CHAPTER 11

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. (d). The final temperatures will depend on the mass of each sample.

3. (c).

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

5. (e). The ratio of the power output of Star A to that of Star B is given by

$$\frac{\wp_A}{\wp_B} = \frac{\sigma A_A e T_A^4}{\sigma A_B e T_B^4} = \frac{\sigma\left(4\pi R_A^2\right)(1)T_A^4}{\sigma\left(4\pi R_B^2\right)(1)T_B^4} = \frac{\left(2R_B\right)^2\left(2T_B\right)^4}{R_B^2 T_B^4} = \left(2^2\right)\left(2^4\right) = 64$$

Problem Solutions

11.1 $Q = mc(\Delta T)$

$$= (0.100\ \text{kg})(129\ \text{J/kg}\cdot{}^\circ\text{C})(100^\circ\text{C} - 20.0^\circ\text{C}) = 1.03\times 10^{3}\ \text{J} = \boxed{1.03\ \text{kJ}}$$

11.2 From $Q = mc(\Delta T)$, the change in temperature is

$$\Delta T = \frac{Q}{mc} = \frac{1200\ \text{J}}{(50\times 10^{-3}\ \text{kg})(387\ \text{J/kg}\cdot{}^\circ\text{C})} = 62^\circ\text{C}$$

Thus, $T_f = T_i + \Delta T = 25^\circ\text{C} + 62^\circ\text{C} = \boxed{87^\circ\text{C}}$

11.3 The mass of water involved is

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

(a) $Q = mc(\Delta T) = (4.00\times 10^{14}\ \text{kg})(4186\ \text{J/kg}\cdot{}^\circ\text{C})(1.00^\circ\text{C}) = \boxed{1.67\times 10^{18}\ \text{J}}$

(b) The power input is $\wp = 1000\ \text{MW} = 1.00\times 10^{9}\ \text{J/s}$,

so, $t = \dfrac{Q}{\wp} = \dfrac{1.67\times 10^{18}\ \text{J}}{1.00\times 10^{9}\ \text{J/s}}\left(\dfrac{1\ \text{yr}}{3.156\times 10^{7}\ \text{s}}\right) = \boxed{53.1\ \text{yr}}$

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

$$\Delta L = \alpha L_i(\Delta T)$$

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

11.5 The mechanical energy converted to internal energy in the collision is $Q = \left|\Delta PE_g\right| = mgh$. Thus, the expected rise in temperature is

$$\Delta T = \frac{Q}{mc} = \frac{m\left(9.80 \text{ m/s}^2\right)\left(110 \text{ m}\right)}{m\left(4186 \text{ J/kg°C}\right)} = \boxed{0.258\text{°C}}$$

11.6 The internal energy converted to mechanical energy in one ascent of the rope is $Q = \Delta PE_g = mgh$. Since $1 \text{ Calorie} = 1000 \text{ calories} = 4186 \text{ Joules}$,

$$Q = \left(50.0 \text{ kg}\right)\left(9.80 \text{ m/s}^2\right)\left(10.0 \text{ m}\right)\left(\frac{1 \text{ Calorie}}{4186 \text{ J}}\right) = \boxed{1.17 \text{ Calorie}}$$

11.7 The internal energy converted to mechanical energy in the climb is $Q = \Delta PE_g = mgh$. Thus, the required height is

$$h = \frac{Q}{mg} = \frac{\left(500 \text{ Calories}\right)\left(4186 \text{ J/1 Calorie}\right)}{\left(75.0 \text{ kg}\right)\left(9.80 \text{ m/s}^2\right)} = 2.85 \times 10^3 \text{ m} = \boxed{2.85 \text{ km}}$$

11.8 The mass of water in the tub is

$$m = \rho V = \left(10^3 \text{ kg/m}^3\right)\left(0.800 \text{ m}^3\right) = 8.00 \times 10^2 \text{ kg},$$

and the internal energy transferred to the water from the body is

$$Q = \left(100 \ \frac{\text{kcal}}{\text{h}}\right)\left(0.750 \text{ h}\right)\left(\frac{4186 \text{ J}}{1 \text{ kcal}}\right) = 3.14 \times 10^5 \text{ J}$$

Thus, the change in the temperature of the water will be

$$\Delta T = \frac{Q}{mc} = \frac{3.14 \times 10^5 \text{ J}}{\left(8.00 \times 10^2 \text{ kg}\right)\left(4186 \text{ J/kg}\cdot\text{°C}\right)} = \boxed{0.0938\text{°C}}$$

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

$$\Delta T = \frac{Q}{mc} = \frac{\frac{1}{4}mv_i^2}{mc} = \frac{\left(300 \text{ m/s}\right)^2}{4\left(128 \text{ J/kg}\cdot\text{°C}\right)} = \boxed{176\text{°C}}$$

11.10 (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

$$\Delta T = \frac{Q}{mc} = \frac{0.85\left(\frac{1}{2}mv_i^2\right)}{mc} = \frac{0.85(3.0\ \text{m/s})^2}{2(387\ \text{J/kg}\cdot°\text{C})} = \boxed{9.9\times10^{-3}\ °\text{C}}$$

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

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

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

$$= \left[(0.800\ \text{kg})\left(4186\ \frac{\text{J}}{\text{kg}\cdot°\text{C}}\right) + (0.200\ \text{kg})\left(900\ \frac{\text{J}}{\text{kg}\cdot°\text{C}}\right)\right](1.5°\text{C}) = 5.3\times10^3\ \text{J}$$

The rate of energy transfer is $\wp = \frac{Q}{\Delta t} = \frac{5.3\times10^3\ \text{J}}{60\ \text{s}} = 88\ \frac{\text{J}}{\text{s}} = \boxed{88\ \text{W}}$

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

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

or the number of pellets required is

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

$$= \frac{(0.500\ \text{kg})(4186\ \text{J/kg}\cdot°\text{C})(25.0°\text{C} - 20.0°\text{C})}{(1.00\times10^{-3}\ \text{kg})(128\ \text{J/kg}\cdot°\text{C})(200°\text{C} - 25.0°\text{C})} = \boxed{467}$$

11.13 The energy absorbed by the water equals the energy given up by the iron, so

$$\left[mc(\Delta T)\right]_{water} = \left[mc|\Delta T|\right]_{iron} \text{ , or}$$

$$(20 \text{ kg})(4186 \text{ J/kg}\cdot{}^\circ\text{C})(T_f - 22^\circ\text{C}) = (0.40 \text{ kg})(448 \text{ J/kg}\cdot{}^\circ\text{C})(500^\circ\text{C} - T_f).$$

Solving for the final temperature gives $T_f = \boxed{23^\circ\text{C}}$

11.14 The mass of water is

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

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

$$T_f = \frac{m_w c_w (90^\circ\text{C}) + m_b c_b (20^\circ\text{C})}{m_w c_w + m_b c_b}.$$

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

$$(T_f)_{silver} = \frac{(0.100)(4186)(90^\circ\text{C}) + (5.0\times10^{-3})(234)(20^\circ\text{C})}{(0.100)(4186) + (5.0\times10^{-3})(234)} = \boxed{89.8^\circ\text{C}}$$

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

$$(T_f)_{copper} = \frac{(0.100)(4186)(90^\circ\text{C}) + (5.0\times10^{-3})(387)(20^\circ\text{C})}{(0.100)(4186) + (5.0\times10^{-3})(387)} = \boxed{89.7^\circ\text{C}}$$

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

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

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

Solving for the mass of the cup gives

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

or $$m_c = \frac{1}{900}\left[(400\text{ g})(234)\frac{(87-32)}{(32-27)} - (40\text{ g})(387) - (225\text{ g})(4186)\right] = \boxed{80\text{ g}}$$

11.16 The total energy absorbed by the 200-g of cold water and the cup equals the energy given up by the 100-g of hot water.

Thus, $\left[m_{cw}c_{\text{w}} + m_{cup}c_{\text{Al}}\right]\left(T_f - 10°\text{C}\right) = m_{hw}c_w\left(100°\text{C} - T_f\right)$, or solving for the final temperature,

$$T_f = \frac{m_{hw}c_w(100°\text{C}) + \left(m_{cw}c_{\text{w}} + m_{cup}c_{\text{Al}}\right)(10°\text{C})}{m_{cw}c_{\text{w}} + m_{cup}c_{\text{Al}} + m_{hw}c_w}$$

Using the numeric data provided yields

$$T_f = \frac{(100\text{ g})(4186)(100°\text{C}) + \left[(200\text{ g})(4186) + (300\text{ g})(900)\right](10°\text{C})}{(200\text{ g})(4186) + (300\text{ g})(900) + (100\text{ g})(4186)} = \boxed{35°\text{C}}$$

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

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

Solving for the specific heat of the unknown material gives

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

$$c_{unk} = \frac{1}{(70\text{ g})(80°\text{C})}\left[(100\text{ g})(900\text{ J/kg}\cdot°\text{C}) + (250\text{ g})(4186\text{ J/kg}\cdot°\text{C})\right](10°\text{C})$$

$$-(50\text{ g})(387\text{ J/kg}\cdot°\text{C})(60°\text{C}) = \boxed{1.8\times10^3\text{ J/kg}\cdot°\text{C}}$$

11.18 Assume that the final temperature is in the range $20.0 < T_f < 26.0°\text{C}$, or that the aluminum gives up energy. Then, the energy absorbed by the water equals the total energy given up by the aluminum and the copper, giving

$$m_w c_w \left(T_f - 20.0°\text{C}\right) = m_{Al} c_{Al} \left(26.0°\text{C} - T_f\right) + m_{Cu} c_{Cu} \left(100°\text{C} - T_f\right)$$

Solving for the final temperature,

$$T_f = \frac{m_{Al} c_{Al} \left(26.0°\text{C}\right) + m_{Cu} c_{Cu} \left(100°\text{C}\right) + m_w c_w \left(20.0°\text{C}\right)}{m_w c_w + m_{Al} c_{Al} + m_{Cu} c_{Cu}},$$

or $$T_f = \frac{(0.400)(900)(26.0°\text{C}) + (0.100)(387)(100°\text{C}) + (0.250)(4186)(20.0°\text{C})}{(0.250)(4186) + (0.400)(900) + (0.100)(387)}$$

$$= \boxed{23.6°\text{C}}$$

If we had assumed the aluminum absorbs energy in this process, the correct conservation of energy equation would have been

$$m_w c_w \left(T_f - 20.0°\text{C}\right) + m_{Al} c_{Al} \left(T_f - 26.0°\text{C}\right) = m_{Cu} c_{Cu} \left(100°\text{C} - T_f\right).$$

Upon solving for the final temperature, we would have obtained

$$T_f = \frac{m_{Al} c_{Al} \left(26.0°\text{C}\right) + m_{Cu} c_{Cu} \left(100°\text{C}\right) + m_w c_w \left(20.0°\text{C}\right)}{m_w c_w + m_{Al} c_{Al} + m_{Cu} c_{Cu}},$$

which is the same as we had earlier. Thus, we would have arrived at the same answer as obtained with the assumption that the aluminum gives up energy.

11.19 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

$$m_{Al} = \left(\frac{c_{Cu}}{c_{Al}}\right)\left[\frac{|\Delta T|_{Cu}}{(\Delta T)_{Al}}\right] m_{Cu}$$

$$= \left(\frac{387}{900}\right)\left(\frac{85°\text{C} - 25°\text{C}}{25°\text{C} - 5.0°\text{C}}\right)(200\text{ g}) = 2.6 \times 10^2\text{ g} = \boxed{0.26\text{ kg}}$$

11.20 The total energy input required is

$$Q = (\text{energy to melt 50 g of ice}) + (\text{energy to warm 50 g of water to 100°C}) + (\text{energy to vaporize 5.0 g water})$$

$$= (50\text{ g})L_f + (50\text{ g})c_{water}(100°\text{C-}0°\text{C}) + (5.0\text{ g})L_v$$

Thus, $Q = (0.050\text{ kg})\left(3.33\times10^5\ \frac{\text{J}}{\text{kg}}\right) + (0.050\text{ kg})\left(4186\ \frac{\text{J}}{\text{kg}\cdot°\text{C}}\right)(100°\text{C-}0°\text{C}) + (5.0\times10^{-3}\text{ kg})\left(2.26\times10^6\ \frac{\text{J}}{\text{kg}}\right)$,

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

11.21 The conservation of energy equation for this process is

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

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

This yields $T_f = \dfrac{m_w c_w(80°\text{C}) - m_{ice}L_f}{(m_{ice}+m_w)c_w}$, so

$$T_f = \frac{(1.0\text{ kg})(4186\text{ J/kg}\cdot°\text{C})(80°\text{C}) - (0.100\text{ kg})(3.33\times10^5\text{ J/kg})}{(1.1\text{ kg})(4186\text{ J/kg}\cdot°\text{C})} = \boxed{65°\text{C}}$$

11.22 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,

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

This yields

$$Q = (40\times10^{-3}\ \text{kg})\Bigg[\left(2090\ \frac{\text{J}}{\text{kg}\cdot°\text{C}}\right)(10°\text{C}) + \left(3.33\times10^{5}\ \frac{\text{J}}{\text{kg}}\right) + \left(4186\ \frac{\text{J}}{\text{kg}\cdot°\text{C}}\right)(100°\text{C}) + \left(2.26\times10^{6}\ \frac{\text{J}}{\text{kg}}\right) + \left(2010\ \frac{\text{J}}{\text{kg}\cdot°\text{C}}\right)(10°\text{C})\Bigg]$$

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

11.23 In order to come to equilibrium at 50°C, the steam must: cool to 100°C, condense, and then cool (as condensed water) to 50°C. Thus, the conservation of energy equation is

$$m_{steam}\left[c_{steam}(120°\text{C-}100°\text{C}) + L_v + c_w(100°\text{C-}50°\text{C})\right] = \left(m_w c_w + m_{cup}c_{\text{Al}}\right)(50°\text{C-}20°\text{C})$$

or $$m_{steam} = \frac{\left(m_w c_w + m_{cup}c_{\text{Al}}\right)(30°\text{C})}{c_{steam}(20°\text{C}) + L_v + c_w(50°\text{C})}.$$

This gives

$$m_{steam} = \frac{\left[(0.350\ \text{kg})(4186\ \text{J/kg}\cdot°\text{C}) + (0.300\ \text{kg})(900\ \text{J/kg}\cdot°\text{C})\right](30°\text{C})}{(2010\ \text{J/kg}\cdot°\text{C})(20°\text{C}) + (2.26\times10^{6}\ \text{J/kg}) + (4186\ \text{J/kg}\cdot°\text{C})(50°\text{C})},$$

and $m_{steam} = 2.1\times10^{-2}\ \text{kg} = \boxed{21\ \text{g}}$

11.24 Because the large block of ice will not all melt, the bullet must give up its original kinetic energy and also cool to 0°C. The conservation of energy equation is

$$m_{melt}L_f = \frac{1}{2}m_b v_i^2 + m_b c_{\text{Pb}}\left(30.0°\text{C-}0°\text{C}\right)$$

Thus, $m_{melt} = m_b\left[\dfrac{\frac{1}{2}v_i^2 + c_{\text{Pb}}\left(30.0°\text{C}\right)}{L_f}\right]$

$$= \left(3.00 \text{ g}\right)\left[\frac{\frac{1}{2}\left(240 \text{ m/s}\right)^2 + \left(128 \text{ J/kg}\cdot°\text{C}\right)\left(30.0°\text{C}\right)}{3.33\times10^5 \text{ J/kg}}\right] = \boxed{0.294 \text{ g}}$$

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

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

11.26 Assuming all the ice melts, the conservation of energy equation is

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

giving

$$T_f = \frac{m_w c_w\left(25°\text{C}\right) - m_{ice}L_f}{\left(m_w + m_{ice}\right)c_w}$$

$$= \frac{\left(650 \text{ g}\right)\left(4186 \text{ J/kg}\cdot°\text{C}\right)\left(25°\text{C}\right) - \left(100 \text{ g}\right)\left(3.33\times10^5 \text{ J/kg}\right)}{\left(650 \text{ g} + 100 \text{ g}\right)\left(4186 \text{ J/kg}\cdot°\text{C}\right)} = \boxed{11°\text{C}}$$

Note: If this had yielded a negative answer for T_f, it would have indicated that the assumption of all ice melting was false. The correct answer in that case would have been $T_f = 0°\text{C}$.

11.27 Assume that all the ice melts. If this yields a result $T_f > 0$, the assumption is valid, otherwise the problem must be solved again based on a different premise. If all ice melts, energy conservation yields

$$m_{ice}\left[c_{ice}\left[0°\text{C-}(-78°\text{C})\right] + L_f + c_w\left(T_f - 0°\text{C}\right)\right] = \left(m_w c_w + m_{cup} c_{\text{Cu}}\right)\left(25°\text{C} - T_f\right),$$

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

With $m_w = 560$ g, $m_{cup} = 80$ g, $m_{ice} = 40$ g, $c_w = 4186\ \text{J/kg}\cdot°\text{C}$,

$c_{\text{Cu}} = 387\ \text{J/kg}\cdot°\text{C}$, $c_{ice} = 2090\ \text{J/kg}\cdot°\text{C}$, and $L_f = 3.33\times10^5\ \text{J/kg}$,

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

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

$$\Delta E = \wp \cdot t = (300\ \text{J/s})(3600\ \text{s}) = 1.08\times10^6\ \text{J}$$

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

$$V = \frac{m}{\rho} = \frac{0.403\ \text{kg}}{1000\ \text{kg/m}^3} = \left(4.03\times10^{-4}\ \text{m}^3\right)\left(\frac{10^6\ \text{cm}^3}{1\ \text{m}^3}\right) = \boxed{403\ \text{cm}^3}$$

11.29 The original kinetic energy all becomes thermal energy:

$$Q = \frac{1}{2}mv_i^2 + \frac{1}{2}mv_i^2 = 2\left(\frac{1}{2}\right)\left(5.00\times10^{-3}\ \text{kg}\right)(500\ \text{m/s})^2 = 1.25\times10^3\ \text{J}$$

Raising the temperature to the melting point requires

$$Q_1 = mc(\Delta T) = \left(10.0\times10^{-3}\ \text{kg}\right)(128\ \text{J/kg}\cdot°\text{C})(327°\text{C} - 20.0°\text{C}) = 393\ \text{J}$$

Since 1250 J > 393 J, the lead starts to melt. Melting it all requires additional energy

$$Q_2 = mL_f = \left(10.0\times10^{-3}\ \text{kg}\right)\left(2.45\times10^{4}\ \text{J/kg}\right) = 245\ \text{J}.$$

Since 1250 J > 393 + 245 J, all the lead will melt. After $Q_1 + Q_2 = 638\ \text{J}$ has been used to melt the lead, there is insufficient energy remaining to reach the boiling point at 1750°C. Rather, the residual energy $Q - (Q_1 + Q_2)$ is used in raising the temperature of the $\boxed{\text{liquid lead}}$. If the specific heat is assumed to be constant, the final temperature will be

$$T_f = 327°\text{C} + \frac{Q-(Q_1+Q_2)}{mc} = 327°\text{C} + \frac{1250\ \text{J} - (393+245)\ \text{J}}{\left(10.0\times10^{-3}\ \text{kg}\right)\left(128\ \text{J/kg}\cdot°\text{C}\right)} = \boxed{805°\text{C}}$$

11.30 The energy that must be absorbed to cool the water and cup to 0°C is

$$Q_1 = \left(m_w c_w + m_{cup} c_{\text{Al}}\right)(\Delta T)$$
$$= \left[(0.180\ \text{kg})(4186\ \text{J/kg}\cdot°\text{C}) + (0.100\ \text{kg})(900\ \text{J/kg}\cdot°\text{C})\right](30.0°\text{C}) = 2.53\times10^{4}\ \text{J}$$

(a) The amount of ice, at 0°C, that must melt to absorb energy equal to Q_1 is

$$m = \frac{Q_1}{L_f} = \frac{2.53\times10^{4}\ \text{J}}{3.33\times10^{5}\ \text{J/kg}} = 7.6\times10^{-2}\ \text{kg} = 76\ \text{g}.$$

Hence, if 100 g of ice is used, not all of it will melt. Rather, the final temperature is $\boxed{0°\text{C with 24 g of ice left over}}$.

(b) If 50 g of ice is used, all of the ice will melt and the conservation of energy equation is

$$m_{ice}\left[L_f + c_w\left(T_f - 0°\text{C}\right)\right] = \left(m_w c_w + m_{cup} c_{\text{Al}}\right)\left(30°\text{C} - T_f\right).$$

Thus,

$$(50\ \text{g})\left[\left(3.33\times10^{5}\ \frac{\text{J}}{\text{kg}}\right) + \left(4186\ \frac{\text{J}}{\text{kg}\cdot\text{C}}\right)T_f\right] =$$
$$\left[(180\ \text{g})\left(4186\ \frac{\text{J}}{\text{kg}\cdot\text{C}}\right) + (100\ \text{g})\left(900\ \frac{\text{J}}{\text{kg}\cdot\text{C}}\right)\right]\left(30°\text{C} - T_f\right)$$

This yields a final temperature of $T_f = \boxed{8.2°\text{C}}$.

11.31 The energy required to melt 50 g of ice is

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

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

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

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

$$Q_3 = m_s L_v = (0.010 \text{ kg})(2260 \text{ kJ/kg}) = 22.6 \text{ kJ}$$

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

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

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

giving $$T_f = \frac{(10 \text{ g})\left[2.26\times10^6 + (4186)(100)\right] - (50 \text{ g})(3.33\times10^5)}{(50 \text{ g} + 10 \text{ g})(4186)} = \boxed{40°\text{C}}$$

(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

$$Q_4 = m_s c_w(\Delta T) = (1.0\times10^{-3} \text{ kg})(4.186 \text{ kJ/kg}\cdot°\text{C})(100°\text{C}) = 0.419 \text{ kJ}$$

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

$$m = \frac{Q_3' + Q_4}{L_f} = \frac{(2.26+0.419) \text{ kJ}}{333 \text{ kJ/kg}} = 8.0\times10^{-3} \text{ kg} = \boxed{8.0 \text{ g}}$$

11.32 Since the temperature of the ice and nail do not change, all of the initial mechanical energy of the hammer is used to melt ice. Thus, the mass of ice melted is found from $m_{ice}L_f = \frac{1}{2}m_{hammer}v_i^2$. This gives

$$m_{ice} = \left(\frac{v_i^2}{2L_f}\right)m_{hammer} = \frac{(2.0\ \text{m/s})^2}{2(3.33\times10^5\ \text{J/kg})}(0.50\ \text{kg}) = 3.0\times10^{-6}\ \text{kg}=3.0\times10^{-3}\ \text{g}$$

or $\quad m_{ice} = \boxed{3.0\ \text{mg}}$

11.33 The rate of energy transfer through a block of the given dimensions is

$$H = \frac{\Delta Q}{\Delta t} = kA\left(\frac{\Delta T}{L}\right) = k\left(15\times10^{-4}\ \text{m}^2\right)\left(\frac{30°\text{C}}{0.080\ \text{m}}\right) = k(0.56\ \text{m}\cdot°\text{C})$$

where k is the thermal conductivity of the material.

(a) For a copper block, $k = 397\ \text{J/s}\cdot\text{m}\cdot°\text{C}$ and

$$H = \left(397\ \frac{\text{J}}{\text{s}\cdot\text{m}\cdot°\text{C}}\right)(0.56\ \text{m}\cdot°\text{C}) = 0.22\ \frac{\text{kJ}}{\text{s}} = \boxed{0.22\ \text{kW}}$$

(b) For air, $H = \left(0.0234\ \frac{\text{J}}{\text{s}\cdot\text{m}\cdot°\text{C}}\right)(0.56\ \text{m}\cdot°\text{C}) = 0.013\ \frac{\text{J}}{\text{s}} = \boxed{13\ \text{mW}}$

(c) For wood, $H = \left(0.10\ \frac{\text{J}}{\text{s}\cdot\text{m}\cdot°\text{C}}\right)(0.56\ \text{m}\cdot°\text{C}) = 0.056\ \frac{\text{J}}{\text{s}} = 56\ \text{mW}$

11.34 (a) With the outside temperature higher than that in the house, we have $\Delta T = T_h - T_c = 90°\text{F} - 70°\text{F} = 20°\text{F} = \frac{5}{9}(20°) = 11°\text{C}$ and the rate of energy transfer *into* the house is

$$H = kA\left(\frac{\Delta T}{L}\right) = \left(0.84\ \frac{\text{J}}{\text{s}\cdot\text{m}\cdot°\text{C}}\right)\left(0.16\ \text{m}^2\right)\left(\frac{11°\text{C}}{3.0\times10^{-3}\ \text{m}}\right) = 5.0\times10^2\ \frac{\text{J}}{\text{s}}$$

or $H = \boxed{0.50\ \text{kW into the house}}$

(b) With the interior warmer than the outside air, we have $\Delta T = T_h - T_c = 70°\text{F} - 0°\text{F} = 70°\text{F} = \frac{5}{9}(70°) = 39°\text{C}$ and the rate of energy transfer *out of* the house is

$$H = kA\left(\frac{\Delta T}{L}\right) = \left(0.84\ \frac{\text{J}}{\text{s}\cdot\text{m}\cdot°\text{C}}\right)\left(0.16\ \text{m}^2\right)\left(\frac{39°\text{C}}{3.0\times10^{-3}\ \text{m}}\right) = 1.7\times10^3\ \frac{\text{J}}{\text{s}}$$

or $H = \boxed{1.7\ \text{kW out of the house}}$

11.35 $H = kA\left(\frac{\Delta T}{L}\right)$, with $k = 0.200\ \frac{\text{cal}}{\text{cm}\cdot°\text{C}\cdot\text{s}}\left(\frac{10^2\ \text{cm}}{1\ \text{m}}\right)\left(\frac{4.186\ \text{J}}{1\ \text{cal}}\right) = 83.7\ \frac{\text{J}}{\text{s}\cdot\text{m}\cdot°\text{C}}$

Thus, the energy transfer rate is

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

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

11.36 Since the air temperature inside the box remains constant, the power input from the heater must equal the energy transfer to the exterior. Thus, $H = kA\left(\frac{\Delta T}{L}\right) = \wp$, giving

$$k = \frac{\wp}{A}\left(\frac{L}{\Delta T}\right) = \frac{(10.0\ \text{W})}{\left(1.20\ \text{m}^2\right)}\left(\frac{4.00\times10^{-2}\ \text{m}}{15.0°\text{C}}\right) = \boxed{2.22\times10^{-2}\ \text{W/m}\cdot°\text{C}}$$

11.37 $R = \Sigma R_i = R_{\substack{outside\\air\ film}} + R_{shingles} + R_{sheathing} + R_{cellulose} + R_{dry\ wall} + R_{\substack{inside\\air\ film}}$

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

11.38 The rate of energy transfer through a compound slab is

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

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

Thus, $$R = 2\left(\frac{0.50\times10^{-2}\ \text{m}}{0.84\ \text{W/m}\cdot{}^\circ\text{C}}\right) + \frac{1.0\times10^{-2}\ \text{m}}{0.0234\ \text{W/m}\cdot{}^\circ\text{C}} = 0.44\ \frac{\text{m}^2\cdot{}^\circ\text{C}}{\text{W}},$$

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

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

$$R = \frac{1.0\times10^{-2}\ \text{m}}{0.84\ \text{W/m}\cdot{}^\circ\text{C}} = 1.2\times10^{-2}\ \frac{\text{m}^2\cdot{}^\circ\text{C}}{\text{W}},$$

so $$H = \frac{(1.0\ \text{m}^2)(23^\circ\text{C})}{1.2\times10^{-2}\ \text{m}^2\cdot{}^\circ\text{C/W}} = 1.9\times10^3\ \text{W} = \boxed{1.9\ \text{kW}}$$, 37 times greater

11.39 When the temperature of the junction stabilizes, the energy transfer rate must be the same for each of the rods, or $H_{\text{Cu}} = H_{\text{Al}}$. 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, $H_{\text{Cu}} = k_{\text{Cu}}A\left(\frac{\Delta T}{L_{\text{Cu}}}\right) = k_{\text{Al}}A\left(\frac{\Delta T}{L_{\text{Al}}}\right) = H_{\text{Al}}$, which gives

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

11.40 The energy transfer rate is $H = \frac{\Delta Q}{\Delta t} = \frac{m_{ice}L_f}{\Delta t} = \frac{(5.0\ \text{kg})(3.33\times10^5\ \text{J/kg})}{(8.0\ \text{h})(3600\ \text{s/1 h})} = 58\ \text{W}$

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

$$k = \frac{H\cdot L}{A(\Delta T)} = \frac{(58\ \text{W})(2.0\times10^{-2}\ \text{m})}{(0.80\ \text{m}^2)(25^\circ\text{C} - 5.0^\circ\text{C})} = \boxed{7.2\times10^{-2}\ \text{W/m}\cdot{}^\circ\text{C}}$$

11.41 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

$$\wp_{net} = \sigma A e\left(T^4 - T_0^4\right)$$
$$= \left(5.67\times10^{-8}\ \frac{\text{W}}{\text{m}^2\cdot\text{K}^4}\right)\left[4\pi(0.060\text{ m})^2\right]\left[(473\text{ K})^4 - (295\text{ K})^4\right]$$

or $\wp_{net} = 1.1\times10^2\text{ W} = \boxed{0.11\text{ kW}}$

11.42 With an emissivity of $e = 0.965$, temperature of $T = 5800\text{ K}$, and radius of $r = 6.96\times10^8\text{ m}$, the total power radiated by the spherical Sun is

$$\wp = \sigma A e T^4 = \left(5.67\times10^{-8}\ \frac{\text{W}}{\text{m}^2\cdot\text{K}^4}\right)\left[4\pi\left(6.96\times10^8\text{ m}\right)^2\right](0.965)(5800\text{ K})^4,$$

or $\wp = \boxed{3.77\times10^{26}\text{ W}}$.

11.43 The absolute temperature of the pizza is $T = 373\text{ K}$ and the total surface area of this cylindrical object is

$$A = \pi r^2 + 2\pi r L + \pi r^2 = 2\pi\left[(0.35\text{ m})^2 + (0.35\text{ m})(0.020\text{ m})\right] = 0.81\text{ m}^2$$

The power radiated into space (or the rate of energy loss) is

$$\wp = \sigma A e T^4 = \left(5.67\times10^{-8}\ \frac{\text{W}}{\text{m}^2\cdot\text{K}^4}\right)\left(0.81\text{ m}^2\right)(0.8)(373\text{ K})^4$$

$$= 7.1\times10^2\text{ W}\ \boxed{\sim 10^3\text{ W}}$$

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

$T = \left[T_0^4 + \frac{\wp_{net}}{\sigma A e}\right]^{\frac{1}{4}}$. If the temperature of the surroundings is $T_0 = 22°\text{C} = 295\text{ K}$,

$$T = \left[(295\text{ K})^4 + \frac{25\text{ W}}{\left(5.67\times10^{-8}\text{ W/m}^2\cdot\text{K}^4\right)\left(2.5\times10^{-5}\text{ m}^2\right)(0.25)}\right]^{\frac{1}{4}}$$

$$= 2.9\times10^3\text{ K} = \boxed{2.6\times10^3\ °\text{C}}$$

11.45 The absolute temperatures of the two stars are $T_x = 6000\text{ K}$ and $T_y = 12\,000\text{ K}$. Thus, the ratio of their radiated powers is

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

11.46 Assume that the ground below the pavement is a very good insulator and that the emissivity of the blacktop is unity. Then, in steady state, the square meter of asphalt must radiate energy at the same rate as receiving it from the Sun. From $\wp = \sigma A e T^4$, the temperature of the asphalt is

$$T = \left[\frac{\wp}{\sigma A e}\right]^{\frac{1}{4}} = \left[\frac{1000\text{ W}}{\left(5.67\times10^{-8}\text{ W/m}^2\cdot\text{K}^4\right)\left(1.00\text{ m}^2\right)(1.00)}\right]^{\frac{1}{4}} = 364\text{ K} = \boxed{91°\text{C}}$$

11.47 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

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

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

11.48 The energy required to raise the temperature of the water to 100°C is

$$Q = mc(\Delta T) = (0.250\text{ kg})(4186\text{ J/kg})(100°\text{C} - 23.0°\text{C}) = 8.06\times10^4\text{ J}.$$

The power input is $\wp = \left(550\text{ W/m}^2\right)\left(1.00\text{ m}^2\right) = 550\text{ W}$, so the time required is

$$t = \frac{Q}{\wp} = \frac{8.06\times10^4\text{ J}}{550\text{ J/s}}\left(\frac{1\text{ min}}{60\text{ s}}\right) = \boxed{2.44\text{ min}}$$

11.49 At an average rate of 1000 W, the energy radiated between 4 PM and 8 AM is

$$Q = \wp t = \left(1000\ \frac{\text{J}}{\text{s}}\right)(16.0\ \text{h})\left(\frac{3600\ \text{s}}{1\ \text{h}}\right) = 5.76\times 10^{7}\ \text{J}$$

The mass of stone which can give up this quantity of energy as its temperature drops from 30°C to 18°C is

$$m = \frac{Q}{c(\Delta T)} = \frac{5.76\times 10^{7}\ \text{J}}{(800\ \text{J/kg}\cdot{}^{\circ}\text{C})(12^{\circ}\text{C})} = \boxed{6.0\times 10^{3}\ \text{kg}}$$

11.50 The energy needed is

$$Q = mc(\Delta T) = (\rho V)c(\Delta T)$$
$$= \left[\left(10^{3}\ \frac{\text{kg}}{\text{m}^{3}}\right)(1.00\ \text{m}^{3})\right](4186\ \text{J/kg})(40.0^{\circ}\text{C}) = 1.67\times 10^{8}\ \text{J}$$

The power input is $\wp = (550\ \text{W/m}^{2})(6.00\ \text{m}^{2}) = 3.30\times 10^{3}\ \text{J/s}$, so the time required is

$$t = \frac{Q}{\wp} = \frac{1.67\times 10^{8}\ \text{J}}{3.30\times 10^{3}\ \text{J/s}}\left(\frac{1\ \text{h}}{3600\ \text{s}}\right) = \boxed{14.1\ \text{h}}$$

11.51 The energy conservation equation is

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

This gives

$$m_{\text{Pb}}\left(128\ \frac{\text{J}}{\text{kg}\cdot{}^{\circ}\text{C}}\right)(86^{\circ}\text{C}) = (0.040\ \text{kg})(3.33\times 10^{5}\ \text{J/kg})$$
$$+\left[(0.24\ \text{kg})(4186\ \text{J/kg}\cdot{}^{\circ}\text{C}) + (0.100\ \text{kg})(357\ \text{J/kg}\cdot{}^{\circ}\text{C})\right](12^{\circ}\text{C}),$$

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

11.52 If we assume that all of the original mechanical energy of the hailstone is converted to internal energy and used to melt ice, the energy conservation equation is $mgh = mL_f$. This gives the required height as

$$h = \frac{L_f}{g} = \frac{3.33 \times 10^5 \text{ J/kg}}{9.80 \text{ m/s}^2} = 3.40 \times 10^4 \text{ m} = \boxed{34.0 \text{ km}}$$

11.53 The conservation of energy equation is

$$\left(m_w c_w + m_{cup} c_{glass}\right)\left(T_f - 27°\text{C}\right) = m_{\text{Cu}} c_{\text{Cu}} \left(90°\text{C} - T_f\right)$$

This gives $$T_f = \frac{m_{\text{Cu}} c_{\text{Cu}} (90°\text{C}) + \left(m_w c_w + m_{cup} c_{glass}\right)(27°\text{C})}{m_w c_w + m_{cup} c_{glass} + m_{\text{Cu}} c_{\text{Cu}}}, \text{ or}$$

$$T_f = \frac{(0.200)(387)(90°\text{C}) + \left[(0.400)(4186) + (0.300)(837)\right](27°\text{C})}{(0.400)(4186) + (0.300)(837) + (0.200)(387)} = \boxed{29°\text{C}}$$

11.54 The energy added to the air in one hour is

$$Q = \left(\wp_{total}\right)t = \left[10(200 \text{ W})\right](3600 \text{ s}) = 7.20 \times 10^6 \text{ J},$$

and the mass of air in the room is

$$m = \rho V = \left(1.3 \text{ kg/m}^3\right)\left[(6.0 \text{ m})(15.0 \text{ m})(3.0 \text{ m})\right] = 3.5 \times 10^2 \text{ kg}$$

The change in temperature is $\Delta T = \dfrac{Q}{mc} = \dfrac{7.2 \times 10^6 \text{ J}}{\left(3.5 \times 10^2 \text{ kg}\right)\left(837 \text{ J/kg} \cdot °\text{C}\right)} = 25°\text{C}$,

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

11.55 The rate of energy transfer to the surface is

$$H = kA\left(\frac{\Delta T}{L}\right) = \left(0.210 \frac{\text{W}}{\text{m} \cdot °\text{C}}\right)\left(1.40 \text{ m}^2\right)\left(\frac{37.0°\text{C} - 34.0°\text{C}}{0.0250 \text{ m}}\right),$$

which gives $$H = 35.3 \frac{\text{J}}{\text{s}}\left(\frac{1 \text{ kcal}}{4186 \text{ J}}\right)\left(\frac{3600 \text{ s}}{1 \text{ h}}\right) = \boxed{30.3 \text{ kcal/h}}$$

Since this is less than 240 kcal/h, blood flow is necessary for cooling.

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

$$H_{\text{Al}} = H_{\text{Fe}}. \text{ Thus, } k_{\text{Al}}A\left(\frac{100°\text{C} - T}{L}\right) = k_{\text{Fe}}A\left(\frac{T - 0°\text{C}}{L}\right),$$

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

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

$$Q = H_{\text{Al}} \cdot t = \left[\left(238 \ \frac{\text{W}}{\text{m} \cdot °\text{C}}\right)\left(5.0 \times 10^{-4} \ \text{m}^2\right)\left(\frac{100°\text{C} - 75.0°\text{C}}{0.15 \text{ m}}\right)\right](1800 \text{ s})$$

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

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

$$H = \frac{\Delta Q}{\Delta t} = \left(\frac{\Delta m}{\Delta t}\right)L_v = \left[\left(0.500 \ \frac{\text{kg}}{\text{min}}\right)\left(\frac{1 \text{ min}}{60 \text{ s}}\right)\right]\left(2.26 \times 10^6 \ \frac{\text{J}}{\text{kg}}\right) = 1.88 \times 10^4 \text{ W}$$

From $H = kA\left(\frac{T - 100°\text{C}}{L}\right)$, the temperature of the bottom surface is

$$T = 100°\text{C} + \frac{H \cdot L}{kA} = 100°\text{C} + \frac{\left(1.88 \times 10^4 \text{ W}\right)\left(0.500 \times 10^{-2} \text{ m}\right)}{\left(238 \text{ W/m} \cdot °\text{C}\right)\left[\pi(0.120 \text{ m})^2\right]} = \boxed{109°\text{C}}$$

11.58 (a) $Q = mc(\Delta T) = (0.600)mgh$ gives $\Delta T = \frac{(0.600)gh}{c}$, or

$$T_f = T_i + \Delta T = 25.0°\text{C} + \frac{(0.600)\left(9.80 \text{ m/s}^2\right)(50.0 \text{ m})}{387 \text{ J/kg} \cdot °\text{C}} = \boxed{25.8°\text{C}}$$

(b) $\boxed{\text{No}}$. As seen in the above calculation, the mass of the coin cancels.

11.59 In the steady state, $H_{\text{Au}} = H_{\text{Ag}}$, 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

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

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

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

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

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

and the change in temperature is

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

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

$$Q = mc(\Delta T) = (60\ \text{kg})(900\,\text{J/kg} \cdot °\text{C})(660°\text{C} - 20°\text{C}) = 3.46 \times 10^7\ \text{J}.$$

The internal energy added to the brakes on each stop is

$$Q_1 = \Delta KE = \frac{1}{2} m_{car} v_i^2 = \frac{1}{2}(1500\ \text{kg})(25\ \text{m/s})^2 = 4.69 \times 10^5\ \text{J}.$$

The number of stops before reaching the melting point is

$$N = \frac{Q}{Q_1} = \frac{3.46 \times 10^7\ \text{J}}{4.69 \times 10^5\ \text{J}} = \boxed{74\ \text{stops}}$$

(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.

11.62 We assume that the time interval is so short that only the part of the rod immersed in the liquid helium undergoes a change in temperature. The mass of this half of the rod is

$$m_{\text{Al}} = \rho_{\text{Al}}\left[A\left(L/2\right)\right] = \left(2.70\times10^{3}\ \text{kg/m}^{3}\right)\left(2.0\times10^{-4}\ \text{m}^{2}\right)\left(0.50\ \text{m}\right) = 0.27\ \text{kg}$$

From conservation of energy, $m_{\text{He}}\left(L_v\right)_{\text{He}} = m_{\text{Al}}c_{\text{Al}}\left|\Delta T\right|$, or the mass of helium evaporated is

$$m_{\text{He}} = \frac{m_{\text{Al}}c_{\text{Al}}\left|\Delta T\right|}{\left(L_v\right)_{\text{He}}} = \frac{\left(0.27\ \text{kg}\right)\left(900\ \text{J/kg}\cdot{}^\circ\text{C}\right)\left(295.8^\circ\text{C}\right)}{2.09\times10^{4}\ \text{J/kg}} = 3.4\ \text{kg}$$

The volume of liquid helium evaporated is then

$$V_{\text{He}} = \frac{m_{\text{He}}}{\rho_{\text{He}}} = \frac{3.4\ \text{kg}}{122\ \text{kg/m}^{3}}\left(\frac{10^{3}\ \text{L}}{1\ \text{m}^{3}}\right) = \boxed{28\ \text{L}}$$

11.63 (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

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

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

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

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

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

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

Answers to Even Numbered Conceptual Questions

2. The mass of the water is very large in comparison to the body's mass. Thus, the body temperature will rise to that of the water, a potentially fatal occurrence. When thermal pollution raises the temperature of a lake or stream, large scale fish kills can occur.

4. In winter the produce is protected from freezing. The specific heat of the Earth is so high that soil freezes only to a depth of a few inches in temperate regions. Throughout the year the temperature will stay nearly constant day and night. Factors to be considered are the insulating properties of the soil, the absence of a path for energy to be radiated away from or to the vegetables, and the hindrance of the formation of convection currents in the small, enclosed space.

6. 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. Evaporation of the water keeps the relative humidity high to protect foodstuffs from drying out.

8. 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

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

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.

10. Convection is the dominant energy transfer process involved in the cooling of the bridge surface. Air currents can flow freely around all parts of the bridge, making convection particularly effective.

12. 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.

14. 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.

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

$$V = \frac{m_{water}c_{water}}{\rho_{air}c_{air}} = \frac{(1000\ \mathrm{kg})(4186\ \ \mathrm{J/kg \cdot °C})}{(1.3\ \ \mathrm{kg/m^3})(1000\ \ \mathrm{J/kg \cdot °C})} = 3.2 \times 10^3\ \ \mathrm{m}^3.$$

18. Making the handle of the poker in the shape of a spring, rather than a solid rod, increases the surface area of metal in contact with the surrounding air. This increases the rate of energy transfer from the handle to the air and keeps the handle at a lower temperature than it would otherwise attain.

Answers to Even Numbered Problems

2. 87°C

4. 0.152 mm

6. 1.17 calories

8. 0.0938°C

10. (a) 9.9×10^{-3} °C
(b) The remaining energy is absorbed by the surface on which the block slides.

12. 467 pellets

14. copper wins, 89.7°C to 89.8°C

16. 35°C

18. 23.6°C

20. 49 kJ

22. 0.12 MJ

24. 0.294 g

26. 11°C

28. $403\ \text{cm}^3/\text{hr}$

30. (a) 0°C, with 24 g of ice left (b) 8.2°C

32. 3.0 mg

34. (a) 0.50 kW into the house (b) 1.7 kW out of the house

36. 2.22×10^{-2} W/m · °C

38. (a) 52 W (b) 1.9 kW, 37 times greater

40. 7.2×10^{-2} W/m · °C

42. 3.77×10^{26} W

44. 2.6×10^{3} °C

46. 91°C

48. 2.44 min

50. 14.1 h

52. 34.0 km

54. 45°C

56. (a) 75.0°C (b) 36 kJ

58. (a) 25.8°C (b) No, the mass cancels.

60. (a) 2.0 kW (b) 4.5°C

62. 28 L

64. 28°C