Energy in Thermal Processes

QUICK QUIZZES

1. (a) Water, glass, iron. Because it has the highest specific heat $(4186\ \text{J/kg}\cdot{}^\circ\text{C})$, water has the smallest change in temperature. Glass is next $(837\ \text{J/kg}\cdot{}^\circ\text{C})$, and iron $(448\ \text{J/kg}\cdot{}^\circ\text{C})$ is last. (b) Iron, glass, water. For a given temperature increase, the energy transfer by heat is proportional to the specific heat.

2. Choice (b). The slopes are proportional to the reciprocal of the specific heat, so larger specific heat results in a smaller slope, meaning more energy to achieve a given change in temperature.

3. Choice (c). The blanket acts as a thermal insulator, slowing the transfer of energy by heat from the air into the cube.

4. Choice (b). The rate of energy transfer by conduction through a rod is proportional to the difference in the temperatures of the ends of the rod. When the rods are in parallel, each rod experiences the full difference in the temperatures of the two regions. If the rods are connected in series, neither rod will experience the full temperature difference between the two regions, and hence neither will conduct energy as rapidly as it did in the parallel connection.

5. (a) $P_\text{A}/P_\text{B} = 4.$ From Stefan's law, the power radiated from an object at absolute temperature T is proportional to the surface area of that object. Star A has twice the radius and four times the surface area of star B. (b) $P_\text{A}/P_\text{B} = 16.$ From Stefan's law, the power radiated from an object having surface area A is proportional to the fourth power of the absolute temperature. Thus, $P_\text{A} = \sigma Ae(2T_\text{B})^4 = 2^4(\sigma AeT_\text{B}^4) = 16P_\text{B}.$ (c) $P_\text{A}/P_\text{B} = 64.$ When star A has both twice the radius and twice the absolute temperature of star B, the ratio of the radiated powers is

$$\frac{P_\text{A}}{P_\text{B}} = \frac{\sigma A_\text{A} eT_\text{A}^4}{\sigma A_\text{B} eT_\text{B}^4} = \frac{\sigma\left(4\pi R_\text{A}^2\right)(1)T_\text{A}^4}{\sigma\left(4\pi R_\text{B}^2\right)(1)T_\text{B}^4} = \frac{\left(2R_\text{B}\right)^2\left(2T_\text{B}\right)^4}{R_\text{B}^2T_\text{B}^4} = \left(2^2\right)\left(2^4\right) = 64$$

ANSWERS TO WARM-UP EXERCISES

1. As a first step, we substitute $M = 4m$ and expand to obtain

$$\cancel{m}L_f + \cancel{m}cT + \left(4\cancel{m}\right)cT - \left(4\cancel{m}\right)c\left(30.0^\circ\text{C}\right) = 0$$

Solving for T then gives

$$5cT = 4c\left(30.0^\circ\text{C}\right) - L_f$$

or

$$T = \frac{4}{5}\left(30.0^\circ\text{C}\right) - \frac{L_f}{5c} = 24^\circ\text{C} - \frac{3.33\times10^5\ \text{J/kg}}{5\left(4\ 186\ \text{J/kg}\cdot\text{K}\right)} = \boxed{8.09^\circ\text{C}}$$

2. (a) The work done by the athlete is given by

$$W = Fd = mgd = \left(175\ \text{kg}\right)\left(9.80\ \text{m/s}^2\right)\left(2.00\ \text{m}\right) = 3\ 430\ \text{J}$$

The power delivered is then

$$P = \frac{W}{\Delta t} = \frac{3\ 430 \text{ J}}{4.30 \text{ s}} = \boxed{798 \text{ W}}$$

(b) In this instance, the power delivered is given by

$$P = Fv = mgv = (175 \text{ kg})(9.80 \text{ m/s}^2)(0.600 \text{ m/s}) = \boxed{1\ 030 \text{ W}}$$

3. From Table 9.1, Young's modulus for copper is 11×10^{10} Pa. Solving Equation 9.5 for the change in length of the cylinder, we obtain

$$\Delta L = \left(\frac{F}{A}\right)\left(\frac{L_0}{Y}\right) = \left(\frac{9.30\times10^3 \text{ N}}{2.50\times10^{-5} \text{ m}^2}\right)\left(\frac{0.200 \text{ m}}{11\times10^{10} \text{ Pa}}\right)$$
$$= \boxed{6.8\times10^{-4} \text{ m}}$$

4. (a) One Calorie = 1 kcal, so

$$3.50\times10^3 \text{ cal} = (3.50\times10^3 \text{ cal})\left(\frac{1 \text{ kcal}}{1\ 000 \text{ cal}}\right)$$
$$= \boxed{3.50 \text{ kcal} = 3.50 \text{ Calorie}}$$

(b) From Equation 11.1,

$$3.50\times10^3 \text{ cal} = (3.50\times10^3 \text{ cal})\left(\frac{4.186 \text{ J}}{1 \text{ cal}}\right) = \boxed{1.47\times10^4 \text{ J}}$$

5. From Equation 11.3, with the specific heat of silicon obtained from Table 11.1 as 703 J/kg · °C, we obtain

$$Q = mc\Delta T = (1.00\times10^{-3} \text{ kg})(703 \text{ J/kg}\cdot°\text{C})(20.0°\text{C}) = \boxed{14.1 \text{ J}}$$

6. (a) The energy required to melt the 2.00 kg of ice is

$$Q = mL_f = (2.00 \text{ kg})(3.33\times10^5 \text{ J/kg}) = \boxed{6.66\times10^5 \text{ J}}$$

(b) The remaining energy is

$$9.30\times10^5 \text{ J} - 6.66\times10^5 \text{ J} = \boxed{2.64\times10^5 \text{ J}}$$

(c) We use Equation 11.3:

$$\Delta T = T_f - T_i = T_f - 0 = T_f = \frac{Q}{mc}$$
$$= \frac{2.64\times10^5 \text{ J}}{(2.00 \text{ kg})(4\ 186 \text{ J/kg}\cdot°\text{C})} = \boxed{31.5°\text{C}}$$

7. The heat lost by the warm air equals the heat gained by the cool air:

$$m_{\text{hot}} \not{c} \left(T_{\text{hot}} - T_f\right) = -m_{\text{cool}} \not{c} \left(T_{\text{cool}} - T_f\right)$$

which gives

$$\begin{aligned} T_f &= \frac{m_{\text{hot}} T_{\text{hot}} + m_{\text{cool}} T_{\text{cool}}}{m_{\text{hot}} + m_{\text{cool}}} \\ &= \frac{(950 \text{ kg})(30.0°\text{C}) + (50.0 \text{ kg})(18.0°\text{C})}{950 \text{ kg} + 50.0 \text{ kg}} = \boxed{29.4°\text{C}} \end{aligned}$$

8. The rate of thermal energy transfer is given by Equation 11.7:

$$\begin{aligned} P &= \frac{kA(T_h - T_c)}{L} = \frac{(0.12 \text{ W/m} \cdot \text{K})(48.0 \text{ m}^2)(25.0°\text{C} - 14.0°\text{C})}{0.040 \text{ m}} \\ &= \boxed{1\ 600 \text{ W}} \end{aligned}$$

9. (a) The temperature of the granite ball is

$$T = T_C + 273.15 = 135°\text{C} + 273.15 = \boxed{408 \text{ K}}$$

(b) The surface area of a sphere is given by

$$A = 4\pi r^2 = 4\pi(2.00 \text{ m})^2 = \boxed{50.3 \text{ m}^2}$$

(c) The net power radiated by the ball is given by Equation 11.11:

$$\begin{aligned} P &= \sigma A e\left(T^4 - T_0^4\right) \\ &= \left(5.669\ 6 \times 10^{-8} \text{ W/m}^2 \cdot \text{K}^4\right)\left(50.3 \text{ m}^2\right)(0.450) \\ &\qquad \times \left[(408 \text{ K})^4 - (298 \text{ K})^4\right] \\ &= \boxed{2.55 \times 10^4 \text{ W}} \end{aligned}$$

ANSWERS TO EVEN NUMBERED CONCEPTUAL QUESTIONS

2. The high thermal capacity of the barrel of water and its high heat of fusion mean that a large amount of energy would have to leak out of the cellar before the water and produce froze solid. Also, evaporation of the water keeps the relative humidity high to protect foodstuffs from drying out.

4. (a) Yes, wrap the blanket around the ice chest. The environment is warmer than the ice, so the low thermal conductivity of the blanket slows energy transfer by heat from the environment to the ice.

(b) Explain to your little sister that her body is warmer than the environment and requires energy transfer by heat into the air to remain at a fixed temperature. The blanket will slow this conduction and cause her to feel warmer, not cool like the ice.

6. Yes, if you know the specific heat of zinc and copper, you can determine the relative fraction of each by heating a known weight of pennies to a specific initial temperature, say 100°C, then dump them into a known quantity of water, at say 20°C. The equation for conservation of energy will be

$$m_{\text{pennies}}\left[x\cdot c_{\text{Cu}}+(1-x)c_{\text{Zn}}\right](100°\text{C}-T)=m_{\text{water}}c_{\text{water}}(T-20°\text{C})$$

The equilibrium temperature, T, and the masses will be measured. The specific heats are known, so the fraction of metal that is copper, *x*, can be computed.

8. Write $m_{\text{water}}c_{\text{water}}(1°\text{C})=(\rho_{\text{air}}V)c_{\text{air}}(1°\text{C})$, to find

$$V=\frac{m_{\text{water}}c_{\text{water}}}{\rho_{\text{air}}c_{\text{air}}}=\frac{(1.0\times10^3\ \text{kg})(4\,186\ \text{J/kg}\cdot°\text{C})}{(1.3\ \text{kg/m}^3)(1.0\times10^3\ \text{J/kg}\cdot°\text{C})}=3.2\times10^3\ \text{m}^3$$

10. The black car absorbs more of the incoming energy from the Sun than does the white car, making it more likely to cook the egg.

12. Keep them dry. The air pockets in the pad conduct energy slowly. Wet pads absorb some energy in warming up themselves, but the pot would still be hot and the water would quickly conduct a lot of energy to your hand.

14. With $e_A=e_B$, $r_A=2r_B$, and $T_A=2T_B$, the ratio of the power output of A to that of B is

$$\frac{P_A}{P_B}=\frac{\not{\sigma}A_A\not{e_A}T_A^4}{\not{\sigma}A_B\not{e_B}T_B^4}=\frac{\not{4\pi}r_A^2T_A^4}{\not{4\pi}r_B^2T_B^4}=\left(\frac{r_A}{r_B}\right)^2\left(\frac{T_A}{T_B}\right)^4=(2)^2(2)^4=(2)^6=64$$

making (e) the correct choice.

ANSWERS TO EVEN NUMBERED PROBLEMS

2. $0.234\ \text{kJ/kg}\cdot°\text{C}$

4. 0.15 mm

6. (a) 2.3×10^6 J (b) 2.8×10^4 stairs (c) 7.0×10^3 stairs

8. (a) $P=Fv$ (b) $P=ma^2t$ (c) $2.20\ \text{m/s}^2$

(d) $P=(363\ \text{W/s})\cdot t$ (e) $1.74\ \text{Cal/s}$

10. $0.105°\text{C}$

12. (a) $9.9\times10^{-3}\ °\text{C}$ (b) It is absorbed by the rough horizontal surface.

14. (a) $Stress=\dfrac{F}{A}=Y[\alpha(\Delta T)]$ (b) $Q=\dfrac{mc}{Y\alpha}\left(\dfrac{F}{A}\right)$ (c) 96.0 kg

(d) 6.7×10^6 J (e) $79°\text{C}$ (f) ~ 4 h

16. 467

18. The copper bullet wins: $T_{copper} = 89.7°C$, $T_{silver} = 89.8°C$

20. $29.6^{o}C$

22. $47^{o}C$

24. 1.18×10^{3} J/kg×oC

26. 49 kJ

28. 0.12 MJ

30. (a) ice at $-10.0°C$ to ice at $0^{o}C$; ice at $0^{o}C$ to liquid water at $0^{o}C$; water at $0^{o}C$ to water at *T*; aluminum at $20.0^{o}C$ to aluminum at *T*; ethyl alcohol at $30.0^{o}C$ to ethyl alcohol at *T*.

(b) See Solution.

(c) $m_{ice}c_{ice}(10.0°C)+m_{ice}L_f+m_{ice}c_{water}(T-0)+m_{Al}c_{Al}[T-20.0°C]+m_{alc}c_{alc}[T-30.0°C]=0$

(d) $4.81°C$

32. 0.33 kg, 0.067 or 6.7%

34. $403\ cm^3$

36. 11.1 W

38. (a) 6×10^{3} W (b) 5×10^{8} J

40. (a) $R_{skin} = 5.0\times10^{-2}\ m^2\cdot K/W$, $R_{fat} = 2.5\times10^{-2}\ m^2\cdot K/W$, $R_{tissue} = 6.4\times10^{-2}\ m^2\cdot K/W$, $R_{total} = 0.14\ m^2\cdot K/W$

(b) 5.3×10^{2} W

42. $39\ m^3$

44. **(a)** 52 W **(b)** 2 kW

46. 7.3×10^{-2} W/m·°C

48. 330 K

50. $1.1\times10^{-5}\ m^2$

52. 1.83 h

54. (a) 1.1×10^{2} W

(b) The positive sign indicates that the body is radiating energy away faster than it absorbs energy from the environment.

56. 1.8 kg

58. (a) 1.6×10^{2} W (b) 2.7×10^{2} W (c) 11 W

(d) 1.2×10^{2} W

60. $45^\circ C$

62. (a) 2.0 kW (b) $4.5^\circ C$

64. $28^\circ C$

66. (a) 2.03×10^3 J/s (b) $7.84 \ ft^2 \cdot {}^\circ F \cdot h/Btu$

68. (a) 0.457 kg

(b) If the samples and inner surface of the insulation are preheated, nothing undergoes a temperature change during the test. Therefore, only the mass of the wax, which undergoes a change of phase, needs to be known.

70. 0.9 kg

72. (a) The processes involved are the removal of energy to: (1) cool liquid water from $20.0\ ^\circ C$ to $0^\circ C$, (2) convert liquid water at $0^\circ C$ to solid water (ice) at $0^\circ C$, and (3) cool ice from $0^\circ C$ to $-8.00^\circ C$.

(b) 32.5 kJ

PROBLEM SOLUTIONS

11.1 As mass m of water drops from the top to the bottom of the falls, the gravitational potential energy given up (and hence, the kinetic energy gained) is $Q = mgh$. If all of this goes into raising the temperature, the rise in temperature will be

$$\Delta T = \frac{Q}{mc_{\text{water}}} = \frac{\cancel{m}gh}{\cancel{m}c_{\text{water}}} = \frac{(9.80 \ m/s^2)(807 \ m)}{4\,186 \ J/kg \cdot {}^\circ C} = 1.89^\circ C$$

and the final temperature is $T_f = T_i + \Delta T = 15.0^\circ C + 1.89^\circ C = \boxed{16.9^\circ C}$

11.2 $$c = \frac{Q}{m(\Delta T)} = \frac{1.23 \times 10^3 \ J}{(0.525 \ kg)(10.0^\circ C)} = 234 \ J/kg \cdot {}^\circ C = \boxed{0.234 \ kJ/kg \cdot {}^\circ C}$$

11.3 The mass of water involved is

$$m = \rho V = \left(10^3 \ \frac{kg}{m^3}\right)\left(4.00 \times 10^{11} \ m^3\right) = 4.00 \times 10^{14} \ kg$$

(a) $Q = mc(\Delta T) = \left(4.00 \times 10^{14} \ kg\right)(4\,186 \ J/kg \cdot {}^\circ C)(1.00^\circ C) = \boxed{1.67 \times 10^{18} \ J}$

(b) The power input is $P = 1\,000 \ MW = 1.00 \times 10^9 \ J/s$,

so $t = \frac{Q}{P} = \frac{1.67 \times 10^{18} \ J}{1.00 \times 10^9 \ J/s}\left(\frac{1 \ yr}{3.156 \times 10^7 \ s}\right) = \boxed{52.9 \ yr}$

11.4 The change in temperature of the rod is

$$\Delta T = \frac{Q}{mc} = \frac{1.00\times 10^4 \text{ J}}{(0.350 \text{ kg})(900 \text{ J/kg°C})} = 31.7\text{°C}$$

and the change in the length is

$$\Delta L = \alpha L_0(\Delta T)$$
$$= \left[24\times 10^{-6}(\text{°C})^{-1}\right](20.0 \text{ cm})(31.7\text{°C}) = 1.5\times 10^{-2} \text{ cm} = \boxed{0.15 \text{ mm}}$$

11.5 (a) $Q = 0.600\left|\Delta PE_g\right| = 0.600\left(mg|h|\right) = 0.600\cdot m\left(9.80 \text{ m/s}^2\right)(50.0 \text{ m})$

or $Q = \left(294 \text{ m}^2/\text{s}^2\right)\cdot m$

From $Q = mc(\Delta T) = mc(T_f - T_i)$, we find the final temperature as

$$T_f = T_i + \frac{Q}{mc} = 25.0\text{°C} + \frac{\left(294 \text{ m}^2/\text{s}^2\right)\cdot \cancel{m}}{\cancel{m}(387 \text{ J/kg}\cdot\text{°C})} = \boxed{25.8\text{°C}}$$

(b) Observe that the mass of the coin cancels out in the calculation of part (a). Hence, the

$\boxed{\text{result is independent of the mass of the coin}}$.

11.6 (a) $Q = 540 \cancel{\text{Cal}}\left(\frac{10^3 \cancel{\text{cal}}}{1 \cancel{\text{Cal}}}\right)\left(\frac{4.186 \text{ J}}{1 \cancel{\text{cal}}}\right) = \boxed{2.3\times 10^6 \text{ J}}$

(b) The work done lifting her weight mg up one stair of height h is $W_1 = mgh$. Thus, the total work done in climbing N stairs is $W = Nmgh$, and we have $W = Nmgh = Q$ or

$$N = \frac{Q}{mgh} = \frac{2.3\times 10^6 \text{ J}}{(55 \text{ kg})\left(9.80 \text{ m/s}^2\right)(0.15 \text{ m})} = \boxed{2.8\times 10^4 \text{ stairs}}$$

(c) If only 25% of the energy from the donut goes into mechanical energy, we have

$$N = \frac{0.25Q}{mgh} = 0.25\left(\frac{Q}{mgh}\right) = 0.25\left(2.8\times 10^4 \text{ stairs}\right) = \boxed{7.0\times 10^3 \text{ stairs}}$$

11.7 (a) $W_{\text{net}} = \Delta KE = \frac{1}{2}m\left(v_f^2 - v_0^2\right) = \frac{1}{2}(75 \text{ kg})\left[(11.0 \text{ m/s})^2 - 0\right] = 4.54\times 10^3 \text{ J} \rightarrow \boxed{4.5\times 10^3 \text{ J}}$

(b) $\overline{P} = \frac{W_{\text{net}}}{\Delta t} = \frac{4.54\times 10^3 \text{ J}}{5.0 \text{ s}} = 9.1\times 10^2 \text{ J/s} = \boxed{910 \text{ W}}$

(c) If the mechanical energy is 25% of the energy gained from converting food energy, then $W_{net} = 0.25(\Delta Q)$ and $\overline{P} = 0.25(\Delta Q)/\Delta t$, so the food energy conversion rate is

$$\frac{\Delta Q}{\Delta t} = \frac{\overline{P}}{0.25} = \left(\frac{910\ \text{J/s}}{0.25}\right)\left(\frac{1\ \text{Cal}}{4\,186\ \text{J}}\right) = \boxed{0.87\ \text{Cal/s}}$$

(d) The excess thermal energy is transported by conduction and convection to the surface of the skin and disposed of through the evaporation of perspiration.

11.8 (a) The instantaneous power is $\boxed{P = Fv}$, where F is the applied force and v is the instantaneous velocity.

(b) From Newton's second law, $F_{net} = ma$, and the kinematics equation $v = v_0 + at$ with $v_0 = 0$, the instantaneous power expression given above may be written as

$$P = Fv = (ma)(0 + at) \qquad \text{or} \qquad \boxed{P = ma^2 t}$$

(c) $a = \dfrac{\Delta v}{\Delta t} = \dfrac{v - 0}{t - 0} = \dfrac{11.0\ \text{m/s}}{5.00\ \text{s}} = \boxed{2.20\ \text{m/s}^2}$

(d) $P = ma^2 t = (75.0\ \text{kg})(2.20\ \text{m/s}^2)^2 t = (363\ \text{kg}\cdot\text{m}^2/\text{s}^4)\cdot t = \boxed{(363\ \text{W/s})\cdot t}$

(e) Maximum instantaneous power occurs when $t = t_{max} = 5.00\ \text{s}$, so

$$P_{max} = (363\ \text{J/s}^2)(5.00\ \text{s}) = 1.82 \times 10^3\ \text{J/s}$$

If this corresponds to 25.0% of the rate of using food energy, that rate must be

$$\frac{\Delta Q}{\Delta t} = \frac{P_{max}}{0.250} = \frac{1.82 \times 10^3\ \text{J/s}}{0.250}\left(\frac{1\ \text{Cal}}{4\,186\ \text{J}}\right) = \boxed{1.74\ \text{Cal/s}}$$

11.9 The mechanical energy transformed into internal energy of the bullet is $Q = \frac{1}{2}(KE_i) = \frac{1}{2}\left(\frac{1}{2}mv_i^2\right) = \frac{1}{4}mv_i^2$. Thus, the change in temperature of the bullet is

$$\Delta T = \frac{Q}{mc} = \frac{\frac{1}{4}\cancel{m}v_i^2}{\cancel{m}c_{lead}} = \frac{(300\ \text{m/s})^2}{4(128\ \text{J/kg}\cdot{}^\circ\text{C})} = \boxed{176\,^\circ\text{C}}$$

11.10 The internal energy added to the system equals the gravitational potential energy given up by the 2 falling blocks, or $Q = \Delta PE_g = 2m_b gh$. Thus,

$$\Delta T = \frac{Q}{m_w c_w} = \frac{2m_b gh}{m_w c_w} = \frac{2(1.50\ \text{kg})(9.80\ \text{m/s}^2)(3.00\ \text{m})}{(0.200\ \text{kg})(4\,186\ \text{J/kg}\cdot{}^\circ\text{C})} = \boxed{0.105^\circ\text{C}}$$

11.11 The quantity of energy transferred from the water-cup combination in a time interval of 1 minute is

$$Q = \left[(mc)_{\text{water}} + (mc)_{\text{cup}}\right](\Delta T)$$

$$= \left[(0.800 \text{ kg})\left(4\,186 \ \frac{\text{J}}{\text{kg}\cdot{}^\circ\text{C}}\right) + (0.200 \text{ kg})\left(900 \ \frac{\text{J}}{\text{kg}\cdot{}^\circ\text{C}}\right)\right](1.5^\circ\text{C}) = 5.3\times10^3 \text{ J}$$

The rate of energy transfer is

$$P = \frac{Q}{\Delta t} = \frac{5.3\times10^3 \text{ J}}{60 \text{ s}} = 88 \ \frac{\text{J}}{\text{s}} = \boxed{88 \text{ W}}$$

11.12 (a) The mechanical energy converted into internal energy of the block is $Q = 0.85(KE_i) = 0.85\left(\frac{1}{2}mv_i^2\right)$. The change in temperature of the block will be

$$\Delta T = \frac{Q}{mc_{\text{Cu}}} = \frac{0.85\left(\frac{1}{2}\cancel{m}v_i^2\right)}{\cancel{m}c_{\text{Cu}}} = \frac{0.85(3.0 \text{ m/s})^2}{2(387 \text{ J/kg}\cdot{}^\circ\text{C})} = \boxed{9.9\times10^{-3}\ {}^\circ\text{C}}$$

(b) The remaining energy is absorbed by the horizontal surface on which the block slides.

11.13 From $\Delta L = \alpha L_0(\Delta T)$, the required increase in temperature is found, using Table 10.1, as

$$\Delta T = \frac{\Delta L}{\alpha_{\text{steel}}L_0} = \frac{3.0\times10^{-3} \cancel{\text{m}}}{\left(11\times10^{-6}\ ({}^\circ\text{C})^{-1}\right)(13 \cancel{\text{yd}})}\left(\frac{1 \cancel{\text{yd}}}{3.0 \cancel{\text{ft}}}\right)\left(\frac{3.281 \cancel{\text{ft}}}{1 \cancel{\text{m}}}\right) = 23^\circ\text{C}$$

The mass of the rail is

$$m = \frac{w}{g} = \frac{(70 \cancel{\text{lb}}/\cancel{\text{yd}})(13 \cancel{\text{yd}})}{9.80 \text{ m/s}^2}\left(\frac{4.448 \text{ N}}{1 \cancel{\text{lb}}}\right) = 4.1\times10^2 \text{ kg}$$

so the required thermal energy (assuming that $c_{\text{steel}} = c_{\text{iron}}$) is

$$Q = mc_{\text{steel}}(\Delta T) = (4.1\times10^2 \text{ kg})(448 \text{ J/kg}\cdot{}^\circ\text{C})(23^\circ\text{C}) = \boxed{4.2\times10^6 \text{ J}}$$

11.14 (a) From the relation between compressive stress and strain, $F/A = Y(\Delta L/L_0)$, where Y is Young's modulus of the material. From the discussion on linear expansion, the strain due to thermal expansion can be written as $(\Delta L/L_0) = \alpha(\Delta T)$, where α is the coefficient of linear expansion. Thus, the stress becomes $\boxed{F/A = Y[\alpha(\Delta T)]}$.

(b) If the concrete slab has mass *m*, the thermal energy required to produce a change in temperature ΔT is $Q = mc(\Delta T)$, where c is the specific heat of concrete. Using the result from part (a), the absorbed thermal energy required to produce compressive stress F/A is

$$Q = mc\left(\frac{F/A}{Y\alpha}\right) \quad \text{or} \quad \boxed{Q = \frac{mc}{Y\alpha}\left(\frac{F}{A}\right)}$$

(c) The mass of the given concrete slab is

$$m = \rho V = \left(2.40\times10^{3}\ \text{kg/m}^{3}\right)\left[\left(4.00\times10^{-2}\ \text{m}\right)(1.00\ \text{m})(1.00\ \text{m})\right] = \boxed{96.0\ \text{kg}}$$

(d) If the maximum compressive stress concrete can withstand is $F/A = 2.00\times10^{7}$ Pa, the maximum thermal energy this slab can absorb before starting to break up is found, using Table 10.1, to be

$$Q_{\max} = \frac{mc}{Y\alpha}\left(\frac{F}{A}\right)_{\max} = \frac{(96.0\ \text{kg})(880\ \text{J/kg}\cdot{}^{\circ}\text{C})}{\left(2.1\times10^{10}\ \text{Pa}\right)\left(12\times10^{-6}\ \left({}^{\circ}\text{C}\right)^{-1}\right)}\left(2.00\times10^{7}\ \text{Pa}\right) = \boxed{6.7\times10^{6}\ \text{J}}$$

(e) The change in temperature of the slab as it absorbs the thermal energy computed above is

$$\Delta T = \frac{Q}{mc} = \frac{6.7\times10^{6}\ \text{J}}{(96.0\ \text{kg})(880\ \text{J/kg}\cdot{}^{\circ}\text{C})} = \boxed{79^{\circ}\text{C}}$$

(f) The rate the slab absorbs solar energy is

$$P_{\text{absorbed}} = 0.5P_{\text{solar}} = 0.5\left(1.00\times10^{3}\ \text{W}\right) = 5\times10^{2}\ \text{J/s}$$

so the time required to absorb the thermal energy computed in (d) above is

$$t = \frac{Q}{P_{\text{absorbed}}} = \frac{6.7\times10^{6}\ \text{J}}{5\times10^{2}\ \text{J/s}}\left(\frac{1\ \text{h}}{3\,600\ \text{s}}\right) \sim \boxed{4\ \text{h}}$$

11.15 When thermal equilibrium is reached, the water and aluminum will have a common temperature of $T_f = 65.0^{\circ}\text{C}$. Assuming that the water-aluminum system is thermally isolated from the environment, $Q_{\text{cold}} = -Q_{\text{hot}}$, so $m_w c_w \left(T_f - T_{i,w}\right) = -m_{\text{Al}} c_{\text{Al}} \left(T_f - T_{i,\text{Al}}\right)$, or

$$m_w = \frac{-m_{\text{Al}} c_{\text{Al}}\left(T_f - T_{i,\text{Al}}\right)}{c_w\left(T_f - T_{i,w}\right)} = \frac{-(1.85\ \text{kg})(900\ \text{J/kg}\cdot{}^{\circ}\text{C})(65.0^{\circ}\text{C} - 150^{\circ}\text{C})}{(4\,186\ \text{J/kg}\cdot{}^{\circ}\text{C})(65.0^{\circ}\text{C} - 25.0^{\circ}\text{C})} = \boxed{0.845\ \text{kg}}$$

11.16 If N pellets are used, the mass of the lead is Nm_{pellet}. Since the energy lost by the lead must equal the energy absorbed by the water,

$$\left|Nm_{\text{pellet}}c(\Delta T)\right|_{\text{lead}} = \left[mc(\Delta T)\right]_{\text{water}}$$

or the number of pellets required is

$$N = \frac{m_w c_w (\Delta T)_w}{m_{\text{pellet}} c_{\text{lead}} |\Delta T|_{\text{lead}}}$$

$$= \frac{(0.500\ \text{kg})(4\,186\ \text{J/kg}\cdot{}^{\circ}\text{C})(25.0^{\circ}\text{C} - 20.0^{\circ}\text{C})}{\left(1.00\times10^{-3}\ \text{kg}\right)(128\ \text{J/kg}\cdot{}^{\circ}\text{C})(200^{\circ}\text{C} - 25.0^{\circ}\text{C})} = \boxed{467}$$

11.17 The total energy absorbed by the cup, stirrer, and water equals the energy given up by the silver sample. Thus,

$$\left[m_c c_{Al} + m_s c_{Cu} + m_w c_w\right](\Delta T)_w = \left[mc|\Delta T|\right]_{Ag}$$

Solving for the mass of the cup gives

$$m_c = \frac{1}{c_{Al}}\left[\left(m_{Ag}c_{Ag}\right)\frac{|\Delta T|_{Ag}}{(\Delta T)_w} - m_s c_{Cu} - m_w c_w\right],$$

or $$m_c = \frac{1}{900}\left[(400\text{ g})(234)\frac{(87-32)}{(32-27)} - (40\text{ g})(387) - (225\text{ g})(4\,186)\right] = \boxed{80\text{ g}}$$

11.18 The mass of water is

$$m_w = \rho_w V_w = \left(1.00\text{ g/cm}^3\right)\left(100\text{ cm}^3\right) = 100\text{ g} = 0.100\text{ kg}$$

For each bullet, the energy absorbed by the bullet equals the energy given up by the water, so $m_b c_b(T - 20.0°\text{C}) = m_w c_w(90.0°\text{C} - T)$. Solving for the final temperature gives

$$T = \frac{m_w c_w(90.0°\text{C}) + m_b c_b(20.0°\text{C})}{m_w c_w + m_b c_b}$$

For the silver bullet, $m_b = 5.00\times10^{-3}$ kg and $c_b = 234$ J/kg·°C, giving

$$T_{\text{silver}} = \frac{(0.100)(4\,186)(90.0°\text{C}) + \left(5.00\times10^{-3}\right)(234)(20.0°\text{C})}{(0.100)(4\,186) + \left(5.00\times10^{-3}\right)(234)} = \boxed{89.8°\text{C}}$$

For the copper bullet, $m_b = 5.00\times10^{-3}$ kg and $c_b = 387$ J/kg·°C, which yields

$$T_{\text{copper}} = \frac{(0.100)(4\,186)(90.0°\text{C}) + \left(5.00\times10^{-3}\right)(387)(20.0°\text{C})}{(0.100)(4\,186) + \left(5.00\times10^{-3}\right)(387)} = \boxed{89.7°\text{C}}$$

Thus, $\boxed{\text{the copper bullet wins}}$ the showdown of the water cups.

11.19 (a) The total energy given up by the copper and the unknown sample equals the total energy absorbed by the calorimeter and water. Hence,

$$m_{Cu}c_{Cu}|\Delta T|_{Cu} + m_{unk}c_{unk}|\Delta T|_{unk} = \left[m_c c_{Al} + m_w c_w\right](\Delta T)_w$$

Solving for the specific heat of the unknown material gives

$$c_{unk} = \frac{\left[m_c c_{Al} + m_w c_w\right](\Delta T)_w - m_{Cu}c_{Cu}|\Delta T|_{Cu}}{m_{unk}|\Delta T|_{unk}},\ \text{or}$$

$$c_{unk} = \frac{1}{(70.0\text{ g})(80.0°\text{C})}\Big\{\left[(100\text{ g})(900\text{ J/kg}\cdot°\text{C}) + (250\text{ g})(4\,186\text{ J/kg}\cdot°\text{C})\right](10.0°\text{C})$$

$$-(50.0\text{ g})(387\text{ J/kg}\cdot°\text{C})(60.0°\text{C})\Big\} = \boxed{1.82\times10^3\text{ J/kg}\cdot°\text{C}}$$

(b) The unknown could be beryllium, but other possibilities also exist.

(c) The material could be an unknown alloy or a material not listed in the table.

11.20 $Q_{cold} = -Q_{hot} \quad \Rightarrow \quad m_w c_w \left(T_f - T_{i,w}\right) = -m_{Fe} c_{Fe} \left(T_f - T_{i,Fe}\right)$

or $T_f = \dfrac{m_w c_w T_{i,w} + m_{Fe} c_{Fe} T_{i,Fe}}{m_w c_w + m_{Fe} c_{Fe}}$

$$= \frac{(20.0\text{ kg})(4\,186\text{ J/kg}\cdot{}^\circ\text{C})(25.0^\circ\text{C}) + (1.50\text{ kg})(448\text{ J/kg}\cdot{}^\circ\text{C})(600^\circ\text{C})}{(20.0\text{ kg})(4\,186\text{ J/kg}\cdot{}^\circ\text{C}) + (1.50\text{ kg})(448\text{ J/kg}\cdot{}^\circ\text{C})}$$

and $T_f = \boxed{29.6^\circ\text{C}}$

11.21 Since the temperature of the water and the steel container is unchanged, and neither substance undergoes a phase change, the internal energy of these materials is constant. Thus, all the energy given up by the copper is absorbed by the aluminum, giving $m_{Al} c_{Al} (\Delta T)_{Al} = m_{Cu} c_{Cu} |\Delta T|_{Cu}$, or

$$m_{Al} = \left(\frac{c_{Cu}}{c_{Al}}\right)\left[\frac{|\Delta T|_{Cu}}{(\Delta T)_{Al}}\right] m_{Cu}$$
$$= \left(\frac{387}{900}\right)\left(\frac{85^\circ\text{C} - 25^\circ\text{C}}{25^\circ\text{C} - 5.0^\circ\text{C}}\right)(200\text{ g}) = 2.6\times10^2\text{ g} = \boxed{0.26\text{ kg}}$$

11.22 The kinetic energy given up by the car is absorbed as internal energy by the four brake drums (a total mass of 32 kg of iron). Thus, $\Delta KE = Q = m_{drums} c_{Fe} (\Delta T)$, or

$$\Delta T = \frac{\frac{1}{2} m_{car} v_i^2}{m_{drums} c_{Fe}} = \frac{\frac{1}{2}(1\,500\text{ kg})(30\text{ m/s})^2}{(32\text{ kg})(448\text{ J/kg}\cdot{}^\circ\text{C})} = \boxed{47^\circ\text{C}}$$

11.23 (a) Assuming that the tin-lead-water mixture is thermally isolated from the environment, we have

$$Q_{cold} = -Q_{hot} \qquad \text{or} \qquad m_w c_w \left(T_f - T_{i,w}\right) = -m_{Sn} c_{Sn} \left(T_f - T_{i,Sn}\right) - m_{Pb} c_{Pb} \left(T_f - T_{i,Pb}\right)$$

and since $m_{Sn} = m_{Pb} = m_{metal} = 0.400\text{ kg}$ and $T_{i,Sn} = T_{i,Pb} = T_{hot} = 60.0^\circ\text{C}$, this yields

$$T_f = \frac{m_w c_w T_{i,w} + m_{metal}\left(c_{Sn} + c_{Pb}\right) T_{hot}}{m_w c_w + m_{metal}\left(c_{Sn} + c_{Pb}\right)}$$
$$= \frac{(1.00\text{ kg})(4\,186\text{ J/kg}\cdot{}^\circ\text{C})(20.0^\circ\text{C}) + (0.400\text{ kg})(227\text{ J/kg}\cdot{}^\circ\text{C} + 128\text{ J/kg}\cdot{}^\circ\text{C})(60.0^\circ\text{C})}{(1.00\text{ kg})(4\,186\text{ J/kg}\cdot{}^\circ\text{C}) + (0.400\text{ kg})(227\text{ J/kg}\cdot{}^\circ\text{C} + 128\text{ J/kg}\cdot{}^\circ\text{C})}$$

yielding $\boxed{T_f = 21.3^\circ\text{C}}$

(b) If an alloy containing a mass m_{Sn} of tin and a mass m_{Pb} of lead undergoes a rise in temperature ΔT, the thermal energy absorbed would be $Q = Q_{Sn} + Q_{Pb}$, or

$$(m_{Sn} + m_{Pb})c_{alloy}(\Delta T) = m_{Sn}c_{Sn}(\Delta T) + m_{Pb}c_{Pb}(\Delta T), \text{ giving } c_{alloy} = \frac{m_{Sn}c_{Sn} + m_{Pb}c_{Pb}}{m_{Sn} + m_{Pb}}$$

If the alloy is a half-and-half mixture, $m_{Sn} = m_{Pb}$, then this reduces to $c_{alloy} = \frac{c_{Sn} + c_{Pb}}{2}$

and yields $c_{alloy} = \frac{227 \text{ J/kg}\cdot°\text{C} + 128 \text{ J/kg}\cdot°\text{C}}{2} = \boxed{178 \text{ J/kg}\cdot°\text{C}}$

(c) For a substance forming monatomic molecules, the number of atoms in a mass equal to the molecular weight of that material is Avogadro's number, N_A. Thus, the number of tin atoms in $m_{Sn} = 0.400 \text{ kg} = 400 \text{ g}$ of tin with a molecular weight of $M_{Sn} = 118.7 \text{ g/mol}$ is

$$N_{Sn} = \left(\frac{m_{Sn}}{M_{Sn}}\right)N_A = \left(\frac{400 \text{ g}}{118.7 \text{ g/mol}}\right)(6.02\times10^{23} \text{ mol}^{-1}) = \boxed{2.03\times10^{24}}$$

and, for the lead, $N_{Pb} = \left(\frac{m_{Pb}}{M_{Pb}}\right)N_A = \left(\frac{400 \text{ g}}{207.2 \text{ g/mol}}\right)(6.02\times10^{23} \text{ mol}^{-1}) = \boxed{1.16\times10^{24}}$

(d) We have $\frac{N_{Sn}}{N_{Pb}} = \frac{2.03\times10^{24}}{1.16\times10^{24}} = \boxed{1.75}$

and observe that $\frac{c_{Sn}}{c_{Pb}} = \frac{227 \text{ J/kg}\cdot°\text{C}}{128 \text{ J/kg}\cdot°\text{C}} = \boxed{1.77}$

from which we conclude that the specific heat of an element is proportional to the number of atoms per unit mass of that element.

11.24 Assuming that the unknown-water-calorimeter system is thermally isolated from the environment, $-Q_{hot} = Q_{cold}$, or $-m_x c_x (T_f - T_{i,x}) = m_w c_w (T_f - T_{i,w}) + m_{Al}c_{Al}(T_f - T_{i,Al})$ and, since $T_{i,w} = T_{i,Al} = T_{cold} = 25.0°\text{C}$, we have

$$c_x = (m_w c_w + m_{Al}c_{Al})(T_f - T_{cold}) / m_x (T_{i,x} - T_f)$$

or $$c_x = \frac{[(0.285 \text{ kg})(4\,186 \text{ J/kg}\cdot°\text{C}) + (0.150 \text{ kg})(900 \text{ J/kg}\cdot°\text{C})](32.0 - 25.0)°\text{C}}{(0.125 \text{ kg})(95.0°\text{C} - 32.0°\text{C})}$$

yielding $c_x = \boxed{1.18\times10^3 \text{ J/kg}\cdot°\text{C}}$

11.25 Remember that energy must be supplied to melt the ice before its temperature will begin to rise. Then, assuming a thermally isolated system, $Q_{\text{cold}} = -Q_{\text{hot}}$, or

$$m_{\text{ice}} L_f + m_{\text{ice}} c_{\text{water}} \left(T_f - 0°\text{C}\right) = -m_{\text{water}} c_{\text{water}} \left(T_f - 25°\text{C}\right)$$

and

$$T_f = \frac{m_{\text{water}} c_{\text{water}} (25°\text{C}) - m_{\text{ice}} L_f}{\left(m_{\text{ice}} + m_{\text{water}}\right) c_{\text{water}}} = \frac{\left(825 \not{g}\right)(4\,186 \text{ J/kg}\cdot°\text{C})(25°\text{C}) - \left(75 \not{g}\right)\left(3.33\times10^5 \text{ J/kg}\right)}{\left(75 \not{g} + 825 \not{g}\right)(4\,186 \text{ J/kg}\cdot°\text{C})}$$

yielding $\boxed{T_f = 16°\text{C}}$

11.26 The total energy input required is

$$\begin{aligned} Q &= (\text{energy to melt 50 g of ice}) \\ &\quad + (\text{energy to warm 50 g of water to } 100°\text{C}) \\ &\quad + (\text{energy to vaporize 5.0 g water}) \\ &= (50 \text{ g}) L_f + (50 \text{ g}) c_{\text{water}} (100°\text{C} - 0°\text{C}) + (5.0 \text{ g}) L_v \end{aligned}$$

$$\begin{aligned} \text{Thus, } Q &= (0.050 \text{ kg})\left(3.33\times10^5 \frac{\text{J}}{\text{kg}}\right) \\ &\quad + (0.050 \text{ kg})\left(4\,186 \frac{\text{J}}{\text{kg}\cdot°\text{C}}\right)(100°\text{C} - 0°\text{C}) \\ &\quad + \left(5.0\times10^{-3} \text{ kg}\right)\left(2.26\times10^6 \frac{\text{J}}{\text{kg}}\right) \end{aligned}$$

which gives $Q = 4.9\times10^4 \text{ J} = \boxed{49 \text{ kJ}}$

11.27 The conservation of energy equation for this process is

$$(\text{energy to melt ice}) + (\text{energy to warm melted ice to } T) = (\text{energy to cool water to } T)$$

Or $m_{\text{ice}} L_f + m_{\text{ice}} c_w (T - 0°\text{C}) = m_w c_w (80°\text{C} - T)$

This yields $T = \dfrac{m_w c_w (80°\text{C}) - m_{\text{ice}} L_f}{\left(m_{\text{ice}} + m_w\right) c_w}$

so

$$T = \frac{(1.0 \text{ kg})(4\,186 \text{ J/kg}\cdot°\text{C})(80°\text{C}) - (0.100 \text{ kg})\left(3.33\times10^5 \text{ J/kg}\right)}{(1.1 \text{ kg})(4\,186 \text{ J/kg}\cdot°\text{C})} = \boxed{65\,°\text{C}}$$

11.28 The energy required is the following sum of terms:

$$Q = (\text{energy to reach melting point}) + (\text{energy to melt}) + (\text{energy to reach boiling point}) + (\text{energy to vaporize}) + (\text{energy to reach } 110°\text{C})$$

Mathematically,

$$Q = m\left[c_{ice}\left[0°\text{C} - (-10°\text{C})\right] + L_f + c_{water}(100°\text{C} - 0°\text{C}) + L_v + c_{steam}(110°\text{C} - 100°\text{C})\right]$$

This yields

$$Q = \left(40\times10^{-3}\ \text{kg}\right)\left[\left(2\,090\ \frac{\text{J}}{\text{kg}\cdot°\text{C}}\right)(10°\text{C}) + \left(3.33\times10^5\ \frac{\text{J}}{\text{kg}}\right) + \left(4\,186\ \frac{\text{J}}{\text{kg}\cdot°\text{C}}\right)(100°\text{C}) + \left(2.26\times10^6\ \frac{\text{J}}{\text{kg}}\right) + \left(2\,010\ \frac{\text{J}}{\text{kg}\cdot°\text{C}}\right)(10°\text{C})\right]$$

or $Q = 1.2\times10^5\ \text{J} = \boxed{0.12\ \text{MJ}}$

11.29 Assuming all work done against friction is used to melt snow, the energy balance equation is $f\cdot s = m_{snow}L_f$. Since $f = \mu_k(m_{skier}g)$, the distance traveled is

$$s = \frac{m_{snow}L_f}{\mu_k(m_{skier}g)} = \frac{(1.0\ \text{kg})(3.33\times10^5\ \text{J/kg})}{0.20(75\ \text{kg})(9.80\ \text{m/s}^2)} = 2.3\times10^3\ \text{m} = \boxed{2.3\ \text{km}}$$

11.30 (a) Observe that the equilibrium temperature will lie between the two extreme temperatures $(-10.0°\text{C}$ and $+30.0°\text{C})$ of the mixed materials. Also, observe that a water-ice change of phase can be expected in this temperature range, but that neither aluminum nor ethyl alcohol undergoes a change of phase in this temperature range. The thermal energy transfers we can anticipate as the system comes to an equilibrium temperature are:

ice at $-10.0°$C to ice at $0°$C; ice at $0°$C to liquid water at $0°$C; water at $0°$C to water at T; aluminum at $20.0°$C to aluminum at T; ethyl alcohol at $30.0°$C to ethyl alcohol at T.

(b)

Q	m (kg)	c (J/kg·°C)	L (J/kg)	T_f (°C)	T_i (°C)	**Expression**
Q_{ice}	1.00	2090		0	−10.0	$m_{ice}c_{ice}\left[0-(-10.0°\text{C})\right]$
Q_{melt}	1.00		3.33×10^5	0	0	$m_{ice}L_f$
Q_{water}	1.00	4 186		T	0	$m_{ice}c_{water}(T-0)$
Q_{Al}	0.500	900		T	20.0	$m_{Al}c_{Al}[T-20.0°\text{C}]$
Q_{alc}	6.00	2 430		T	30.0	$m_{alc}c_{alc}[T-30.0°\text{C}]$

(c) $\boxed{m_{ice}c_{ice}(10.0°C)+m_{ice}L_f+m_{ice}c_{water}(T-0)+m_{Al}c_{Al}[T-20.0°C]+m_{alc}c_{alc}[T-30.0°C]=0}$

(d) $$T=\frac{m_{Al}c_{Al}(20.0°C)+m_{alc}c_{alc}(30.0°C)-m_{ice}\left[c_{ice}(10.0°C)+L_f\right]}{m_{ice}c_{water}+m_{Al}c_{Al}+m_{alc}c_{alc}}$$

Substituting in numeric values from the table in (b) above gives

$$T=\frac{(0.500)(900)(20.0)+(6.00)(2\,430)(30.0)-(1.00)\left[(2\,090)(10.0)+3.33\times10^5\right]}{(1.00)(4\,186)+(0.500)(900)+(6.00)(2\,430)}$$

and yields $\boxed{T=4.81°C}$

11.31 Assume that all the ice melts. If this yields a result $T>0$, the assumption is valid, otherwise the problem must be solved again based on a different premise. If all ice melts, energy conservation $(Q_{cold}=-Q_{hot})$ yields

$$m_{ice}\left[c_{ice}\left[0°C-(-78°C)\right]+L_f+c_w(T-0°C)\right]=-(m_wc_w+m_{cal}c_{Cu})(T-25°C)$$

or $$T=\frac{(m_wc_w+m_{cal}c_{Cu})(25°C)-m_{ice}\left[c_{ice}(78°C)+L_f\right]}{(m_w+m_{ice})c_w+m_{cal}c_{Cu}}$$

With $m_w=0.560$ kg, $m_{cal}=0.080$ g, $m_{ice}=0.040$ g, $c_w=4\,186$ J/kg·°C,

$c_{Cu}=387$ J/kg·°C, $c_{ice}=2\,090$ J/kg·°C, and $L_f=3.33\times10^5$ J/kg,

this gives

$$T=\frac{\left[(0.560)(4\,186)+(0.080)(387)\right](25°C)-(0.040)\left[(2\,090)(78°C)+3.33\times10^5\right]}{(0.560+0.040)(4\,186)+0.080(387)}$$

or $T=\boxed{16°C}$ and the assumption that all ice melts is seen to be valid.

11.32 At a rate of 400 kcal/h, the excess internal energy that must be eliminated in a half-hour run is

$$Q=\left(400\times10^3\ \frac{\text{cal}}{\text{h}}\right)\left(\frac{4.186\ \text{J}}{1\ \text{cal}}\right)(0.500\ \text{h})=8.37\times10^5\ \text{J}$$

The mass of water that will be evaporated by this amount of excess energy is

$$m_{evaporated}=\frac{Q}{L_v}=\frac{8.37\times10^5\ \text{J}}{2.5\times10^6\ \text{J/kg}}=\boxed{0.33\ \text{kg}}$$

The mass of fat burned (and thus, the mass of water produced at a rate of 1 gram of water per gram of fat burned) is

$$m_{produced}=\frac{(400\ \text{kcal/h})(0.500\ \text{h})}{9.0\ \text{kcal/gram of fat}}=22\ \text{g}=22\times10^{-3}\ \text{kg}$$

so the fraction of water needs provided by burning fat is

$$f = \frac{m_{\text{produced}}}{m_{\text{evaporated}}} = \frac{22\times10^{-3}\ \text{kg}}{0.33\ \text{kg}} = \boxed{0.067 \text{ or } 6.7\%}$$

11.33 (a) The mass of 2.Oliters of water is $m_w = \rho V = \left(10^3\ \text{kg/m}^3\right)\left(2.0\times10^{-3}\ \text{m}^3\right) = 2.0\ \text{kg}.$

The energy required to raise the temperature of the water (and pot) up to the boiling point of water is

$$Q_{\text{boil}} = \left(m_w c_w + m_{\text{Al}} c_{\text{Al}}\right)(\Delta T)$$

or $Q_{\text{boil}} = \left[(2.0\ \text{kg})\left(4\,186\ \frac{\text{J}}{\text{kg}}\right) + (0.25\ \text{kg})\left(900\ \frac{\text{J}}{\text{kg}}\right)\right](100°\text{C} - 20°\text{C}) = 6.9\times10^5\ \text{J}$

The time required for the 14000 Btu/h burner to produce this much energy is

$$t_{\text{boil}} = \frac{Q_{\text{boil}}}{14\,000\ \text{Btu/h}} = \frac{6.9\times10^5\ \text{J}}{14\,000\ \text{Btu/h}}\left(\frac{1\ \text{Btu}}{1.054\times10^3\ \text{J}}\right) = 4.7\times10^{-2}\ \text{h} = \boxed{2.8\ \text{min}}$$

(b) Once the boiling temperature is reached, the additional energy required to evaporate all of the water is

$$Q_{\text{evaporate}} = m_w L_v = (2.0\ \text{kg})\left(2.26\times10^6\ \text{J/kg}\right) = 4.5\times10^6\ \text{J}$$

and the time required for the burner to produce this energy is

$$t_{\text{evaporate}} = \frac{Q_{\text{evaporate}}}{14\,000\ \text{Btu/h}} = \frac{4.5\times10^6\ \text{J}}{14\,000\ \text{Btu/h}}\left(\frac{1\ \text{Btu}}{1.054\times10^3\ \text{J}}\right) = 0.30\ \text{h} = \boxed{18\ \text{min}}$$

11.34 In one hour, the energy dissipated by the runner is

$$\Delta E = P\cdot t = (300\ \text{J/s})(3\,600\ \text{s}) = 1.08\times10^6\ \text{J}$$

Ninety percent, or $Q = 0.900\left(1.08\times10^6\ \text{J}\right) = 9.72\times10^5\ \text{J},$ of this is used to evaporate bodily fluids. The mass of fluid evaporated is

$$m = \frac{Q}{L_v} = \frac{9.72\times10^5\ \text{J}}{2.41\times10^6\ \text{J/kg}} = 0.403\ \text{kg}$$

Assuming the fluid is primarily water, the volume of fluid evaporated in one hour is

$$V = \frac{m}{\rho} = \frac{0.403\ \text{kg}}{1\,000\ \text{kg/m}^3} = \left(4.03\times10^{-4}\ \text{m}^3\right)\left(\frac{10^6\ \text{cm}^3}{1\ \text{m}^3}\right) = \boxed{403\ \text{cm}^3}$$

11.35 The energy required to melt 50 g of ice is

$$Q_1 = m_{\text{ice}} L_f = (0.050\ \text{kg})(333\ \text{kJ/kg}) = 17\ \text{kJ}$$

The energy needed to warm 50 g of melted ice from 0°C to 100°C is

$$Q_2 = m_{\text{ice}} c_{\text{w}} (\Delta T) = (0.050\ \text{kg})(4.186\ \text{kJ/kg}\cdot{}^\circ\text{C})(100^\circ\text{C}) = 21\ \text{kJ}$$

(a) If 10 *g* of steam is used, the energy it will give up as it condenses is

$$Q_3 = m_{\text{steam}} L_v = (0.010\ \text{kg})(2\,260\ \text{kJ/kg}) = 23\ \text{kJ}$$

Since $Q_3 > Q_1$, all of the ice will melt. However, $Q_3 < Q_1 + Q_2$, so the final temperature is less than 100°C. From conservation of energy, we find

$$Q_{\text{cold}} = -Q_{\text{hot}}$$

$$m_{\text{ice}}\left[L_f + c_{\text{w}}(T - 0^\circ\text{C})\right] = -m_{\text{steam}}\left[-L_v + c_{\text{w}}(T - 100^\circ\text{C})\right]$$

or

$$T = \frac{m_{\text{steam}}\left[L_v + c_{\text{w}}(100^\circ\text{C})\right] - m_{\text{ice}} L_f}{(m_{\text{ice}} + m_{\text{steam}})c_{\text{w}}},$$

giving $T = \dfrac{(10\ \text{g})\left[2.26\times 10^6 + (4\,186)(100)\right] - (50\ \text{g})(3.33\times 10^5)}{(50\ \text{g} + 10\ \text{g})(4\,186)} = \boxed{40^\circ\text{C}}$

(b) If only 1.0 g of steam is used, then $Q_3' = m_{\text{steam}} L_v = 2.26\ \text{kJ}$. The energy 1.0 g of condensed steam can give up as it cools from 100°C to 0°C is

$$Q_4 = m_{\text{steam}} c_{\text{w}} (\Delta T) = (1.0\times 10^{-3}\ \text{kg})(4.186\ \text{kJ/kg}\cdot{}^\circ\text{C})(100^\circ\text{C}) = 0.42\ \text{kJ}$$

Since $Q_3' + Q_4$ is less than Q_1, not all of the 50 g of ice will melt, so the final temperature will be $\boxed{0^\circ\text{C}}$. The mass of ice which melts as the steam condenses and the condensate cools to 0°C is

$$m = \frac{Q_3' + Q_4}{L_f} = \frac{(2.26 + 0.42)\ \text{kJ}}{333\ \text{kJ/kg}} = 8.0\times 10^{-3}\ \text{kg} = \boxed{8.0\ \text{g}}$$

11.36 First, we use the ideal gas law (with $V = 0.600\ \text{L} = 0.600\times 10^{-3}\ \text{m}^3$ and $T = 37.0^\circ\text{C} = 310\ \text{K}$) to determine the quantity of water vapor in each exhaled breath:

$$PV = nRT \;\Rightarrow\; n = \frac{PV}{RT} = \frac{(3.20\times 10^3\ \text{Pa})(0.600\times 10^{-3}\ \text{m}^3)}{(8.31\ \text{J/mol}\cdot\text{K})(310\ \text{K})} = 7.45\times 10^{-4}\ \text{mol}$$

or $m = nM_{\text{water}} = (7.45\times 10^{-4}\ \cancel{\text{mol}})\left(18.0\ \dfrac{\cancel{\text{g}}}{\cancel{\text{mol}}}\right)\left(\dfrac{1\ \text{kg}}{10^3\ \cancel{\text{g}}}\right) = 1.34\times 10^{-5}\ \text{kg}$

The energy required to vaporize this much water, and hence the energy carried from the body with each breath, is

$$Q = mL_v = (1.34\times 10^{-5}\ \text{kg})(2.26\times 10^6\ \text{J/kg}) = 30.3\ \text{J}$$

The rate of losing energy by exhaling humid air is then

$$P = Q\cdot(\textit{respiration rate}) = \left(30.3\ \frac{\text{J}}{\text{breath}}\right)\left(22.0\ \frac{\text{breaths}}{\text{min}}\right)\left(\frac{1\ \text{min}}{60\ \text{s}}\right) = \boxed{11.1\ \text{W}}$$

11.37 (a) The bullet loses all of its kinetic energy as it is stopped by the ice. Also, thermal energy is transferred from the bullet to the ice as the bullet cools from $30.0^o C$ to the final temperature. The sum of these two quantities of energy equals the energy required to melt part of the ice. The $\boxed{\text{final temperature is 0°C}}$ because not all of the ice melts.

(b) The total energy transferred from the bullet to the ice is

$$Q = KE_i + m_{\text{bullet}} c_{\text{lead}} \left|0°\text{C} - 30.0°\text{C}\right| = \frac{1}{2} m_{\text{bullet}} v_i^2 + m_{\text{bullet}} c_{\text{lead}} (30.0°\text{C})$$

$$= \left(3.00\times10^{-3}\ \text{kg}\right)\left[\frac{\left(2.40\times10^2\ \text{m/s}\right)^2}{2} + \left(128\ \text{J/kg}\cdot°\text{C}\right)\left(30.0°\text{C}\right)\right] = 97.9\ \text{J}$$

The mass of ice that melts when this quantity of thermal energy is absorbed is

$$m = \frac{Q}{\left(L_f\right)_{\text{water}}} = \frac{97.9\ \text{J}}{3.33\times10^5\ \text{J/kg}} = 2.94\times10^{-4}\ \text{kg}\left(\frac{10^3\ \text{g}}{1\ \text{kg}}\right) = \boxed{0.294\ \text{g}}$$

11.38 (a) The rate of energy transfer by conduction through a material of area A, thickness L, with thermal conductivity k, and temperatures $T_h > T_c$ on opposite sides is $P = kA(T_h - T_c)/L.$ For the given windowpane, this is

$$P = \left(0.8\ \frac{\text{J}}{\text{s}\cdot\text{m}\cdot°\text{C}}\right)\left[(1.0\ \text{m})(2.0\ \text{m})\right]\frac{(25°\text{C} - 0°\text{C})}{0.62\times10^{-2}\ \text{m}} = 6\times10^3\ \text{J/s} = \boxed{6\times10^3\ \text{W}}$$

(b) The total energy lost per day is

$$E = P\cdot\Delta t = \left(6\times10^3\ \text{J/s}\right)\left(8.64\times10^4\ \text{s}\right) = \boxed{5\times10^8\ \text{J}}$$

11.39 The rate of energy transfer by conduction through a material having thermal conductivity κ, cross-sectional area A, thickness L and a temperature change of $T_h - T_c$ across it is $P = \kappa A\ (T_h - T_c)/L.$ Hence, with $\kappa = 0.6\ \text{J/s}\cdot\text{m}\cdot°\text{C}$ for water, the rate of energy transfer by conduction to the bottom of the pond is

$$P = \frac{\left(0.6\ \text{J/s}\cdot\text{m}\cdot°\text{C}\right)\left(820\ \text{m}^2\right)\left(25°\text{C} - 12°\text{C}\right)}{2.0\ \text{m}} = 3\times10^3\ \text{J/s} = \boxed{3\times10^3\ \text{W}}$$

11.40 (a) The R value of a material is $R = L/\kappa,$ where L is its thickness and κ is the thermal conductivity. The R values of the three layers covering the core tissues in this body are:

$$R_{\text{skin}} = \frac{1.0\times10^{-3}\ \text{m}}{0.020\ \text{W/m}\cdot\text{K}} = \boxed{5.0\times10^{-2}\ \text{m}^2\cdot\text{K/W}}$$

$$R_{\text{fat}} = \frac{0.50\times10^{-2}\ \text{m}}{0.020\ \text{W/m}\cdot\text{K}} = \boxed{2.5\times10^{-2}\ \text{m}^2\cdot\text{K/W}}$$

and

$$R_{\text{tissue}} = \frac{3.2\times10^{-2}\ \text{m}}{0.50\ \text{W/m}\cdot\text{K}} = \boxed{6.4\times10^{-2}\ \text{m}^2\cdot\text{K/W}}$$

so the total R value of the three layers taken together is

$$R_{\text{total}} = \sum_{i=1}^{3} R_i = (5.0 + 2.5 + 6.4)\times10^{-2}\ \frac{\text{m}^2\cdot\text{K}}{\text{W}} = 14\times10^{-2}\ \frac{\text{m}^2\cdot\text{K}}{\text{W}} = \boxed{0.14\ \frac{\text{m}^2\cdot\text{K}}{\text{W}}}$$

(b) The rate of energy transfer by conduction through these three layers with a surface area of $A = 2.0 \text{ m}^2$ and temperature difference of $\Delta T = (37-0)°\text{C} = 37°\text{C} = 37 \text{ K}$ is

$$P = \frac{A(\Delta T)}{R_{\text{total}}} = \frac{(2.0 \text{ m}^2)(37 \text{ K})}{0.14 \text{ m}^2\cdot\text{K/W}} = \boxed{5.3\times10^2 \text{ W}}$$

11.41 $P = \kappa A\left(\frac{\Delta T}{L}\right)$, with $\kappa = 0.200 \ \frac{\text{cal}}{\text{cm}\cdot°\text{C}\cdot\text{s}}\left(\frac{10^2 \text{ cm}}{1 \text{ m}}\right)\left(\frac{4.186 \text{ J}}{1 \text{ cal}}\right) = 83.7 \ \frac{\text{J}}{\text{s}\cdot\text{m}\cdot°\text{C}}$

Thus, the energy transfer rate is

$$P = \left(83.7 \ \frac{\text{J}}{\text{s}\cdot\text{m}\cdot°\text{C}}\right)\left[(8.00 \text{ m})(50.0 \text{ m})\right]\left(\frac{200°\text{C} - 20.0°\text{C}}{1.50\times10^{-2} \text{ m}}\right)$$

$$= 4.02\times10^8 \text{ J/s} = 4.02\times10^8 \text{ W} = \boxed{402 \text{ MW}}$$

11.42 The total surface area of the house is

$$A = A_{\text{side walls}} + A_{\text{end walls}} + A_{\text{gables}} + A_{\text{roof}}$$

where $A_{\text{side walls}} = 2\left[(5.00 \text{ m})\times(10.0 \text{ m})\right] = 100 \text{ m}^2$

$$A_{\text{end walls}} = 2\left[(5.00 \text{ m})\times(8.00 \text{ m})\right] = 80.0 \text{ m}^2$$

$$A_{\text{gables}} = 2\left[\tfrac{1}{2}(\textit{base})\times(\textit{altitude})\right] = 2\left[\tfrac{1}{2}(8.00 \text{ m})\times(4.00 \text{ m})\tan 37.0°\right] = 24.1 \text{ m}^2$$

$$A_{\text{roof}} = 2\left[(10.0 \text{ m})\times(4.00 \text{ m}/\cos 37.0°)\right] = 100 \text{ m}^2$$

Thus, $A = 100 \text{ m}^2 + 80.0 \text{ m}^2 + 24.1 \text{ m}^2 + 100 \text{ m}^2 = 304 \text{ m}^2$

With an average thickness of 0.210 m, average thermal conductivity of $4.8\times10^{-4} \text{ kW/m}\cdot°\text{C}$, and a $25.0°\text{C}$ difference between inside and outside temperatures, the energy transfer from the house to the outside air each day is

$$E = P(\Delta t) = \left[\frac{\kappa A(\Delta T)}{L}\right](\Delta t) = \left[\frac{(4.8\times10^{-4} \text{ kW/m}\cdot°\text{C})(304 \text{ m}^2)(25.0°\text{C})}{0.210 \text{ m}}\right](86\,400 \text{ s})$$

or $E = 1.5\times10^6 \text{ kJ} = 1.5\times10^9 \text{ J}$

The volume of gas that must be burned to replace this energy is

$$V = \frac{E}{\textit{heat of combustion}} = \frac{1.5\times10^9 \text{ J}}{(9\,300 \text{ kcal/m}^3)(4\,186 \text{ J/kcal})} = \boxed{39 \text{ m}^3}$$

11.43 Because the two pots hold the same quantity of water at the same initial temperature, the same amount, Q, of thermal energy is required to boil away the water in each pot. The time required to do this for one of the pots is $t = Q/P$, where P is the rate of energy conduction from the stove to the water through the bottom of the pot. The ratio of the times required for the two pots is

$$\frac{t_{Al}}{t_{Cu}} = \left(\frac{\cancel{Q}}{P_{Al}}\right)\left(\frac{P_{Cu}}{\cancel{Q}}\right) = \frac{\kappa_{Cu}\cancel{A}\left(\cancel{\Delta T}\right)/\cancel{L}}{\kappa_{Al}\cancel{A}\left(\cancel{\Delta T}\right)/\cancel{L}} = \frac{\kappa_{Cu}}{\kappa_{Al}}$$

Note that in the above calculation everything except the thermal conductivities canceled because the two pots are identical except for the material making up the bottoms. Thus, the time required to boil away the water in the aluminum bottomed pot is

$$t_{Al} = \left(\frac{\kappa_{Cu}}{\kappa_{Al}}\right)t_{Cu} = \left(\frac{397\ \text{W/m}\cdot{}^\circ\text{C}}{238\ \text{W/m}\cdot{}^\circ\text{C}}\right)(425\ \text{s}) = \boxed{709\ \text{s}}$$

11.44 The rate of energy transfer through a compound slab is

$$P = \frac{A(\Delta T)}{R},\ \text{where}\ R = \Sigma L_i/\kappa_i$$

(a) For the thermopane, $R = R_{pane} + R_{trapped\ air} + R_{pane} = 2R_{pane} + R_{trapped\ air}$

Thus, $R = 2\left(\frac{0.50\times10^{-2}\ \text{m}}{0.8\ \text{W/m}\cdot{}^\circ\text{C}}\right) + \frac{1.0\times10^{-2}\ \text{m}}{0.023\,4\ \text{W/m}\cdot{}^\circ\text{C}} = (0.01+0.43)\ \frac{\text{m}^2\cdot{}^\circ\text{C}}{\text{W}} = 0.44\ \frac{\text{m}^2\cdot{}^\circ\text{C}}{\text{W}}$

and $P = \frac{(1.0\ \text{m}^2)(23^\circ\text{C})}{0.44\ \text{m}^2\cdot{}^\circ\text{C/W}} = \boxed{52\ \text{W}}$

(b) For the 1.0 cm thick pane of glass,

$$R = \frac{1.0\times10^{-2}\ \text{m}}{0.8\ \text{W/m}\cdot{}^\circ\text{C}} = 1\times10^{-2}\ \frac{\text{m}^2\cdot{}^\circ\text{C}}{\text{W}}$$

so $P = \frac{(1.0\ \text{m}^2)(23^\circ\text{C})}{1\times10^{-2}\ \text{m}^2\cdot{}^\circ\text{C/W}} = 2\times10^3\ \text{W} = \boxed{2\ \text{kW}}$, about 38 times greater

11.45 When the temperature of junction stabilizes, the energy transfer rate must be the same for each of the rods, or $P_{Cu} = P_{Al}$. The cross-sectional areas of the rods are equal, and if the temperature of the junction is 50°C, the temperature difference is $\Delta T = 50^\circ\text{C}$ for each rod.

Thus, $P_{Cu} = \kappa_{Cu}A\left(\frac{\Delta T}{L_{Cu}}\right) = \kappa_{Al}A\left(\frac{\Delta T}{L_{Al}}\right) = P_{Al}$, which gives

$$L_{Al} = \left(\frac{\kappa_{Al}}{\kappa_{Cu}}\right)L_{Cu} = \left(\frac{238\ \text{W/m}\cdot{}^\circ\text{C}}{397\ \text{W/m}\cdot{}^\circ\text{C}}\right)(15\ \text{cm}) = \boxed{9.0\ \text{cm}}$$

11.46 The energy transfer rate is $P = \frac{\Delta Q}{\Delta t} = \frac{m_{ice} L_f}{\Delta t} = \frac{(5.0 \text{ kg})(3.33\times10^5 \text{ J/kg})}{(8.0 \text{ h})(3\,600 \text{ s/1 h})} = 58 \text{ W}$

Thus, $P = \kappa A\left(\frac{\Delta T}{L}\right)$ gives the thermal conductivity as

$$\kappa = \frac{P\cdot L}{A(\Delta T)} = \frac{(58 \text{ W})(2.0\times10^{-2} \text{ m})}{(0.80 \text{ m}^2)(25°\text{C} - 5.0°\text{C})} = \boxed{7.3\times10^{-2} \text{ W/m}\cdot°\text{C}}$$

11.47 The window will consist of the glass pane and a stagnant air layer on each side (see Example 11.10 in text). From Tables 11.3 and 11.4, the R-values for these layers are

$$R_{pane} = \frac{L}{\kappa_{glass}} = \frac{0.40\times10^{-2} \text{ m}}{0.80 \text{ W/m}\cdot°\text{C}} = 5.0\times10^{-3} \ \frac{\text{m}^2\cdot°\text{C}}{\text{W}}$$

and $R_{\substack{air\\layer}} = 0.17 \ \frac{\text{ft}^2\cdot°\text{F}}{\text{Btu/h}}\cdot\left(\frac{1 \text{ Btu/h}}{0.293 \text{ W}}\right)\left(\frac{1 \text{ m}}{3.281 \text{ ft}}\right)^2\left(\frac{1 °\text{C}}{9/5 °\text{F}}\right) = 0.030 \ \frac{\text{m}^2\cdot°\text{C}}{\text{W}}$

Thus, $R_{total} = \Sigma R_i = (0.030 + 5.0\times10^{-3} + 0.030) \ \frac{\text{m}^2\cdot°\text{C}}{\text{W}} = 0.065 \ \frac{\text{m}^2\cdot°\text{C}}{\text{W}}$

The energy loss through the window in a 12 hour interval is then

$$Q = P\cdot t = \frac{A(T_h - T_c)}{\Sigma R_i}\cdot t = \frac{(2.0 \text{ m}^2)(20°\text{C})}{0.065 \text{ m}^2\cdot°\text{C/W}}\cdot(12 \text{ h})\left(\frac{3\,600 \text{ s}}{1 \text{ h}}\right) = \boxed{2.7\times10^7 \text{ J}}$$

11.48 Since 97% of the incident energy is reflected, the rate of energy absorption from the sunlight is $P_{absorbed} = 3.0\% \times (I\cdot A) = 0.030(I\cdot A)$, where I is the intensity of the solar radiation.

$$P_{absorbed} = 0.030(1.40\times10^3 \text{ W/m}^2)(1.00\times10^3 \text{ m})^2 = 4.2\times10^7 \text{ W}$$

Assuming the sail radiates equally from both sides (so $A = 2(1.00 \text{ km})^2 = 2.00\times10^6 \text{ m}^2$), the rate at which it will radiate energy to a 0 K environment when it has absolute temperature T is

$$P_{radiated} = \sigma A e(T^4 - 0)$$
$$= \left(5.669\,6\times10^{-8} \ \frac{\text{W}}{\text{m}^2\cdot\text{K}^4}\right)(2.00\times10^6 \text{ m}^2)(0.03)\cdot T^4 = \left(3.4\times10^{-3} \ \frac{\text{W}}{\text{K}^4}\right)\cdot T^4$$

At the equilibrium temperature, where $P_{radiated} = P_{absorbed}$, we then have

$$\left(3.4\times10^{-3} \ \frac{\text{W}}{\text{K}^4}\right)\cdot T^4 = 4.2\times10^7 \text{ W} \qquad \text{or} \qquad T = \left[\frac{4.2\times10^7 \text{ W}}{3.4\times10^{-3} \text{ W/K}^4}\right]^{1/4} = \boxed{330 \text{ K}}$$

11.49 The absolute temperatures of the two stars are $T_X = 5\,727 + 273 = 6\,000$ K and $T_Y = 11\,727 + 273 = 12\,000$ K. Thus, the ratio of their radiated powers is

$$\frac{P_Y}{P_X} = \frac{\sigma A e T_Y^4}{\sigma A e T_X^4} = \left(\frac{T_Y}{T_X}\right)^4 = (2)^4 = \boxed{16}$$

11.50 From Stefan's law, the power radiated by an object at absolute temperature T and surface area A is $P = \sigma A e T^4$, where $\sigma = 5.6696\times10^{-8}\ \text{W/m}^2\cdot\text{K}$ and e is the emissivity. Thus, the surface area of the filament must be

$$A = \frac{P}{\sigma e T^4} = \frac{75\ \text{W}}{\left(5.669\,6\times10^{-8}\ \text{W/m}^2\cdot\text{K}^4\right)(1.0)(3\,300\ \text{K})^4} = \boxed{1.1\times10^{-5}\ \text{m}^2}$$

11.51 At a pressure of 1 atm, water boils at 100°C, Thus, the temperature on the interior of the copper kettle is 100°C and the energy transfer rate through the bottom is

$$P = \kappa A\left(\frac{\Delta T}{L}\right) = \left(397\ \frac{\text{W}}{\text{m}\cdot{}^\circ\text{C}}\right)\left[\pi(0.10\ \text{m})^2\right]\left(\frac{102^\circ\text{C} - 100^\circ\text{C}}{2.0\times10^{-3}\ \text{m}}\right)$$

$$= 1.2\times10^4\ \text{W} = \boxed{12\ \text{kW}}$$

11.52 The mass of the water in the heater is

$$m = \rho V = \left(10^3\ \frac{\text{kg}}{\text{m}^3}\right)(50.0\ \text{gal})\left(\frac{3.786\ \text{L}}{1\ \text{gal}}\right)\left(\frac{1\ \text{m}^3}{10^3\ \text{L}}\right) = 189\ \text{kg}$$

The energy required to raise the temperature of the water from 20.0°C to 60.0°C is

$$Q = mc(\Delta T) = (189\ \text{kg})(4\,186\ \text{J/kg})(60.0^\circ\text{C} - 20.0^\circ\text{C}) = 3.16\times10^7\ \text{J}$$

The time required for the water heater to transfer this energy is

$$t = \frac{Q}{P} = \frac{3.16\times10^7\ \text{J}}{4\,800\ \text{J/s}}\left(\frac{1\ \text{h}}{3\,600\ \text{s}}\right) = \boxed{1.83\ \text{h}}$$

11.53 The energy conservation equation is $Q_{\text{cold}} = -Q_{\text{hot}}$, or

$$m_{\text{ice}}L_f + \left[(m_{\text{ice}} + m_{\text{w}})c_{\text{w}} + m_{\text{cup}}c_{\text{Cu}}\right](12^\circ\text{C} - 0^\circ\text{C}) = -m_{\text{Pb}}c_{\text{Pb}}(12^\circ\text{C} - 98^\circ\text{C})$$

This gives

$$m_{\text{Pb}}\left(128\ \frac{\text{J}}{\text{kg}\cdot{}^\circ\text{C}}\right)(86^\circ\text{C}) = (0.040\ \text{kg})\left(3.33\times10^5\ \text{J/kg}\right)$$
$$+\left[(0.24\ \text{kg})(4\,186\ \text{J/kg}\cdot{}^\circ\text{C}) + (0.100\ \text{kg})(387\ \text{J/kg}\cdot{}^\circ\text{C})\right](12^\circ\text{C})$$

or $m_{\text{Pb}} = \boxed{2.3\ \text{kg}}$

11.54 (a) The net rate of energy transfer by radiation between a body at absolute temperature T and its surroundings at absolute temperature T_0 is $P_{net} = \sigma A e(T^4 - T_0^4)$. Hence, with $T = 33.0^\circ\text{C} = 306\ \text{K}$, $T_0 = 20.0^\circ\text{C} = 293\ \text{K}$, emissivity $= e = 0.95$, and surface area $A = 1.50\ \text{m}^2$, the net power radiated is

$$P_{\text{net}} = \left(5.669\,6\times10^{-8}\ \frac{\text{W}}{\text{m}^2\cdot\text{K}^4}\right)\left(1.50\ \text{m}^2\right)(0.95)\left[(306\ \text{K})^4-(293\ \text{K})^4\right]=\boxed{+1.1\times10^2\ \text{W}}$$

(b) The positive sign on the net power radiated means that the body is radiating energy away faster than it is absorbing energy from the environment.

11.55 The conservation of energy equation is $Q_{\text{cold}} = -Q_{\text{hot}}$, or

$$\left(m_\text{w}c_\text{w}+m_\text{cup}c_\text{glass}\right)(T-27^\circ\text{C})=-m_\text{Cu}c_\text{Cu}\left(T-90^\circ\text{C}\right)$$

This gives $T=\dfrac{m_\text{Cu}c_\text{Cu}\left(90^\circ\text{C}\right)+\left(m_\text{w}c_\text{w}+m_\text{cup}c_\text{glass}\right)\left(27^\circ\text{C}\right)}{m_\text{w}c_\text{w}+m_\text{cup}c_\text{glass}+m_\text{Cu}c_\text{Cu}}$, or

$$T=\frac{(0.200)(387)(90^\circ\text{C})+\left[(0.400)(4\,186)+(0.300)(837)\right](27^\circ\text{C})}{(0.400)(4\,186)+(0.300)(837)+(0.200)(387)}=\boxed{29^\circ\text{C}}$$

11.56 (a) The energy delivered to the heating element (a resistor) is transferred to the liquid nitrogen, causing part of it to vaporize in a liquid-to-gas phase transition. The total energy delivered to the element equals the product of the power and the time interval of 4.0 h.

(b) The mass of nitrogen vaporized in a 4.0 h period is

$$m=\frac{Q}{L_f}=\frac{P\cdot(\Delta t)}{L_f}=\frac{(25\ \text{J/s})(4.0\ \text{h})(3\,600\ \text{s/h})}{2.01\times10^5\ \text{J/kg}}=\boxed{1.8\ \text{kg}}$$

11.57 Assuming the aluminium-water-calorimeter system is thermally isolated from the environment, $Q_{\text{cold}} = -Q_{\text{hot}}$, or

$$m_\text{Al}c_\text{Al}\left(T_f-T_{i,\text{Al}}\right)=-m_\text{w}c_\text{w}\left(T_f-T_{i,\text{w}}\right)-m_\text{cal}c_\text{cal}\left(T_f-T_{i,\text{cal}}\right)$$

Since $T_f = 66.3^\circ\text{C}$ and $T_{i,\text{cal}} = T_{i,\text{w}} = 70.0^\circ\text{C}$, this gives $c_\text{Al}=\dfrac{\left(m_\text{w}c_\text{w}+m_\text{cal}c_\text{cal}\right)\left(T_{i,\text{w}}-T_f\right)}{m_\text{Al}\left(T_f-T_{i,\text{Al}}\right)}$, or

$$c_\text{Al}=\frac{\left[(0.400\ \text{kg})\left(4\,186\ \frac{\text{J}}{\text{kg}\cdot{}^\circ\text{C}}\right)+(0.040\ \text{kg})\left(630\ \frac{\text{J}}{\text{kg}\cdot{}^\circ\text{C}}\right)\right](70.0-66.3)^\circ\text{C}}{(0.200\ \text{kg})(66.3-27.0)^\circ\text{C}}=\boxed{8.00\times10^2\ \frac{\text{J}}{\text{kg}\cdot{}^\circ\text{C}}}$$

The variation between this result and the value from Table 11.1 is

$$\%=\left(\frac{|\text{variation}|}{\text{accepted value}}\right)\times100\%=\left(\frac{|800-900|\ \text{J/kg}\cdot{}^\circ\text{C}}{900\ \text{J/kg}\cdot{}^\circ\text{C}}\right)\times100\%=\boxed{11.1\%}$$

which is within the 15% tolerance.

11.58 (a) With a body temperature of $T = 37^\circ\text{C} + 273 = 310\text{ K}$ and surroundings at temperature $T_0 = 24^\circ\text{C} + 273 = 297\text{ K},$ the rate of energy transfer by radiation is

$$P_{\text{radiation}} = \sigma A e\left(T^4 - T_0^4\right)$$

$$= \left(5.669\,6\times10^{-8}\ \frac{\text{W}}{\text{m}^2\cdot\text{K}^4}\right)\left(2.0\text{ m}^2\right)(0.97)\left[(310\text{ K})^4 - (297\text{ K})^4\right] = \boxed{1.6\times10^2\text{ W}}$$

(b) The rate of energy transfer by evaporation of perspiration is

$$P_{\text{perspiration}} = \frac{Q}{\Delta t} = \frac{mL_{v,\text{perspiration}}}{\Delta t} = \frac{(0.40\text{ kg})\left(2.43\times10^3\ \text{kJ/kg}\right)\left(10^3\ \text{J/kJ}\right)}{3\,600\text{ s}} = \boxed{2.7\times10^2\text{ W}}$$

(c) The rate of energy transfer by evaporation from the lungs is

$$P_{\text{lungs}} = \left(38\ \frac{\text{kJ}}{\text{h}}\right)\left(\frac{1\text{ h}}{3\,600\text{ s}}\right)\left(\frac{10^3\text{ J}}{1\text{ kJ}}\right) = \boxed{11\text{ W}}$$

(d) The excess thermal energy that must be dissipated is

$$P_{\text{excess}} = 0.80P_{\text{metabolic}} = 0.80\left(2.50\times10^3\ \frac{\text{kJ}}{\text{h}}\right)\left(\frac{1\text{ h}}{3\,600\text{ s}}\right)\left(\frac{10^3\text{ J}}{1\text{ kJ}}\right) = 5.6\times10^2\text{ W}$$

so the rate energy must be transferred by conduction and convection is

$$P_{\text{c\&c}} = P_{\text{excess}} - \left(P_{\text{radiation}} + P_{\text{perspiration}} + P_{\text{lungs}}\right) = (5.6 - 1.6 - 2.7 - .11)\times10^2\text{ W} = \boxed{1.2\times10^2\text{ W}}$$

11.59 The total energy needed is

$$Q = mL_v = (2.00\text{ kg})\left(2.00\times10^4\ \text{J/kg}\right) = 4.00\times10^4\text{ J}$$

and the time required to supply this energy is

$$t = \frac{Q}{P} = \frac{4.00\times10^4\text{ J}}{10.0\ \text{J/s}} = 4.00\times10^3\text{ s}\left(\frac{1\text{ min}}{60.0\text{ s}}\right) = \boxed{66.7\text{ min}}$$

11.60 The energy added to the air in one hour is

$$Q = \left(P_{\text{total}}\right)t = \left[10(200\text{ W})\right](3\,600\text{ s}) = 7.20\times10^6\text{ J}$$

and the mass of air in the room is

$$m = \rho V = \left(1.3\ \text{kg/m}^3\right)\left[(6.0\text{ m})(15.0\text{ m})(3.0\text{ m})\right] = 3.5\times10^2\text{ kg}$$

The change in temperature is $\Delta T = \dfrac{Q}{mc} = \dfrac{7.2\times10^6\text{ J}}{\left(3.5\times10^2\text{ kg}\right)\left(837\ \text{J/kg}\cdot{}^\circ\text{C}\right)} = 25^\circ\text{C}$

giving $T = T_0 + \Delta T = 20^\circ\text{C} + 25^\circ\text{C} = \boxed{45^\circ\text{C}}$

11.61 In the steady state, $P_{Au} = P_{Ag}$, or $\kappa_{Au} A\left(\frac{80.0°\text{C} - T}{L}\right) = \kappa_{Ag} A\left(\frac{T - 30.0°\text{C}}{L}\right)$

This gives

$$T = \frac{\kappa_{Au}(80.0°\text{C}) + \kappa_{Ag}(30.0°\text{C})}{\kappa_{Au} + \kappa_{Ag}} = \frac{314(80.0°\text{C}) + 427(30.0°\text{C})}{314 + 427} = \boxed{51.2°\text{C}}$$

11.62 (a) The rate work is done against friction is

$$P = f \cdot v = (50\text{ N})(40\text{ m/s}) = 2.0 \times 10^3\text{ J/s} = \boxed{2.0\text{ kW}}$$

(b) In a time interval of 10 s, the energy added to the 10 kg of iron is

$$Q = P \cdot t = (2.0 \times 10^3\text{ J/s})(10\text{ s}) = 2.0 \times 10^4\text{ J}$$

and the change in temperature is

$$\Delta T = \frac{Q}{mc} = \frac{2.0 \times 10^4\text{ J}}{(10\text{ kg})(448\text{ J/kg}\cdot°\text{C})} = \boxed{4.5°\text{C}}$$

11.63 (a) The energy required to raise the temperature of the brakes to the melting point at $660°\text{C}$ is

$$Q = mc(\Delta T) = (6.00\text{ kg})(900\text{ J/kg}\cdot°\text{C})(660°\text{C} - 20.0°\text{C}) = 3.46 \times 10^6\text{ J}$$

The internal energy added to the brakes on each stop is

$$Q_1 = \Delta KE = \frac{1}{2} m_{car} v_i^2 = \frac{1}{2}(1\,500\text{ kg})(25.0\text{ m/s})^2 = 4.69 \times 10^5\text{ J}$$

The number of stops before reaching the melting point is

$$N = \frac{Q}{Q_1} = \frac{3.46 \times 10^6\text{ J}}{4.69 \times 10^5\text{ J}} = \boxed{7\text{ stops}}$$

(b) As the car stops, it transforms part of its kinetic energy into internal energy due to air resistance. As soon as the brakes rise above air temperature, they transfer energy by heat to the air. If they reach a high temperature, they transfer energy to the air very quickly.

11.64 When liquids 1 and 2 are mixed, the conservation of energy equation is

$$mc_1(17°\text{C} - 10°\text{C}) = mc_2(20°\text{C} - 17°\text{C}) \qquad \text{or} \qquad c_2 = \left(\frac{7}{3}\right)c_1$$

When liquids 2 and 3 are mixed, energy conservation yields

$$mc_3(30°\text{C} - 28°\text{C}) = mc_2(28°\text{C} - 20°\text{C}) \qquad \text{or} \qquad c_3 = 4c_2$$

Thus, we now know that $c_3 = 4(7c_1/3)$ or $c_3/c_1 = 28/3$

Mixing liquids 1 and 3 will give $mc_1(T - 10°\text{C}) = mc_3(30°\text{C} - T)$

or $T = \dfrac{c_1(10°\text{C}) + c_3(30°\text{C})}{c_1 + c_3} = \dfrac{10°\text{C} + (28/3)(30°\text{C})}{1 + (28/3)} = \boxed{28\,°\text{C}}$

11.65 (a) The internal energy ΔQ added to the volume ΔV of liquid that flows through the calorimeter in time Δt is $\Delta Q = (\Delta m)c(\Delta T) = p(\Delta V)c(\Delta T)$. Thus, the rate of adding energy is

$$\boxed{\frac{\Delta Q}{\Delta t} = pc(\Delta T)(\frac{\Delta V}{\Delta t})}$$

where $\left(\dfrac{\Delta V}{\Delta t}\right)$ is the flow rate through the calorimeter.

(b) From the result of part (a), the specific heat is

$$c = \frac{\Delta Q/\Delta t}{\rho(\Delta T)(\Delta V/\Delta t)} = \frac{40\ \text{J/s}}{(0.72\ \text{g/cm}^3)(5.8°\text{C})(3.5\ \text{cm}^3/\text{s})}$$

$$= \left(2.7\ \frac{\text{J}}{\text{g}\cdot°\text{C}}\right)\left(\frac{10^3\ \text{g}}{1\ \text{kg}}\right) = \boxed{2.7\times10^3\ \text{J/kg}\cdot°\text{C}}$$

11.66 (a) The surface area of the stove is $A_{\text{stove}} = A_{\text{ends}} + A_{\substack{\text{cylindrical}\\ \text{side}}} = 2(\pi r^2) + (2\pi rh)$, or

$$A_{\text{stove}} = 2\pi(0.200\ \text{m})^2 + 2\pi(0.200\ \text{m})(0.500\ \text{m}) = 0.880\ \text{m}^2$$

The temperature of the stove is $T_{\text{stove}} = \frac{5}{9}(400°\text{F} - 32.0°\text{F}) = 204°\text{C} = 477\ \text{K}$ while that of the air in the room is $T_{\text{room}} = \frac{5}{9}(70.0°\text{F} - 32.0°\text{F}) = 21.1°\text{C} = 294\ \text{K}$. If the emissivity of the stove is $e = 0.920$, the net power radiated to the room is

$$P = \sigma A_{\text{stove}} e\left(T_{\text{stove}}^4 - T_{\text{room}}^4\right)$$

$$= \left(5.669\,6\times10^{-8}\ \text{W/m}^2\cdot\text{K}^4\right)\left(0.880\ \text{m}^2\right)(0.920)\left[(477\ \text{K})^4 - (294\ \text{K})^4\right]$$

or $P = 2.03\times10^3\ \text{W} = \boxed{2.03\times10^3\ \text{J/s}}$

(b) The total surface area of the walls and ceiling of the room is

$$A = 4A_{\text{wall}} + A_{\text{ceiling}} = 4\left[(8.00\ \text{ft})(25.0\ \text{ft})\right] + (25.0\ \text{ft})^2 = 1.43\times10^3\ \text{ft}^2$$

If the temperature of the room is constant, the power lost by conduction through the walls and ceiling must equal the power radiated by the stove. Thus, from thermal conduction equation, $P = A\left(T_h - T_c\right)/\Sigma R_i$, the net R value needed in the walls and ceiling is

$$\Sigma R_i = \frac{A\left(T_h - T_c\right)}{P} = \frac{\left(1.43\times10^3\ \text{ft}^2\right)(70.0°\text{F} - 32.0°\text{F})}{2.03\times10^3\ \text{J/s}}\left(\frac{1\,054\ \text{J}}{1\ \text{Btu}}\right)\left(\frac{1\ \text{h}}{3\,600\ \text{s}}\right)$$

or $\Sigma R_i = \boxed{7.84\ \text{ft}^2\cdot°\text{F}\cdot\text{h/Btu}}$

11.67 A volume of 1.0 L of water has a mass of $m = \rho V = \left(10^3 \text{ kg/m}^3\right)\left(1.0\times10^{-3} \text{ m}^3\right) = 1.0 \text{ kg}$ The energy required to raise the temperature of the water to 100°C and then completely evaporate it is $Q = mc(\Delta T) + mL_v$, or

$$Q = (1.0 \text{ kg})(4\,186 \text{ J/kg}\cdot{}^\circ\text{C})(100^\circ\text{C} - 20^\circ\text{C}) + (1.0 \text{ kg})\left(2.26\times10^6 \text{ J/kg}\right) = 2.59\times10^6 \text{ J}$$

The power input to the water from the solar cooker is

$$P = (\textit{efficiency})\,IA = (0.50)\left(600 \text{ W/m}^2\right)\left[\frac{\pi(0.50 \text{ m})^2}{4}\right] = 59 \text{ W}$$

so the time required to evaporate the water is

$$t = \frac{Q}{P} = \frac{2.59\times10^6 \text{ J}}{59 \text{ J/s}} = \left(4.4\times10^4 \text{ s}\right)\left(\frac{1 \text{ h}}{3\,600 \text{ s}}\right) = \boxed{12 \text{ h}}$$

11.68 (a) From the thermal conductivity equation, $P = \kappa A\left[\left(T_h - T_c\right)/L\right]$, the total energy lost by conduction through the insulation during the 24-h period will be

$$Q = P_1(12.0 \text{ h}) + P_2(12.0 \text{ h}) = \frac{\kappa A}{L}\left[(37.0^\circ\text{C} - 23.0^\circ\text{C}) + (37.0^\circ\text{C} - 16.0^\circ\text{C})\right](12.0 \text{ h})$$

$$\text{or } Q = \frac{(0.012\,0 \text{ J/s}\cdot\text{m}^\circ\text{C})\left(0.490 \text{ m}^2\right)}{9.50\times10^{-2} \text{ m}}\left[14.0^\circ\text{C} + 21.0^\circ\text{C}\right](12.0 \text{ h})\left(\frac{3\,600 \text{ s}}{1 \text{ h}}\right) = 9.36\times10^4 \text{ J}$$

The mass of molten wax which will give off this much energy as it solidifies (all at 37°C) is

$$m = \frac{Q}{L_f} = \frac{9.36\times10^4 \text{ J}}{205\times10^3 \text{ J/kg}} = \boxed{0.457 \text{ kg}}$$

(b) If the test samples and the inner surface of the insulation are preheated to 37.0°C during the assembly of the box, **[nothing undergoes a temperature change]** during the test period. Thus, the masses of the samples and insulation do not enter into the calculation. Only the duration of the test, inside and outside temperatures, along with the surface area, thickness, and thermal conductivity of the insulation need to be known.

11.69 The total power radiated by the Sun is $P = \sigma A e T^4$, where $\sigma = 5.669\,6\times10^{-8} \text{ W/m}^2\cdot\text{K}^4$, the emissivity is $e = 0.986$, the surface area (a sphere) is $A = 4\pi r^2$, and the absolute temperature is $T = 5\,800$ K. Thus,

$$P = \left(5.669\,6\times10^{-8} \text{ W/m}^2\cdot\text{K}^4\right)4\pi\left(6.96\times10^8 \text{ m}\right)^2(0.986)(5\,800 \text{ K})^4$$

or $P = 3.85\times10^{26}$ W. Thus, the energy radiated each second is

$$E = P\cdot\Delta t = \left(3.85\times10^{26} \text{ J/s}\right)(1.00 \text{ s}) = \boxed{3.85\times10^{26} \text{ J}}$$

11.70 We approximate the latent heat of vaporization of water on the skin (at 37°C) by asking how much energy would be needed to raise the temperature of 1.0 kg of water to the boiling point and evaporate it. The answer is

$$L_v^{37°C} = c_{water}(\Delta T) + L_v^{100°C} = (4\,186\ \text{J/kg}\cdot°\text{C})(100°\text{C} - 37°\text{C}) + 2.26\times10^6\ \text{J/kg}$$

or $L_v^{37°C} = 2.5\times10^6\ \text{J/kg}$

Assuming that you are approximately 2.0 m tall and 0.30 m wide, you will cover an area of $A = (2.0\ \text{m})(0.30\ \text{m}) = 0.60\ \text{m}^2$ of the beach, and the energy you receive from the sunlight in one hour is

$$Q = IA(\Delta t) = (1\,000\ \text{W/m}^2)(0.60\ \text{m}^2)(3\,600\ \text{s}) = 2.2\times10^6\ \text{J}$$

The quantity of water this much energy could evaporate from your body is

$$m = \frac{Q}{L_v^{37°C}} = \frac{2.2\times10^6\ \text{J}}{2.5\times10^6\ \text{J/kg}} = \boxed{0.9\ \text{kg}}$$

The volume of this quantity of water is $V = \dfrac{m}{\rho} = \dfrac{0.9\ \text{kg}}{10^3\ \text{kg/m}^3} \approx 10^{-3}\ \text{m}^3 = 1\ \text{L}$

Thus, you will need to drink almost a liter of water each hour to stay hydrated. Note, of course, that any perspiration that drips off your body does not contribute to the cooling process, so drink up!

11.71 During the first 50 minutes, the energy input is used converting *m* kilograms of ice at 0°C into liquid water at 0°C. The energy required is $Q_1 = mL_f = m(3.33\times10^5\ \text{J/kg})$, so the constant power input must be

$$P = \frac{Q_1}{(\Delta t)_1} = \frac{m(3.33\times10^5\ \text{J/kg})}{50\ \text{min}}$$

During the last 10 minutes, the same constant power input raises the temperature of water having a total mass of $(m + 10\ \text{kg})$ by 2.0°C. The power input needed to do this is

$$P = \frac{Q_2}{(\Delta t)_2} = \frac{(m+10\ \text{kg})c(\Delta T)}{(\Delta t)_2} = \frac{(m+10\ \text{kg})(4\,186\ \text{J/kg}\cdot°\text{C})(2.0°\text{C})}{10\ \text{min}}$$

Since the power input is the same in the two periods, we have

$$\frac{m(3.33\times10^5\ \text{J/kg})}{50\ \text{min}} = \frac{(m+10\ \text{kg})(4\,186\ \text{J/kg}\cdot°\text{C})(2.0°\text{C})}{10\ \text{min}}$$

which simplifies to $(8.0)m = m + 10\ \text{kg}$ or $m = \dfrac{10\ \text{kg}}{7.0} = \boxed{1.4\ \text{kg}}$

11.72 (a) First, energy must be removed from the liquid water to cool it to 0°C. Next, energy must be removed from the water at 0°C to freeze it, which corresponds to a liquid-to-solid phase transition. Finally, once all the water has frozen, additional energy must be removed from the ice to cool it from 0°C to -8.00°C.

(b) The total energy that must be removed is

$$Q = \left|Q_{\substack{\text{cool water}\\ \text{to } 0^\circ\text{C}}}\right| + \left|Q_{\substack{\text{freeze}\\ \text{at } 0^\circ\text{C}}}\right| + \left|Q_{\substack{\text{cool ice}\\ \text{to } -8.00^\circ\text{C}}}\right| = m_w c_w \left|0^\circ\text{C} - T_i\right| + m_w L_f + m_w c_{\text{ice}} \left|T_f - 0^\circ\text{C}\right|$$

or

$$Q = \left(75.0\times10^{-3}\ \text{kg}\right)\left[\left(4\,186\ \frac{\text{J}}{\text{kg}\cdot{}^\circ\text{C}}\right)\left|-20.0\ ^\circ\text{C}\right| + 3.33\times10^{5}\ \frac{\text{J}}{\text{kg}} + \left(2\,090\ \frac{\text{J}}{\text{kg}\cdot{}^\circ\text{C}}\right)\left|-8.00\ ^\circ\text{C}\right|\right]$$

$$= 3.25\times10^{4}\ \text{J} = \boxed{32.5\ \text{kJ}}$$

11.73 (a) In steady state, the energy transfer rate is the same for each of the rods, or $P_{\text{Al}} = P_{\text{Fe}}$.

Thus,

$$\kappa_{\text{Al}} A\left(\frac{100^\circ\text{C} - T}{L}\right) = \kappa_{\text{Fe}} A\left(\frac{T - 0^\circ\text{C}}{L}\right)$$

giving

$$T = \left(\frac{\kappa_{\text{Al}}}{\kappa_{\text{Al}} + \kappa_{\text{Fe}}}\right)(100^\circ\text{C}) = \left(\frac{238}{238 + 79.5}\right)(100^\circ\text{C}) = \boxed{75.0^\circ\text{C}}$$

(b) If $L = 15$ cm and $A = 5.0\ \text{cm}^2$, the energy conducted in 30 min is

$$Q = P_{\text{Al}}\cdot t = \left[\left(238\ \frac{\text{W}}{\text{m}\cdot{}^\circ\text{C}}\right)\left(5.0\times10^{-4}\ \text{m}^2\right)\left(\frac{100^\circ\text{C} - 75.0^\circ\text{C}}{0.15\ \text{m}}\right)\right](1\,800\ \text{s})$$

$$= 3.6\times10^{4}\ \text{J} = \boxed{36\ \text{kJ}}$$