrm{kg/m^3})(15°\mathrm{C})} = 2.5\times10^3\,\mathrm{J/kg{\cdot}C°}\ .$$

95. This follows from Eq. 19-35 by dividing numerator and denominator by the product k_1k_2 as shown below:

$$T_X = \frac{\frac{1}{k_1k_2}(k_1L_2T_C + k_2L_1T_H)}{\frac{1}{k_1k_2}(k_1L_2 + k_2L_1)} = \frac{\frac{L_2}{k_2}T_C + \frac{L_1}{k_1}T_H}{\frac{L_2}{k_2} + \frac{L_1}{k_1}} = \frac{R_2T_C + R_1T_H}{R_2 + R_1}$$

where the definition $Eq.\ 19-33$ has also been used.

96. We note that there is no work done in process $c \to b$, since there is no change of volume. We also note that the *magnitude* of work done in process $b \to c$ is given, but not its sign (which we identify as negative as a result of the discussion in §19-8). The total (or *net*) heat transfer is $Q_{\rm net} = (-40) + (-130) + (+400) =$ 230 J. By the First Law of Thermodynamics (or, equivalently, conservation of energy), we have

$$\begin{aligned} Q_{\rm net} &= W_{\rm net} \\ 230\,\mathrm{J} &= W_{a\,\to\,c} + W_{c\,\to\,b} + W_{b\,\to\,a} \\ &= W_{a\,\to\,c} + 0 + (-80\,\mathrm{J}) \end{aligned}$$

Therefore, $W_{a\,\to\,c} = 310$ J.

97. (a) and (b) Regarding part (a), it is important to recognize that the problem is asking for the total work done during the two-step "path": $a \to b$ followed by $b \to c$. During the latter part of this "path" there is no volume change and consequently no work done. Thus, the answer to part (b) is also the answer to part (a). Since ΔU for process $c \to a$ is -160 J, then $U_c - U_a = 160$ J. Therefore, using the First Law of Thermodynamics, we have

$$\begin{aligned} 160 &= U_c - U_b + U_b - U_a \\ &= Q_{b\,\to\,c} - W_{b\,\to\,c} + Q_{a\,\to\,b} - W_{a\,\to\,b} \\ &= 40 - 0 + 200 - W_{a\,\to\,b} \end{aligned}$$

Therefore, $W_{a\,\to\,b} = 80$ J.

98. Let the initial water temperature be T_{wi} and the initial thermometer temperature be T_{ti}. Then, the heat absorbed by the thermometer is equal (in magnitude) to the heat lost by the water:

$$c_tm_t(T_f - T_{ti}) = c_wm_w(T_{wi} - T_f)\ .$$

We solve for the initial temperature of the water:

$$\begin{aligned} T_{wi} &= \frac{c_tm_t(T_f - T_{ti})}{c_wm_w} + T_f \\ &= \frac{(0.0550\,\mathrm{kg})(0.837\,\mathrm{kJ/kg{\cdot}\,K})(44.4 - 15.0)\,\mathrm{K}}{(4.18\,\mathrm{kJ/kg{\cdot}C°})(0.300\,\mathrm{kg})} + 44.4°\mathrm{C} \\ &= 45.5°\mathrm{C}\ . \end{aligned}$$

99. (a) A change of five Celsius degrees is equivalent to a change of nine Fahrenheit degrees. Using Table 19-2,

$$\alpha = \left(23\times10^{-6}/\mathrm{C°}\right)\left(\frac{5\,\mathrm{C°}}{9\,\mathrm{F°}}\right) = 13\times10^{-6}/\mathrm{F°}\ .$$

(b) For $\Delta T = 55\,\mathrm{F}^\circ$ and $L = 6.0$ m, we find $\Delta L = L\alpha\Delta T = 0.0042$ m.

100. The initial volume V_0 of the liquid is $h_0 A_0$ where A_0 is the initial cross-section area and $h_0 = 0.64$ m. Its final volume is $V = hA$ where $h - h_0$ is what we wish to compute. Now, the area expands according to how the glass expands, which is we analyze as follows.

$$\begin{aligned} A &= \pi r^2 \\ dA &= 2\pi r\,dr \\ dA &= 2\pi r\,(r\alpha\,dT) \\ dA &= 2\alpha A\,dT \end{aligned}$$

Therefore, the height is

$$h = \frac{V}{A} = \frac{V_0\,(1+\beta_{\text{liquid}}\Delta T)}{A_0\,(1+2\alpha_{\text{glass}}\Delta T)}\ .$$

Thus, with $V_0/A_0 = h_0$ we obtain

$$\begin{aligned} h - h_0 &= h_0\left(\frac{1+\beta_{\text{liquid}}\Delta T}{1+2\alpha_{\text{glass}}\Delta T} - 1\right) \\ &= (0.64)\left(\frac{1+\left(4\times10^{-5}\right)(10^\circ)}{1+2\,(1\times10^{-5})\,(10^\circ)}\right) \\ &= 1.3\times10^{-4}\ \text{m}\ . \end{aligned}$$

101. The heat required to warm up to the melting point is $Q = cm\Delta T = (2220)(15.0)(20.0) = 666$ kJ, which is less than the total 7000 kJ added to the sample. Therefore, 6334 kJ remain for melting the block and warming the sample (now in the form of liquid water) further. Melting the block requires

$$Q = L_F m = (333\,\text{kJ/kg})(15.0\,\text{kg}) = 4995\ \text{kJ}$$

which leaves $6334 - 4995 = 1339$ kJ. The final temperature of the (liquid) water, which has $c = 4190\,\text{J/kg}\cdot\text{C}^\circ$, is found from

$$Q = cm\,(T_f - 0^\circ\text{C}) \implies T_f = \frac{1339\times10^3}{(4190)(15.0)} = 21.3^\circ\text{C}\ .$$

102. Using Eq. 19-40 with $T = 323$ K and $T_{\text{env}} = 293$ K, we find

$$P_{\text{net}} = \sigma\varepsilon A\left(T_{\text{env}}^4 - T^4\right) = -3.8\times10^{-7}\ \text{W}$$

where we have used the fact that the surface area of the cube is $A = 6A_{\text{face}} = 6\left(2.0\times10^{-5}\,\text{m}\right)^2 = 2.4\times10^{-9}\ \text{m}^2$.

103. Let $m_w = 14\,\text{kg}$, $m_c = 3.6\,\text{kg}$, $m_m = 1.8\,\text{kg}$, $T_{i1} = 180^\circ\text{C}$, $T_{i2} = 16.0^\circ\text{C}$, and $T_f = 18.0^\circ\text{C}$. The specific heat c_m of the metal then satisfies

$$(m_w c_w + m_c c_m)\,(T_f - T_{i2}) + m_m c_m\,(T_f - T_{i1}) = 0$$

which we solve for c_m:

$$\begin{aligned} c_m &= \frac{m_w c_w (T_{i2} - T_f)}{m_c (T_f - T_{i2}) + m_m (T_f - T_{i1})} \\ &= \frac{(14\,\text{kg})(4.18\,\text{kJ/kg}\cdot\text{K})(16.0^\circ\text{C} - 18.0^\circ\text{C})}{(3.6\,\text{kg})(18.0^\circ\text{C} - 16.0^\circ\text{C}) + (1.8\,\text{kg})(18.0^\circ\text{C} - 180^\circ\text{C})} \\ &= 0.41\ \text{kJ/kg}\cdot\text{C}^\circ\ . \end{aligned}$$

104. The energy (which was originally in the form $K = \frac{1}{2}mv^2$) dissipated as a result of friction melts a portion of mass m. Therefore,

$$\begin{aligned} \frac{1}{2}(50.0\,\text{kg})(5.38\,\text{m/s})^2 &= mL_F \\ 723\,\text{J} &= m(333\,\text{kJ/kg} \end{aligned}$$

which, for consistency of the energy units, is best written $723\,\text{J} = m(333\,\text{J/g})$. This yields $m = 2.17$ g.

105. We demand $\sum Q = 0$ as an expression of the fact that the system is isolated. Only temperature changes (with $Q = cm\Delta T$) are involved (no phase changes). Let masses be in kilograms, heat in Joules and temperature on the Celsius scale.

$$\begin{aligned} Q_{\text{copper}} + Q_{\text{water}} &= 0 \\ (386)(3.00)\,(T_f - 70.0^\circ) + (4190)(4.00)\,(T_f - 10.0^\circ) &= 0 \end{aligned}$$

Therefore, we find

$$T_f = \frac{(386)(3.00)\,(70.0^\circ) + (4190)(4.00)\,(10.0^\circ)}{(386)(3.00) + (4190)(4.00)} = 13.9^\circ\text{C} \ .$$

106. We use $Q = cm\Delta T$ and $m = \rho V$. The volume of water needed is

$$V = \frac{m}{\rho} = \frac{Q}{\rho C \Delta T} = \frac{(1.00 \times 10^6\,\text{kcal/day})(5\,\text{days})}{(1.00 \times 10^3\,\text{kg/m}^3)(1.00\,\text{kcal/kg})(50.0^\circ\text{C} - 22.0^\circ\text{C})} = 35.7\ \text{m}^3 \ .$$

107. (a) Let the number of weight lift repetitions be N. Then $Nmgh = Q$, or (using Eq. 19-12 and the discussion preceding it)

$$N = \frac{Q}{mgh} = \frac{(3500\,\text{Cal})(4186\,\text{J/Cal})}{(80.0\,\text{kg})\,(9.8\,\text{m/s}^2)\,(1.00\,\text{m})} \approx\ 18700 \ .$$

(b) The time required is

$$t = (18700)(2.00\,\text{s})\left(\frac{1.00\,\text{h}}{3600\,\text{s}}\right) = 10.4\ \text{h} \ .$$

108. We assume scales X and Y are linearly related in the sense that reading is x is related to reading y by a linear relationship $y = mx + b$. We determine the constants m and b by solving the simultaneous equations:

$$\begin{aligned} -70.00 &= m(-125.0) + b \\ -30.00 &= m(375.0) + b \end{aligned}$$

which yield the solutions $m = 40.00/500.0 = 8.000 \times 10^{-2}$ and $b = -60.00$. With these values, we find x for $y = 50.00$:

$$x = \frac{y - b}{m} = \frac{50.00 + 60.00}{0.08000} = 1375^\circ X \ .$$

109. (a) The 8.0 cm thick layer of air in front of the glass conducts heat at a rate of

$$P_{\text{cond}} = kA\frac{T_H - T_C}{L} = (0.026)(0.36)\frac{15}{0.08} = 1.8\ \text{W}$$

which must be the same as the heat conduction current through the glass if a steady-state heat transfer situation is assumed.

(b) For the glass pane,

$$\begin{aligned} P_{\text{cond}} &= kA\frac{T_H - T_C}{L} \\ 1.8 &= (1.0)(0.36)\frac{T_H - T_C}{0.005} \end{aligned}$$

which yields $T_H - T_C = 0.024\,\mathrm{C}^\circ$.

110. One method is to simply compute the change in length in each edge ($x_0 = 0.200$ m and $y_0 = 0.300$ m) from Eq. 19-9 ($\Delta x = 3.6 \times 10^{-5}$ m and $\Delta y = 5.4 \times 10^{-5}$ m) and then compute the area change:

$$A - A_0 = (x_0 + \Delta x)\,(y_0 + \Delta y) - x_0 y_0 = 2.16 \times 10^{-5}\ \mathrm{m}^2\ .$$

Another (though related) method uses $\Delta A = 2\alpha A_0 \Delta T$ (valid for $\Delta A/A \ll 1$) which can be derived by taking the differential of $A = xy$ and replacing d's with Δ's.