PROBLEM SOLUTIONS

11.1 As mass m of water drops from top to 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

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

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

11.2 $Q = mc\,(\Delta T) = (1.50\ \text{kg})(230\ \text{J/kg}\cdot{}^\circ\text{C})(150^\circ\text{C} - 20.0^\circ\text{C}) = 4.49 \times 10^4\ \text{J} = \boxed{44.9\ \text{kJ}}$

11.3 The mass of water involved is

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

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

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

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

11.4 The change in temperature of the rod is

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

and the change in the length is

$$\Delta L = \alpha L_0\,(\Delta T)$$

$$= \left[24 \times 10^{-6}\ \left({}^\circ\text{C}\right)^{-1}\right](20.0\ \text{cm})(31.7^\circ\text{C}) = 1.52 \times 10^{-2}\ \text{cm} = \boxed{0.152\ \text{mm}}$$

11.5 $\Delta T = T_f - 25^\circ\text{C} = \dfrac{Q}{mc} = \dfrac{750\ \text{cal}}{(75\ \text{g})(0.168\ \text{cal/g}\cdot{}^\circ\text{C})} = 60^\circ\text{C}$

so

$$T_f = 25°\text{C} + 60°\text{C} = \boxed{85°\text{C}}$$

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

(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

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

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

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

11.7 (a)

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

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

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

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

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

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

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

$$\mathcal{P} = Fv = \ ma\quad 0 + at \ \text{ or } \boxed{\mathcal{P} = ma^2t}$$

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

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

$$\mathcal{P}_{\text{max}} = \left(363 \text{ J/s}^2\right)(5.00 \text{ s}) = 1.82 \times 10^3 \text{ J/s}$$

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

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

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

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

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,

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

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

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

$$= \left[(0.800 \text{ kg})\left(4\,186 \frac{\text{J}}{\text{kg} \cdot {}^\circ\text{C}}\right) + (0.200 \text{ kg})\left(900 \frac{\text{J}}{\text{kg} \cdot {}^\circ\text{C}}\right)\right](1.5^\circ\text{C}) = 5.3 \times 10^3 \text{ J}$$

The rate of energy transfer is

$$\mathcal{P} = \frac{Q}{\Delta t} = \frac{5.3 \times 10^3 \text{ J}}{60 \text{ s}} = 88 \frac{\text{J}}{\text{s}} = \boxed{88 \text{ W}}$$

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

$$\Delta T = \frac{Q}{mc_{\text{Cu}}} = \frac{0.85\left(\frac{1}{2}\cancel{m}v_i^2\right)}{\cancel{m}c_{\text{Cu}}} = \frac{0.85\left(3.0 \text{ m/s}\right)^2}{2\left(387 \text{ J/kg}\cdot{}^\circ\text{C}\right)} = \boxed{9.9 \times 10^{-3}\ {}^\circ\text{C}}$$

(b) The remaining energy is $\boxed{\text{absorbed by the horizontal surface}}$ on which the block slides.

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

$$\Delta T = \frac{\Delta L}{\alpha_{\text{steel}} L_0} = \frac{3.0 \times 10^{-3}\ \cancel{\text{m}}}{\left[11 \times 10^{-6}\left({}^\circ\text{C}\right)^{-1}\right]\left(13\ \cancel{\text{yd}}\right)}\left(\frac{1\ \cancel{\text{yd}}}{3.0\ \cancel{\text{ft}}}\right)\left(\frac{3.281\ \cancel{\text{ft}}}{1\ \cancel{\text{m}}}\right) = 23^\circ\text{C}$$

The mass of the rail is

$$m = \frac{w}{g} = \frac{\left(70\ \cancel{\text{lb}}/\cancel{\text{yd}}\right)\left(13\ \cancel{\text{yd}}\right)}{9.80 \text{ m/s}^2}\left(\frac{4.448 \text{ N}}{1\ \cancel{\text{lb}}}\right) = 4.1 \times 10^2 \text{ kg}$$

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

$$Q = mc_{\text{steel}}\left(\Delta T\right) = \left(4.1 \times 10^2 \text{ kg}\right)\left(448 \text{ J/kg}\cdot{}^\circ\text{C}\right)\left(23^\circ\text{C}\right) = \boxed{4.2 \times 10^6 \text{ J}}$$

11.14 (a) From the relation between compressive stress and strain, $F/A = Y\left(\Delta L/L_0\right)$, 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 $\boxed{F/A = Y\left[\alpha\left(\Delta T\right)\right]}$.

(b) If the concrete slab has mass *m*, the thermal energy required to produce a change in temperature ΔT is $Q = mc\left(\Delta T\right)$ 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

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

(c) The mass of the given concrete slab is

$$m = \rho V = \left(2.40 \times 10^3 \text{ kg/m}^3\right)\left[\left(4.00 \times 10^{-2} \text{ m}\right)\left(1.00 \text{ m}\right)\left(1.00 \text{ m}\right)\right] = \boxed{96.0 \text{ kg}}$$

(d) If the maximum compressive stress concrete can withstand is $F/A = 2.00 \times 10^7$ Pa, the maximum thermal energy this slab can absorb before starting to break up is found, using Table 10.1, to be

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

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

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

(f) The rate the slab absorbs solar energy is

$$\mathcal{P}_{\text{absorbed}} = 0.5\mathcal{P}_{\text{solar}} = 0.5\;\;1.00\times10^{3}\text{ W} \;\; = 5\times10^{2}\text{ J/s}$$

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

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

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 $m_w c_w\;\; T_f - T_{i,w}\;\; = -m_{\text{Al}}c_{\text{Al}}\;\; T_f - T_{i,\text{Al}}$, or

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

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

$$N = \frac{m_w c_w\;\;\Delta T\;_w}{m_{\text{pellet}}c_{\text{lead}}\left|\Delta T\right|_{\text{lead}}}$$

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

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

Thus,

$$\left[m_c c_{\text{Al}} + m_s c_{\text{Cu}} + m_w c_w\right] \Delta T_{w} = \left[mc\left|\Delta T\right|\right]_{\text{Ag}}$$

Solving for the mass of the cup gives

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

or

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

11.18 The mass of water is

$$m_w = \rho_w V_w = 1.00\text{ g/cm}^3 \quad 100\text{ cm}^3 = 100\text{ g} = 0.100\text{ kg}$$

For each bullet, the energy absorbed by the bullet equals the energy given up by the water, so $m_b c_b \; T - 20°\text{C} = m_w c_w \; 90°\text{C} - T$. Solving for the final temperature gives

$$T = \frac{m_w c_w \; 90°\text{C} + m_b c_b \; 20°\text{C}}{m_w c_w + m_b c_b}.$$

For the silver bullet, $m_b = 5.0 \times 10^{-3}$ kg and $c_b = 234$ J/kg · °C, giving

$$T_{\text{silver}} = \frac{0.100 \quad 4\,186 \quad 90°\text{C} + 5.0 \times 10^{-3} \quad 234 \quad 20°\text{C}}{0.100 \quad 4\,186 + 5.0 \times 10^{-3} \quad 234} = \boxed{89.8°\text{C}}$$

For the copper bullet, $m_b = 5.0 \times 10^{-3}$ kg and $c_b = 387$ J/kg · °C, which yields

$$T_{\text{copper}} = \frac{0.100 \quad 4\,186 \quad 90°\text{C} + 5.0 \times 10^{-3} \quad 387 \quad 20°\text{C}}{0.100 \quad 4\,186 + 5.0 \times 10^{-3} \quad 387} = \boxed{89.7°\text{C}}$$

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

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

$$m_{\text{Cu}} c_{\text{Cu}} \left|\Delta T\right|_{\text{Cu}} + m_{\text{unk}} c_{\text{unk}} \left|\Delta T\right|_{\text{unk}} = \left[m_c c_{\text{Al}} + m_w c_w\right] \Delta T_{w}$$

Solving for the specific heat of the unknown material gives

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

$$c_{\text{unk}} = \frac{1}{(70\text{ g})(80°\text{C})}\Big[\big[(100\text{ g})(900\text{ J/kg}\cdot°\text{C}) + (250\text{ g})(4\,186\text{ J/kg}\cdot°\text{C})\big](10°\text{C})$$
$$- (50\text{ g})(387\text{ J/kg}\cdot°\text{C})(60°\text{C})\Big] = \boxed{1.8\times10^3\text{ J/kg}\cdot°\text{C}}$$

11.20 The energy absorbed by the water equals the energy given up by the iron and they come to thermal equilibrium at 100°F. Thus, considering cooling 1.00 kg of iron, we have

$$m_w c_w (\Delta T)_w = m_{\text{Fe}} c_{\text{Fe}} \left|\Delta T\right|_{\text{Fe}} \text{ or } m_w = \frac{(1.00\text{ kg})\, c_{\text{Fe}} \left|\Delta T\right|_{\text{Fe}}}{c_w (\Delta T)_w}$$

giving

$$m_w = \frac{(1.00\text{ kg})(448\text{ J/kg}\cdot°\text{C})(500°\text{F} - 100°\text{F})\left(\cancel{1°\text{C}/\tfrac{9}{5}°\text{F}}\right)}{(4\,186\text{ J/kg}\cdot°\text{C})(100°\text{F} - 75°\text{F})\left(\cancel{1°\text{C}/\tfrac{9}{5}°\text{F}}\right)} = \boxed{1.7\text{ kg}}$$

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 $m_{\text{Al}} c_{\text{Al}} (\Delta T)_{\text{Al}} = m_{\text{Cu}} c_{\text{Cu}} \left|\Delta T\right|_{\text{Cu}}$, or

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

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, $\Delta KE = Q = m_{\text{drums}} c_{\text{Fe}} (\Delta T)$ or

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

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

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

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

$$T_f = \frac{m_w c_w T_{i,w} + m_{\text{metal}}\left(c_{\text{Sn}} + c_{\text{Pb}}\right) T_{\text{hot}}}{m_w c_w + m_{\text{metal}}\left(c_{\text{Sn}} + c_{\text{Pb}}\right)}$$

$$= \frac{(1.00\text{ kg})(4\,186\text{ J/kg}\cdot°\text{C})(20.0°\text{C}) + (0.400\text{ kg})(227\text{ J/kg}\cdot°\text{C} + 128\text{ J/kg}\cdot°\text{C})(60.0°\text{C})}{(1.00\text{ kg})(4\,186\text{ J/kg}\cdot°\text{C}) + (0.400\text{ kg})(227\text{ J/kg}\cdot°\text{C} + 128\text{ J/kg}\cdot°\text{C})}$$

yielding $\boxed{T_f = 21.3°\text{C}}$

(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 $Q = Q_{\text{Sn}} + Q_{\text{Pb}}$, or

$$\left(m_{\text{Sn}} + m_{\text{Pb}}\right) c_{\text{alloy}} \left(\cancel{\Delta T}\right) = m_{\text{Sn}} c_{\text{Sn}} \left(\cancel{\Delta T}\right) + m_{\text{Pb}} c_{\text{Pb}} \left(\cancel{\Delta T}\right) \text{ giving}$$

$$c_{\text{alloy}} = \frac{m_{\text{Sn}} c_{\text{Sn}} + m_{\text{Pb}} c_{\text{Pb}}}{m_{\text{Sn}} + m_{\text{Pb}}}$$

If the alloy is a half-and-half mixture, so $m_{\text{Sn}} = m_{\text{Pb}}$, this reduces to $c_{\text{alloy}} = (c_{\text{Sn}} + c_{\text{Pb}})/2$ and yields

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

(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 $m_{\text{Sn}} = 0.400\text{ kg} = 400\text{ g}$ of tin with a molecular weight of $M_{\text{Sn}} = 118.7\text{ g/mol}$ is

$$N_{\text{Sn}} = \left(\frac{m_{\text{Sn}}}{M_{\text{Sn}}}\right) N_A = \left(\frac{400\text{ g}}{118.7\text{ g/mol}}\right)\left(6.02 \times 10^{23}\text{ mol}^{-1}\right) = \boxed{2.03 \times 10^{24}}$$

and, for the lead,

$$N_{\text{Pb}} = \left(\frac{m_{\text{Pb}}}{M_{\text{Pb}}}\right) N_A = \left(\frac{400\text{ g}}{207.2\text{ g/mol}}\right)\left(6.02 \times 10^{23}\text{ mol}^{-1}\right) = \boxed{1.16 \times 10^{24}}$$

(d) We have

$$\frac{N_{\text{Sn}}}{N_{\text{Pb}}} = \frac{2.03 \times 10^{24}}{1.16 \times 10^{24}} = \boxed{1.75}$$

and observe that

$$\frac{c_{\text{Sn}}}{c_{\text{Pb}}} = \frac{227\ \text{J/kg}\cdot{}^\circ\text{C}}{128\ \text{J/kg}\cdot{}^\circ\text{C}} = \boxed{1.77}$$

$\boxed{\text{from which we conclude that the specific heat of an element is proportional to the number of atoms per unit mass of that element.}}$

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

or

$$c_x = \frac{\left[\ 0.285\ \text{kg}\quad 4\,186\ \text{J/kg}\cdot{}^\circ\text{C}\ +\ 0.150\ \text{kg}\quad 900\ \text{J/kg}\cdot{}^\circ\text{C}\ \right]\ 32.0 - 25.0\ {}^\circ\text{C}}{0.125\ \text{kg}\quad 95.0^\circ\text{C} - 32.0^\circ\text{C}}$$

yielding $c_x = \boxed{1.18 \times 10^3\ \text{J/kg}\cdot{}^\circ\text{C}}$.

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

$$m_{\text{ice}} L_f + m_{\text{ice}} c_{\text{water}}\ \ T_f - 0^\circ\text{C}\ \ = -m_w c_{\text{water}}\ \ T_f - 25^\circ\text{C}$$

and

$$T_f = \frac{m_w c_{\text{water}}\ \ 25^\circ\text{C}\ \ - m_{\text{ice}} L_f}{m_{\text{ice}} + m_w\ \ c_{\text{water}}} = \frac{\left(825\ \cancel{\text{g}}\right)\left(4\,186\ \text{J/kg}\cdot{}^\circ\text{C}\right)\left(25^\circ\text{C}\right) - \left(75\ \cancel{\text{g}}\right)\left(3.33\times 10^5\ \text{J/kg}\right)}{\left(75\ \cancel{\text{g}} + 825\ \cancel{\text{g}}\right)\left(4\,186\ \text{J/kg}\cdot{}^\circ\text{C}\right)}$$

yielding $\boxed{T_f = 16^\circ\text{C}}$.

11.26 The total energy input required is

$Q =$ energy to melt 50 g of ice
+ energy to warm 50 g of water to 100°C
+ energy to vaporize 5.0 g water

$$= 50\ \text{g}\ \ L_f + \ 50\ \text{g}\ \ c_{\text{water}}\ \ 100^\circ\text{C} - 0^\circ\text{C}\ \ +\ \ 5.0\ \text{g}\ \ L_v$$

Thus,

$$Q = 0.050\ \text{kg}\left(3.33 \times 10^5\ \frac{\text{J}}{\text{kg}}\right) + 0.050\ \text{kg}\left(4\,186\ \frac{\text{J}}{\text{kg}\cdot{}^\circ\text{C}}\right) 100^\circ\text{C} - 0^\circ\text{C} + 5.0 \times 10^{-3}\ \text{kg}\left(2.26 \times 10^6\ \frac{\text{J}}{\text{kg}}\right)$$

which gives $Q = 4.9 \times 10^4\ \text{J} = \boxed{49\ \text{kJ}}$.

11.27 The conservation of energy equation for this process is

energy to melt ice + energy to warm melted ice to T = energy to cool water to T

or

$$m_{\text{ice}}L_f + m_{\text{ice}}c_w\ T - 0^\circ\text{C} = m_w c_w\ 80^\circ\text{C} - T$$

This yields

$$T = \frac{m_w c_w\ 80^\circ\text{C} - m_{\text{ice}}L_f}{m_{\text{ice}} + m_w\ c_w}$$

so

$$T = \frac{1.0\ \text{kg}\ \ 4\,186\ \text{J/kg}\cdot{}^\circ\text{C}\ \ 80^\circ\text{C} - 0.100\ \text{kg}\ \ 3.33 \times 10^5\ \text{J/kg}}{1.1\ \text{kg}\ \ 4\,186\ \text{J/kg}\cdot{}^\circ\text{C}} = \boxed{65\,^\circ\text{C}}$$

11.28 The energy required is the following sum of terms:

$Q =$ energy to reach melting point
+ energy to melt + energy to reach boiling point
+ energy to vaporize + energy to reach 110°C

Mathematically,

$$Q = m\Big[c_{\text{ice}}\big[0^\circ\text{C} - \ -10^\circ\text{C}\ \big] + L_f + c_w\ 100^\circ\text{C} - 0^\circ\text{C}\ + L_v + c_{\text{steam}}\ 110^\circ\text{C} - 100^\circ\text{C}\ \Big]$$

This yields

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

or

$$Q = 1.2\times 10^{5}\ \text{J} = \boxed{0.12\ \text{MJ}}$$

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

$$s = \frac{m_{\text{snow}} L_f}{\mu_k\ m_{\text{skier}} g} = \frac{1.0\ \text{kg}\ \ 3.33\times 10^{5}\ \text{J/kg}}{0.20\ \ 75\ \text{kg}\ \ 9.80\ \text{m/s}^2} = 2.3\times 10^{3}\ \text{m} = \boxed{2.3\ \text{km}}$$

11.30 (a) Observe that the equilibrium temperature will lie between the two extreme temperatures -10.0°C and $+30.0^\circ\text{C}$ 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 come to an equilibrium temperature are:

$$\boxed{\begin{array}{l}\text{ice at } -10.0^\circ\text{C to ice at } 0^\circ\text{C; ice at } 0^\circ\text{C to liquid water at } 0^\circ\text{C; water at } 0^\circ\text{C to} \\ \text{water at } T\text{; aluminum at } 20.0^\circ\text{C to aluminum at } T\text{; ethyl alcohol at } 30.0^\circ\text{C} \\ \text{to ethyl alcohol at } T.\end{array}}$$

(b)

Q	***m*(kg)**	***c* J/kg·°C**	***L* J/kg**	***T*$_f$ °C**	***T*$_i$ °C**	**Expression**
Q_{ice}	1.00	2 090		0	−10.0	
$m_{\text{ice}} c_{\text{ice}}\left[0 - \ -10.0^\circ\text{C}\ \right]$			Q_{melt}	1.00	3.33×10^{5}	0
0		$m_{\text{ice}} L_f$				
Q_{water}	1.00	4 186		T	0	
$m_{\text{ice}} c_{\text{water}}\ \ T - 0$						
Q_{Al}	0.500	900		T	20.0	
$m_{\text{Al}} c_{\text{Al}}\ \ T - 20.0^\circ\text{C}$						
Q_{alc}	6.00	2 430		T	30.0	
$m_{\text{alc}} c_{\text{alc}}\ \ T - 30.0^\circ\text{C}$						

(c)

$$\boxed{m_{\text{ice}}c_{\text{ice}}\;\;10.0°\text{C}\;\;+m_{\text{ice}}L_f+m_{\text{ice}}c_{\text{water}}\;\;T-0\;\;+m_{\text{Al}}c_{\text{Al}}\;\;T-20.0°\text{C}\;\;+m_{\text{alc}}c_{\text{alc}}\;\;T-30.0°\text{C}\;\;=0}$$

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

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 $\boxed{T=4.81°\text{C}}$.

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

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

or

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

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

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

this gives

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

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

11.32 At a rate of $400\;\;\text{kcal/h}$, 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

$$m_{\text{evaporated}} = \frac{Q}{L_v} = \frac{8.37 \times 10^5 \text{ J}}{2.5 \times 10^6 \text{ J/kg}} = \boxed{0.33 \text{ kg}}$$

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

$$m_{\text{produced}} = \frac{(400 \text{ kcal/h})(0.500 \text{ h})}{9.0 \text{ kcal/gram of fat}} = 22 \text{ g} = 22 \times 10^{-3} \text{ kg}$$

so the fraction of water needs provided by burning fat is

$$f = \frac{m_{\text{produced}}}{m_{\text{evaporated}}} = \frac{22 \times 10^{-3} \text{ kg}}{0.33 \text{ kg}} = \boxed{0.066 \text{ or } 6.6\%}$$

11.33 The mass of 2.0 liters of water is $m_w = \rho V = (10^3 \text{ kg/m}^3)(2.0 \times 10^{-3} \text{ m}^3) = 2.0 \text{ kg}$.

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

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

or

$$Q_{\text{boil}} = \left[(2.0 \text{ kg})\left(4\,186 \frac{\text{J}}{\text{kg}}\right) + (0.25 \text{ kg})\left(900 \frac{\text{J}}{\text{kg}}\right)\right](100°\text{C} - 20°\text{C}) = 6.9 \times 10^5 \text{ J}$$

The time required for the $14\,000 \text{ Btu/h}$ burner to produce this much energy is

$$t_{\text{boil}} = \frac{Q_{\text{boil}}}{14\,000 \text{ Btu/h}} = \frac{6.9 \times 10^5 \text{ J}}{14\,000 \text{ Btu/h}}\left(\frac{1 \text{ Btu}}{1.054 \times 10^3 \text{ J}}\right) = 4.7 \times 10^{-2} \text{ h} = \boxed{2.8 \text{ min}}$$

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

$$Q_{\text{evaporate}} = m_w L_v = (2.0 \text{ kg})(2.26 \times 10^6 \text{ J/kg}) = 4.5 \times 10^6 \text{ J}$$

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

$$t_{\text{boil}} = \frac{Q_{\text{evaporate}}}{14\,000 \text{ Btu/h}} = \frac{4.5 \times 10^6 \text{ J}}{14\,000 \text{ Btu/h}}\left(\frac{1 \text{ Btu}}{1.054 \times 10^3 \text{ J}}\right) = 0.31 \text{ h} = \boxed{18 \text{ min}}$$

11.34 In 1 hour, the energy dissipated by the runner is

$$\Delta E = \mathcal{P} \cdot t = (300 \text{ J/s})(3\,600 \text{ s}) = 1.08 \times 10^6 \text{ J}$$

Ninety percent, or $Q = 0.900(1.08 \times 10^6 \text{ J}) = 9.72 \times 10^5 \text{ J}$, of this is used to evaporate bodily fluids. The mass of fluid evaporated is

$$m = \frac{Q}{L_v} = \frac{9.72 \times 10^5 \text{ J}}{2.41 \times 10^6 \text{ J/kg}} = 0.403 \text{ kg}$$

Assuming the fluid is primarily water, the volume of fluid evaporated in 1 hour is

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

11.35 The energy required to melt 50 g of ice is

$$Q_1 = m_{\text{ice}} L_f = (0.050 \text{ kg})(333 \text{ kJ/kg}) = 16.7 \text{ kJ}$$

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

$$Q_2 = m_{\text{ice}} c_w (\Delta T) = (0.050 \text{ kg})(4.186 \text{ kJ/kg} \cdot °\text{C})(100°\text{C}) = 20.9 \text{ kJ}$$

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

$$Q_3 = m_s L_v = (0.010 \text{ kg})(2\,260 \text{ kJ/kg}) = 22.6 \text{ kJ}$$

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

$$m_{\text{ice}} \left[L_f + c_w (T - 0°\text{C}) \right] = m_{\text{steam}} \left[L_v + c_w (100°\text{C} - T) \right]$$

or

$$T = \frac{m_{\text{steam}} \left[L_v + c_w (100°\text{C}) \right] - m_{\text{ice}} L_f}{(m_{\text{ice}} + m_{\text{steam}}) c_w}$$

giving

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

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

$$Q_4 = m_s c_w (\Delta T) = (1.0 \times 10^{-3} \text{ kg})(4.186 \text{ kJ/kg} \cdot °\text{C})(100°\text{C}) = 0.419 \text{ kJ}$$

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 $\boxed{0\,°\text{C}}$. The mass of ice which melts as the steam condenses and the condensate cools to 0°C is

$$m = \frac{Q_3' + Q_4}{L_f} = \frac{(2.26 + 0.419) \text{ kJ}}{333 \text{ kJ/kg}} = 8.0 \times 10^{-3} \text{ kg} = \boxed{8.0 \text{ g}}$$

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

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

or

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

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

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

The rate of losing energy by exhaling humid air is then

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

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°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

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

$$= \left(3.00 \times 10^{-3}\text{ kg}\right)\left[\frac{\left(2.40 \times 10^2\text{ m/s}\right)^2}{2} + \left(128\text{ J/kg}\cdot°\text{C}\right)\left(30.0°\text{C}\right)\right] = 97.9\text{ J}$$

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

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

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 $\mathcal{P} = kA\left(T_h - T_c\right)/L$. For the given windowpane, this is

$$\mathcal{P} = \left(0.84 \ \frac{\text{J}}{\text{s} \cdot \text{m} \cdot {}^\circ\text{C}}\right)\left[\left(1.0 \text{ m}\right)\left(2.0 \text{ m}\right)\right]\frac{25^\circ\text{C} - 0^\circ\text{C}}{0.62 \times 10^{-2} \text{ m}} = 6.8 \times 10^3 \text{ J/s} = \boxed{6.8 \times 10^3 \text{ W}}$$

(b) The total energy lost per day is

$$E = \mathcal{P} \cdot \Delta t = \left(6.8 \times 10^3 \text{ J/s}\right)\left(8.64 \times 10^4 \text{ s}\right) = \boxed{5.9 \times 10^8 \text{ J}}$$

11.39 The thermal conductivity of concrete is $k = 1.3 \text{ J/s} \cdot \text{m} \cdot {}^\circ\text{C}$, so the energy transfer rate through the slab is

$$\mathcal{P} = kA\frac{T_h - T_c}{L} = \left(1.3 \ \frac{\text{J}}{\text{s} \cdot \text{m} \cdot {}^\circ\text{C}}\right)\left(5.0 \text{ m}^2\right)\left(\frac{20^\circ\text{C}}{12 \times 10^{-2} \text{ m}}\right) = 1.1 \times 10^3 \text{ J/s} = \boxed{1.1 \times 10^3 \text{ W}}$$

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

$$R_{\text{skin}} = \frac{1.0 \times 10^{-3} \text{ m}}{0.020 \text{ W/m} \cdot \text{K}} = \boxed{5.0 \times 10^{-2} \text{ m}^2 \cdot \text{K/W}}$$

$$R_{\text{fat}} = \frac{0.50 \times 10^{-2} \text{ m}}{0.20 \text{ W/m} \cdot \text{K}} = \boxed{2.5 \times 10^{-2} \text{ m}^2 \cdot \text{K/W}}$$

and

$$R_{\text{tissue}} = \frac{3.0 \times 10^{-2} \text{ m}}{0.50 \text{ W/m} \cdot \text{K}} = \boxed{6.0 \times 10^{-2} \text{ m}^2 \cdot \text{K/W}}$$

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

$$R_{\text{total}} = \sum_{i=1}^{3} R_i = \left(5.0 + 2.5 + 6.0\right) \times 10^{-2} \ \frac{\text{m}^2 \cdot \text{K}}{\text{W}} = 14 \times 10^{-2} \ \frac{\text{m}^2 \cdot \text{K}}{\text{W}} = \boxed{0.14 \ \frac{\text{m}^2 \cdot \text{K}}{\text{W}}}$$

(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 $\Delta T = \left(37 - 0\right)^\circ\text{C} = 37^\circ\text{C} = 37 \text{ K}$ is

$$\mathcal{P} = \frac{A\left(\Delta T\right)}{R_{\text{total}}} = \frac{\left(2.0 \text{ m}^2\right)\left(37 \text{ K}\right)}{0.14 \text{ m}^2 \cdot \text{K/W}} = \boxed{5.3 \times 10^2 \text{ W}}$$

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

Thus, the energy transfer rate is

$$\mathcal{P} = \left(83.7 \ \frac{\text{J}}{\text{s} \cdot \text{m} \cdot {}^\circ\text{C}}\right)\left[\ 8.00 \text{ m} \quad 50.0 \text{ m} \ \right]\left(\frac{200^\circ\text{C} - 20.0^\circ\text{C}}{1.50 \times 10^{-2} \text{ m}}\right)$$
$$= 4.02 \times 10^8 \ \frac{\text{J}}{\text{s}} = \boxed{402 \text{ MW}}$$

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

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

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

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

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

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 $4.8 \times 10^{-4} \ \text{kW/m} \cdot {}^\circ\text{C}$, and a 25.0°C difference between inside and outside temperatures, the energy transfer from the house to the outside air each day is

$$E = \mathcal{P} \ \Delta t = \left[\frac{kA \ \ \Delta T}{L}\right] \Delta t = \left[\frac{4.8 \times 10^{-4} \ \text{kW/m} \cdot {}^\circ\text{C} \quad 304 \text{ m}^2 \quad 25.0^\circ\text{C}}{0.210 \text{ m}}\right] 86\,400 \text{ s}$$

or

$$E = 1.5 \times 10^6 \text{ kJ} = 1.5 \times 10^9 \text{ J}$$

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

$$V = \frac{E}{heat \ of \ combustion} = \frac{1.5 \times 10^9 \text{ J}}{9\,300 \ \text{kcal/m}^3 \quad 4\,186 \ \text{J/kcal}} = \boxed{39 \text{ m}^3}$$

11.43 $R = \Sigma R_i = R_{\substack{\text{outside}\\ \text{air film}}} + R_{\text{shingles}} + R_{\text{sheathing}} + R_{\text{cellulose}} + R_{\text{dry wall}} + R_{\substack{\text{inside}\\ \text{air film}}}$

$$R = \left[0.17 + 0.87 + 1.32 + 3\left(3.70\right) + 0.45 + 0.17\right]\frac{\text{ft}^2 \cdot {}^\circ\text{F}}{\text{Btu/h}} = \boxed{14\ \frac{\text{ft}^2 \cdot {}^\circ\text{F}}{\text{Btu/h}}}$$

11.44 The rate of energy transfer through a compound slab is

$$\mathcal{P} = \frac{A\left(\Delta T\right)}{R}, \text{ where } R = \Sigma\, L_i/k_i$$

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

Thus,

$$R = 2\left(\frac{0.50 \times 10^{-2}\ \text{m}}{0.84\ \text{W/m} \cdot {}^\circ\text{C}}\right) + \frac{1.0 \times 10^{-2}\ \text{m}}{0.0234\ \text{W/m} \cdot {}^\circ\text{C}} = 0.44\ \frac{\text{m}^2 \cdot {}^\circ\text{C}}{\text{W}}$$

and

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

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

$$R = \frac{1.0 \times 10^{-2}\ \text{m}}{0.84\ \text{W/m} \cdot {}^\circ\text{C}} = 1.2 \times 10^{-2}\ \frac{\text{m}^2 \cdot {}^\circ\text{C}}{\text{W}}$$

so

$$\mathcal{P} = \frac{\left(1.0\ \text{m}^2\right)\left(23^\circ\text{C}\right)}{1.2 \times 10^{-2}\ \text{m}^2 \cdot {}^\circ\text{C/W}} = 1.9 \times 10^3\ \text{W} = \boxed{1.9\ \text{kW}}, \text{ 37 times greater}$$

11.45 When the temperature of the junction stabilizes, the energy transfer rate must be the same for each of the rods, or $\mathcal{P}_{\text{Cu}} = \mathcal{P}_{\text{Al}}$ 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,

$$\mathcal{P}_{\text{Cu}} = k_{\text{Cu}}A\left(\frac{\Delta T}{L_{\text{Cu}}}\right) = k_{\text{Al}}A\left(\frac{\Delta T}{L_{\text{Al}}}\right) = \mathcal{P}_{\text{Al}},$$

which gives

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

11.46 The energy transfer rate is

$$\mathcal{P} = \frac{\Delta Q}{\Delta t} = \frac{m_{\text{ice}} L_f}{\Delta t} = \frac{5.0\text{ kg}\quad 3.33\times 10^{5}\text{ J/kg}}{8.0\text{ h}\quad 3\,600\text{ s/1 h}} = 58\text{ W}$$

Thus, $\mathcal{P} = kA(\Delta T/L)$ gives the thermal conductivity as

$$k = \frac{\mathcal{P}\cdot L}{A\ \ \Delta T} = \frac{58\text{ W}\quad 2.0\times 10^{-2}\text{ m}}{0.80\text{ m}^2\quad 25°\text{C} - 5.0°\text{C}} = \boxed{7.2\times 10^{-2}\text{ W/m}\cdot°\text{C}}$$

11.47 The absolute temperature of the sphere is $T = 473\text{ K}$ and that of the surroundings is $T_0 = 295\text{ K}$ For a perfect black-body radiator, the emissivity is $e = 1$ The net power radiated by the sphere is

$$\begin{aligned}\mathcal{P}_{\text{net}} &= \sigma Ae\ \ T^4 - T_0^4 \\ &= \left(5.67\times 10^{-8}\ \frac{\text{W}}{\text{m}^2\cdot\text{K}^4}\right)\left[4\pi\ \ 0.060\text{ m}\ ^2\right]\left[\ 473\text{ K}\ ^4 - \ 295\text{ K}\ ^4\right]\end{aligned}$$

or

$$\mathcal{P}_{\text{net}} = 1.1\times 10^{2}\text{ W} = \boxed{0.11\text{ kW}}$$

11.48 Since 97.0% of the incident energy is reflected, the rate of energy absorption from the sunlight is $\mathcal{P}_{\text{absorbed}} = 3.00\%\times\ \ I\cdot A\ \ = 0.0300\ \ I\cdot A$, where I is the intensity of the solar radiation.

$$\mathcal{P}_{\text{absorbed}} = 0.0300\ \ 1.40\times 10^{3}\text{ W/m}^2\quad 1.00\times 10^{3}\text{ m}\ ^2 = 4.20\times 10^{7}\text{ W}$$

Assuming the sail radiates equally from both sides (so $A = 2\ \ 1.00\text{ km}\ ^2 = 2.00\times 10^{6}\text{ m}^2$), the rate at which it will radiate energy to a 0 K environment when it has absolute temperature T is

$$\mathcal{P}_{\text{rad}} = \sigma Ae\ \ T^4 - 0\ \ = \left(5.669\,6\times 10^{-8}\ \frac{\text{W}}{\text{m}^2\cdot\text{K}^4}\right)\ 2.00\times 10^{6}\text{ m}^2\quad 0.03\ \ \cdot T^4 = \left(3.40\times 10^{-3}\ \frac{\text{W}}{\text{K}^4}\right)\cdot T^4$$

At the equilibrium temperature, where $\mathcal{P}_{\text{rad}} = \mathcal{P}_{\text{absorbed}}$, we then have

$$\left(3.40\times 10^{-3}\ \frac{\text{W}}{\text{K}^4}\right)\cdot T^4 = 4.20\times 10^{7}\text{ W} \text{ or } \qquad T = \left[\frac{4.20\times 10^{7}\text{ W}}{3.40\times 10^{-3}\ \text{W/K}^4}\right]^{1/4} = \boxed{333\text{ K}}$$

11.49 The absolute temperatures of the two stars are $T_X = 6\ 000\ \text{K}$ and $T_Y = 12\ 000\ \text{K}$ Thus, the ratio of their radiated powers is

$$\frac{\mathcal{P}_Y}{\mathcal{P}_X} = \frac{\sigma A e T_Y^4}{\sigma A e T_X^4} = \left(\frac{T_Y}{T_X}\right)^4 = 2^4 = \boxed{16}$$

11.50 The net power radiated is $\mathcal{P}_{\text{net}} = \sigma A e\left(T^4 - T_0^4\right)$, so the temperature of the radiator is

$$T = \left[T_0^4 + \frac{\mathcal{P}_{\text{net}}}{\sigma A e}\right]^{\frac{1}{4}}$$

If the temperature of the surroundings is $T_0 = 22°\text{C} = 295\ \text{K}$,

$$T = \left[(295\ \text{K})^4 + \frac{25\ \text{W}}{\left(5.67 \times 10^{-8}\ \text{W/m}^2 \cdot \text{K}^4\right)\left(2.5 \times 10^{-5}\ \text{m}^2\right)(0.90)}\right]^{\frac{1}{4}}$$
$$= 2.1 \times 10^3\ \text{K} = \boxed{1.8 \times 10^3\ °\text{C}}$$

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 it is

$$\mathcal{P} = kA\left(\frac{\Delta T}{L}\right) = \left(397\ \frac{\text{W}}{\text{m}\cdot°\text{C}}\right)\left[\pi(0.10\ \text{m})^2\right]\left(\frac{102°\text{C} - 100°\text{C}}{2.0 \times 10^{-3}\ \text{m}}\right)$$
$$= 1.2 \times 10^4\ \text{W} = \boxed{12\ \text{kW}}$$

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

$$Q = mc(\Delta T) = (189\ \text{kg})(4\ 186\ \text{J/kg})(60.0°\text{C} - 20.0°\text{C}) = 3.17 \times 10^7\ \text{J}$$

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

$$t = \frac{Q}{\mathcal{P}} = \frac{3.17 \times 10^7\ \text{J}}{4\ 800\ \text{J/s}}\left(\frac{1\ \text{h}}{3\ 600\ \text{s}}\right) = \boxed{1.83\ \text{h}}$$

11.53 The energy conservation equation is

$$m_{\mathrm{Pb}} c_{\mathrm{Pb}} \; 98°\mathrm{C} - 12°\mathrm{C} \; = m_{\mathrm{ice}} L_f + \left[\; m_{\mathrm{ice}} + m_w \; c_w + m_{\mathrm{cup}} c_{\mathrm{Cu}} \right] \; 12°\mathrm{C} - 0°\mathrm{C}$$

This gives

$$m_{\mathrm{Pb}} \left(128 \; \frac{\mathrm{J}}{\mathrm{kg} \cdot °\mathrm{C}} \right) \; 86°\mathrm{C} \; = \; 0.040 \text{ kg} \quad 3.33 \times 10^5 \; \mathrm{J/kg}$$
$$+ \left[\; 0.24 \text{ kg} \quad 4\,186 \; \mathrm{J/kg} \cdot °\mathrm{C} \; + \; 0.100 \text{ kg} \quad 357 \; \mathrm{J/kg} \cdot °\mathrm{C} \; \right] \; 12°\mathrm{C}$$

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

11.54 The energy needed is

$$Q = mc \; \Delta T \; = \; \rho V \; c \; \Delta T$$
$$= \left[\left(10^3 \; \frac{\mathrm{kg}}{\mathrm{m}^3} \right) \; 1.00 \text{ m}^3 \; \right] \; 4\,186 \; \mathrm{J/kg} \quad 40.0°\mathrm{C} \; = 1.67 \times 10^8 \text{ J}$$

The power input is $\mathcal{P} = \; 550 \; \mathrm{W/m^2} \quad 6.00 \text{ m}^2 \; = 3.30 \times 10^3 \; \mathrm{J/s}$, so the time required is

$$t = \frac{Q}{\mathcal{P}} = \frac{1.67 \times 10^8 \text{ J}}{3.30 \times 10^3 \; \mathrm{J/s}} \left(\frac{1 \text{ h}}{3\,600 \text{ s}} \right) = \boxed{14.1 \text{ h}}$$

11.55 The conservation of energy equation is

$$m_w c_w + m_{\mathrm{cup}} c_{\mathrm{glass}} \quad T - 27°\mathrm{C} \; = m_{\mathrm{Cu}} c_{\mathrm{Cu}} \; 90°\mathrm{C} - T$$

This gives

$$T = \frac{m_{\mathrm{Cu}} c_{\mathrm{Cu}} \; 90°\mathrm{C} \; + \; m_w c_w + m_{\mathrm{cup}} c_{\mathrm{glass}} \quad 27°\mathrm{C}}{m_w c_w + m_{\mathrm{cup}} c_{\mathrm{glass}} + m_{\mathrm{Cu}} c_{\mathrm{Cu}}}$$

or

$$T = \frac{0.200 \quad 387 \quad 90°\mathrm{C} \; + \left[\; 0.400 \quad 4\,186 \; + \; 0.300 \quad 837 \; \right] \; 27°\mathrm{C}}{0.400 \quad 4\,186 \; + \; 0.300 \quad 837 \; + \; 0.200 \quad 387} = \boxed{29\,°\mathrm{C}}$$

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

$$m = \frac{Q}{L_f} = \frac{\mathcal{P} \cdot \Delta t}{L_f} = \frac{(25 \text{ J/s})(4.0 \text{ h})(3\,600 \text{ s/h})}{2.01 \times 10^5 \text{ J/kg}} = \boxed{1.8 \text{ kg}}$$

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

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

Since $T_f = 66.3°\text{C}$ and $T_{i,\text{cal}} = T_{i,w} = 70.0°\text{C}$, this gives

$$c_{\text{Al}} = \frac{(m_w c_w + m_{\text{cal}} c_{\text{cal}})(T_{i,w} - T_f)}{m_{\text{Al}} (T_f - T_{i,\text{Al}})}$$

or

$$c_{\text{Al}} = \frac{\left[(0.400 \text{ kg})\left(4\,186 \frac{\text{J}}{\text{kg} \cdot °\text{C}}\right) + (0.040 \text{ kg})\left(630 \frac{\text{J}}{\text{kg} \cdot °\text{C}}\right)\right](70.0 - 66.3)°\text{C}}{(0.200 \text{ kg})(66.3 - 27.0)°\text{C}} = \boxed{8.00 \times 10^2 \frac{\text{J}}{\text{kg} \cdot °\text{C}}}$$

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

$$\% = \left(\frac{|\text{variation}|}{\text{accepted value}}\right) \times 100\% = \left(\frac{|800 - 900|\ \text{J/kg} \cdot °\text{C}}{900 \text{ J/kg} \cdot °\text{C}}\right) \times 100\% = \boxed{11.1\%}$$

which is within the 15% tolerance.

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

$$\mathcal{P}_{\text{rad}} = \sigma A e (T^4 - T_0^4)$$
$$= \left(5.669\,6 \times 10^{-8} \frac{\text{W}}{\text{m}^2 \cdot \text{K}^4}\right)(2.0 \text{ m}^2)(0.97)\left[(310 \text{ K})^4 - (297 \text{ K})^4\right] = \boxed{1.6 \times 10^2 \text{ W}}$$

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

$$\mathcal{P}_{\text{sweat}} = \frac{Q}{\Delta t} = \frac{mL_{v,\text{sweat}}}{\Delta t} = \frac{(0.40\text{ kg})(2.43\times10^{3}\text{ kJ/kg})(10^{3}\text{ J/kJ})}{3\,600\text{ s}} = \boxed{2.7\times10^{2}\text{ W}}$$

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

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

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

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

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

$$\mathcal{P}_{c\&c} = \mathcal{P}_{\text{excess}} - (\mathcal{P}_{\text{rad}} + \mathcal{P}_{\text{sweat}} + \mathcal{P}_{\text{lungs}}) = (5.6 - 1.6 - 2.7 - .11)\times10^{2}\text{ W} = \boxed{1.2\times10^{2}\text{ W}}$$

11.59 The rate at which energy must be added to the water is

$$\mathcal{P} = \frac{\Delta Q}{\Delta t} = \left(\frac{\Delta m}{\Delta t}\right)L_{v} = \left[\left(0.500\ \frac{\text{kg}}{\text{min}}\right)\left(\frac{1\text{ min}}{60\text{ s}}\right)\right]\left(2.26\times10^{6}\ \frac{\text{J}}{\text{kg}}\right) = 1.88\times10^{4}\text{ W}$$

From $\mathcal{P} = kA(T - 100°\text{C})/L$, the temperature of the bottom surface is

$$T = 100°\text{C} + \frac{\mathcal{P}\cdot L}{k\,A} = 100°\text{C} + \frac{(1.88\times10^{4}\text{ W})(0.500\times10^{-2}\text{ m})}{(238\text{ W/m}\cdot°\text{C})\left[\pi(0.120\text{ m})^{2}\right]} = \boxed{109\,°\text{C}}$$

11.60 The energy added to the air in one hour is

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

and the mass of air in the room is

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

The change in temperature is

$$\Delta T = \frac{Q}{mc} = \frac{7.2\times10^{6}\text{ J}}{(3.5\times10^{2}\text{ kg})(837\text{ J/kg}\cdot°\text{C})} = 25°\text{C}$$

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

11.61 In the steady state, $\mathcal{P}_{\text{Au}} = \mathcal{P}_{\text{Ag}}$, or

$$k_{\text{Au}} A\left(\frac{80.0°\text{C} - T}{L}\right) = k_{\text{Ag}} A\left(\frac{T - 30.0°\text{C}}{L}\right)$$

This gives

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

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

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

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

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

and the change in temperature is

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

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

$$Q = mc\left(\Delta T\right) = \left(6.0\ \text{kg}\right)\left(900\ \text{J/kg} \cdot °\text{C}\right)\left(660°\text{C} - 20°\text{C}\right) = 3.46 \times 10^6\ \text{J}$$

The internal energy added to the brakes on each stop is

$$Q_1 = \Delta KE = \frac{1}{2} m_{\text{car}} v_i^2 = \frac{1}{2}\left(1\ 500\ \text{kg}\right)\left(25\ \text{m/s}\right)^2 = 4.69 \times 10^5\ \text{J}$$

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) This calculation assumes no energy loss to the surroundings and that all internal energy generated stays with the brakes. Neither of these will be true in a realistic case.

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

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

When liquids 2 and 3 are mixed, energy conservation yields

$$mc_3(30°\text{C} - 28°\text{C}) = mc_2(28°\text{C} - 20°\text{C}), \text{ or } c_3 = 4c_2 = \left(\frac{28}{3}\right)c_1$$

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

or

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

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

$$\boxed{\frac{\Delta Q}{\Delta t} = \rho c(\Delta T)\left(\frac{\Delta V}{\Delta t}\right)}$$

where $\Delta V/\Delta t$ is the flow rate through the calorimeter.

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

$$c = \frac{\Delta Q/\Delta t}{\rho(\Delta T)(\Delta V/\Delta t)} = \frac{40 \text{ J/s}}{(0.72 \text{ g/cm}^3)(5.8°\text{C})(3.5 \text{ cm}^3/\text{s})}$$
$$= \left(2.7 \frac{\text{J}}{\text{g} \cdot °\text{C}}\right)\left(\frac{10^3 \text{ g}}{1 \text{ kg}}\right) = \boxed{2.7 \times 10^3 \text{ J/kg} \cdot °\text{C}}$$

11.66 (a) The surface area of the stove is $A_{\text{stove}} = A_{\text{ends}} + A_{\substack{\text{cylindrical}\\ \text{side}}} = 2(\pi r^2) + (2\pi r)h$, 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 $T_s = \frac{5}{9}(400°\text{F} - 32.0°\text{F}) = 204°\text{C} = 477 \text{ K}$ while that of the air in the room is $T_r = \frac{5}{9}(70.0°\text{F} - 32.0°\text{F}) = 21.1°\text{C} = 294 \text{ K}$ If the emissivity of the stove is $e = 0.920$, the net power radiated to the room is

$$\mathcal{P} = \sigma A_{\text{stove}} e \left(T_s^4 - T_r^4\right)$$

$$= \left(5.67 \times 10^{-8}\ \text{W/m}^2 \cdot \text{K}^4\right)\left(0.880\ \text{m}^2\right)\left(0.920\right)\left[\left(477\ \text{K}\right)^4 - \left(294\ \text{K}\right)^4\right]$$

or

$$\mathcal{P} = \boxed{2.03 \times 10^3\ \text{W}}$$

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

$$A = 4A_{\text{wall}} + A_{\text{ceiling}} = 4\left[\left(8.00\ \text{ft}\right)\left(25.0\ \text{ft}\right)\right] + \left(25.0\ \text{ft}\right)^2 = 1.43 \times 10^3\ \text{ft}^2$$

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, $\mathcal{P} = A\left(T_h - T_c\right)/\Sigma R_i$, the net R value needed in the walls and ceiling is

$$\Sigma R_i = \frac{A\left(T_h - T_c\right)}{\mathcal{P}} = \frac{\left(1.43 \times 10^3\ \text{ft}^2\right)\left(70.0°\text{F} - 32.0°\text{F}\right)}{2.03 \times 10^3\ \text{J/s}}\left(\frac{1\ 054\ \text{J}}{1\ \text{Btu}}\right)\left(\frac{1\ \text{h}}{3\ 600\ \text{s}}\right)$$

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 $m = \rho V = \left(10^3\ \text{kg/m}^3\right)\left(1.0 \times 10^{-3}\ \text{m}^3\right) = 1.0\ \text{kg}$.

The energy required to raise the temperature of the water to 100°C and then completely evaporate it is $Q = mc\left(\Delta T\right) + mL_v$, or

$$Q = \left(1.0\ \text{kg}\right)\left(4\ 186\ \text{J/kg} \cdot °\text{C}\right)\left(100°\text{C} - 20°\text{C}\right) + \left(1.0\ \text{kg}\right)\left(2.26 \times 10^6\ \text{J/kg}\right) = 2.59 \times 10^6\ \text{J}$$

The power input to the water from the solar cooker is

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

so the time required to evaporate the water is

$$t = \frac{Q}{\mathcal{P}} = \frac{2.59 \times 10^6\ \text{J}}{59\ \text{J/s}} = \left(4.4 \times 10^4\ \text{s}\right)\left(\frac{1\ \text{h}}{3\ 600\ \text{s}}\right) = \boxed{12\ \text{h}}$$

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

$$Q = \mathcal{P}_1 (12.0 \text{ h}) + \mathcal{P}_2 (12.0 \text{ h}) = \frac{kA}{L}\left[(37.0°\text{C} - 23.0°\text{C}) + (37.0°\text{C} - 16.0°\text{C})\right](12.0 \text{ h})$$

or

$$Q = \frac{(0.012\,0 \text{ J/s}\cdot\text{m°C})(0.490 \text{ m}^2)}{0.095\,0 \text{ m}}(14.0°\text{C} + 21.0°\text{C})(12.0 \text{ h})\left(\frac{3\,600 \text{ s}}{1 \text{ h}}\right) = 9.36 \times 10^4 \text{ J}$$

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

$$m = \frac{Q}{L_f} = \frac{9.36 \times 10^4 \text{ J}}{205 \times 10^3 \text{ J/kg}} = \boxed{0.457 \text{ kg}}$$

(b) If the test samples and the inner surface of the insulation is preheated to 37.0°C during the assembly of the box, $\boxed{\text{nothing undergoes a temperature change}}$ 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 energy m kilograms of steam give up as it (i) cools to the boiling point of 100°C, (ii) condenses into a liquid, and (iii) cools on down to the final temperature of 50.0°C is

$$\begin{aligned} Q_m &= mc_{\text{steam}}(\Delta T)_1 + mL_v + mc_{\substack{\text{liquid}\\ \text{water}}}(\Delta T)_2 \\ &= m\left[(2.01 \times 10^3 \text{ J/kg}\cdot°\text{C})(130°\text{C} - 100°\text{C}) + 2.26 \times 10^6 \text{ J/kg}\right. \\ &\qquad \left. + (4\,186 \text{ J/kg}\cdot°\text{C})(100°\text{C} - 50.0°\text{C})\right] \\ &= m(2.53 \times 10^6 \text{ J/kg}) \end{aligned}$$

The energy needed to raise the temperature of the 200-g of original water and the 100-g glass container from 20.0°C to 50.0°C is

$$\begin{aligned} Q_{\text{needed}} &= (m_w c_w + m_g c_g)\Delta T = \left[(0.200 \text{ kg})(4\,186 \text{ J/kg}\cdot°\text{C}) + (0.100 \text{ kg})(837 \text{ J/kg}\cdot°\text{C})\right](30.0°\text{C}) \\ &= 2.76 \times 10^4 \text{ J} \end{aligned}$$

Equating the energy available from the steam to the energy required gives

$$m\left(2.53\times 10^{6}\ \text{J/kg}\right) = 2.76\times 10^{4}\ \text{J} \quad \text{or} \qquad m = \frac{2.76\times 10^{4}\ \text{J}}{2.53\times 10^{6}\ \text{J/kg}} = 0.010\,9\ \text{kg} = \boxed{10.9\ \text{g}}$$

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

$$L_v^{37°\text{C}} \approx c_{\text{water}}(\Delta T) + L_v^{100°\text{C}} = \left(4\,186\ \text{J/kg}\cdot°\text{C}\right)\left(100°\text{C} - 37°\text{C}\right) + 2.26\times 10^{6}\ \text{J/kg}$$

or

$$L_v^{37°\text{C}} \approx 2.5\times 10^{6}\ \text{J/kg}$$

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

$$Q = IA(\Delta t) = \left(1\,000\ \text{W/m}^2\right)\left(0.60\ \text{m}^2\right)\left(3\,600\ \text{s}\right) = 2.2\times 10^{6}\ \text{J}$$

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

$$m = \frac{Q}{L_v^{37°\text{C}}} \approx \frac{2.2\times 10^{6}\ \text{J}}{2.5\times 10^{6}\ \text{J/kg}} = \boxed{0.9\ \text{kg}}$$

The volume of this quantity of water is

$$V = \frac{m}{\rho} = \frac{0.9\ \text{kg}}{10^{3}\ \text{kg/m}^3} \approx 10^{-3}\ \text{m}^3 = 1\ \text{L}$$

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 $Q_1 = mL_f = m\left(3.33\times 10^{5}\ \text{J/kg}\right)$, so the constant power input must be

$$\mathcal{P} = \left(\frac{Q}{\Delta t}\right)_1 = \frac{m\left(3.33\times 10^{5}\ \text{J/kg}\right)}{50\ \text{min}}$$

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

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

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

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

which simplifies to $8.0\,m = m + 10\ \text{kg}$, or

$$m = \frac{10\ \text{kg}}{7.0} = \boxed{1.4\ \text{kg}}$$

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

$$Q = \left(75.0\times 10^{-3}\ \text{kg}\right)\left[\left(4\,186\ \frac{\text{J}}{\text{kg}\cdot{}^\circ\text{C}}\right)\left|-20.0^\circ\text{C}\right| + 3.33\times 10^{5}\ \frac{\text{J}}{\text{kg}} + \left(2\,090\ \frac{\text{J}}{\text{kg}\cdot{}^\circ\text{C}}\right)\left|-8.00^\circ\text{C}\right|\right]$$

$$= 3.25\times 10^{4}\ \text{J} = \boxed{32.5\ \text{kJ}}$$

11.73 (a) In steady state, the energy transfer rate is the same for each of the rods, or

$$\mathcal{P}_{\text{Al}} = \mathcal{P}_{\text{Fe}}. \text{ Thus, } k_{\text{Al}} A\left(\frac{100^\circ\text{C} - T}{L}\right) = k_{\text{Fe}} A\left(\frac{T - 0^\circ\text{C}}{L}\right)$$

giving

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

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

$$Q = \mathcal{P}_{\text{Al}}\cdot t = \left[\left(238\ \frac{\text{W}}{\text{m}\cdot{}^\circ\text{C}}\right)\left(5.0\times 10^{-4}\ \text{m}^2\right)\left(\frac{100^\circ\text{C} - 75.0^\circ\text{C}}{0.15\ \text{m}}\right)\right](1\,800\ \text{s})$$

$$= 3.6\times 10^{4}\ \text{J} = \boxed{36\ \text{kJ}}$$