CHAPTER 14: Heat

Answers to Questions

1. The work goes primarily into increasing the temperature of the orange juice, by increasing the average kinetic energy of the molecules comprising the orange juice.

2. When a hot object warms a cooler object, energy is transferred from the hot object to the cold object. Temperature does NOT flow. The temperature changes of the two objects are not necessarily equal in magnitude. Under certain circumstances, they can be equal in magnitude, however. In an ideal case, the amount of heat lost by the warmer object is the same as the amount of heat gained by the cooler object.

3. (a) Internal energy depends on both the number of molecules of material and the temperature of the material. Heat will flow naturally from the object with the higher temperature to the object with the lower temperature. The object with the high temperature may or may not be the object with the higher internal energy.
   (b) The two objects may consist of one with a higher temperature and smaller number of molecules, and the other with a lower temperature and a larger number of molecules. In that case it is possible for both objects to have the same internal energy, but heat will still flow from the object with the higher temperature to the one with the lower temperature.

4. The water will coat the plants, and so the water, not the plant, is in contact with the cold air. Thus as the air cools, the water cools before the plant does – the water insulates the plant. As the water cools, it releases energy, and raises the temperature of its surroundings, which includes the plant. Particularly if the water freezes, relatively large amounts of heat are released due to the relatively large heat of fusion for water.

5. Because the specific heat of water is quite large, it can contain a relatively large amount of thermal energy per unit mass with a relatively small increase in temperature. Since the water is a liquid, it is relatively easy to transport from one location to another, and so large quantities of energy can be moved from one place to another with relative simplicity by water.

6. The mechanism of evaporation of the water from the moist cloth jacket requires energy (the latent heat of vaporization), some of which will come from the interior of the canteen. This removal of energy from the interior helps to keep the interior of the canteen cool. Also, the metal canteen is a good thermal conductor, and so heat can transfer from the water to the cloth jacket to cool the water.

7. Steam at $100^{o}C$ contains more thermal energy than water at $100^{o}C$. The difference is due to the latent heat of vaporization, which for water is quite high. As the steam touches the skin and condenses, a large amount of energy is released, causing more severe burns. And the condensed water is still at $100^{o}C$, and so more burning can occur as that water cools.

8. Evaporation involves water molecules escaping the intermolecular bonds that hold the water together in the liquid state. It takes energy for the molecules to break those bonds (to overcome the bonding forces). This energy is the latent heat of vaporization. The most energetic molecules (those having the highest speed) are the ones that will be able to provide the most energy (from their kinetic energy) to be able to overcome the bonding forces. The slower moving molecules remain, lowering the average kinetic energy and thus lowering the internal energy and temperature of the liquid.

9. The potatoes will not cook faster if the water is boiling faster. The boiling water is the same temperature whether it is boiling fast or slow.

10. An ordinary fan does not cool the air directly. It actually warms the air slightly, because the motor used to power the fan will exhaust some heat into the air, and the increase in average kinetic energy of the air molecules caused by the fan blades pushing them means the air temperature increases slightly. The reason for using the fan is that it keeps air moving. The human body warms the air immediately around it, assuming the air is initially cooler than the body. If that warmed air stays in contact with the body, then the body will lose little further heat after the air is warmed. The fan, by circulating the air, removes the heated air from close to the body and replaces it with cooler air. Likewise, the body is also cooled by evaporation of water from the skin. As the relative humidity of the air close to the body increases, less water can be evaporated, and cooling by evaporation is decreased. The fan, by circulating the air, removes the humid air from close to the body and replaces it with less humid air, so that evaporation can continue.

11. Even though the temperature is high in the upper atmosphere, the density of gas particles is very low. There would be relatively very few collisions of high-temperature gas molecules with the animal to warm it. Instead, the animal would radiate heat to the rarified atmosphere. The emissivity of the animal is much greater than that of the rarified atmosphere, and so the animal will lose much more energy by radiation than it can gain from the atmosphere.

12. Snow, particularly at very low temperatures, has a low thermal conductivity because it has many tiny air pockets trapped in its structure – it might be described as “fluffy”. Since this “fluffy” snow has a low thermal conductivity, the snow will not conduct much heat away from an object covered in it.

13. We assume that the wet sand has been wetted fairly recently with water that is cooler than the sand’s initial temperature. Water has a higher heat capacity than sand, and so for equal masses of sand and water, the sand will cool more than the water warms as their temperatures move towards equilibrium. Thus the wet sand may actually be cooler than the dry sand. Also, if both the wet and dry sand are at a lower temperature than your feet, the sand with the water in it is a better thermal conductor and so heat will flow more rapidly from you into the wet sand than into the dry sand, giving more of a sensation of having touched something cold.

14. An object with “high heat content” does not have to have a high temperature. If a given amount of heat energy is transferred into equal-mass samples of two substances initially at the same temperature, the substance with the lower specific heat will have the higher final temperature. But both substances would have the same “heat content” relative to their original state. So an object with “high heat content” might be made of material with a very high specific heat, and therefore not necessarily be at a high temperature.

15. A hot-air furnace heats primarily by air convection. A return path (often called a “cold air return”) is necessary for the convective currents to be able to completely circulate. If the flow of air is blocked, then the convective currents and the heating process will be interrupted. Heating will be less efficient and less uniform if the convective currents are prevented from circulating.

16. A ceiling fan makes more of a “breeze” when it is set to blow the air down (usually called the “forward” direction by fan manufacturers). This is the setting for the summer, when the breeze will feel cooling since it accelerates evaporation from the skin. In the winter, the fan should be set to pull air up. This forces the warmer air at the top of the room to move out towards the walls and down. The relocation of warmer air keeps the room feeling warmer, and there is less “breeze” effect on the occupants of the room.

17. When the garment is fluffed up, it will have the most air trapped in its structure. The air has a low thermal conductivity, and the more the garment can be "fluffed", the more air it will trap, making it a better insulator. The "loft" value is similar to the R value of insulation, since the thicker the insulation, the higher the R value. The rate of thermal conduction is inversely proportional to the thickness of the conductor, so a thick conductor (high loft value) means a lower thermal conduction rate, and so a lower rate of losing body heat.

18. For all mechanisms of cooling, the rate of heat transfer from the hot object to the cold one is dependent on surface area. The heat sink with fins provides much more surface area than just a solid piece of metal, and so there is more cooling of the microprocessor chip. A major mechanism for cooling the heat sink is that of convection. More air is in contact with the finned heat sink than would be in contact with a solid piece of metal. There is often a cooling fan circulating air around that heat sink as well, so that heated air can continually be replaced with cool air to promote more cooling.

19. When there is a temperature difference in air, convection currents arise. Since the temperature of the land rises more rapidly than that of the water, the air above the land will be warmer than the air above the water. The warm air above the land will rise, and that rising warm air will be replaced by cooler air from over the body of water. The result is a breeze from the water towards the land.

20. We assume that the temperature in the house is higher than that under the house. Thus heat will flow through the floor out of the house. If the house sits directly on the ground or on concrete, the heat flow will warm the ground or concrete. Dirt and concrete are relatively poor conductors of heat, and so the thermal energy that goes into them will stay for a relatively long time, allowing their temperature to rise and thus reducing the heat loss through the floor. If the floor is over a crawlspace, then the thermal energy from the floor will be heating air instead of dirt or concrete. If that warmed air gets moved away by wind currents or by convection and replaced with colder air, then the temperature difference between the inside and outside will stay large, and more energy will leave through the floor, making the inside of the house cooler.

21. Air is a poorer conductor of heat than water by roughly a factor of 20, and so the rate of heat loss from your body to the air is roughly 20 times less than the rate of heat loss from your body to the water. Thus you lose heat quickly in the water, and feel cold. Another contributing factor is that water has a high heat capacity, and so as heat leaves your body and enters the water, the temperature rise for the water close to your body is small. Air has a smaller heat capacity, and so the temperature rise for the air close to your body is larger. This reduces the temperature difference between your body and the air, which reduces the rate of heat loss to the air as well.

22. A thermometer in the direct sunlight would gain thermal energy (and thus show a higher temperature) due to receiving radiation directly from the Sun. The emissivity of air is small, and so it does not gain as much energy from the Sun as the mercury and glass do. The thermometer is to reach its equilibrium temperature by heat transfer with the air, in order to measure the air temperature.

23. Premature babies have underdeveloped skin, and they can lose a lot of moisture through their skin by evaporation. For a baby in a very warm environment, like an incubator at $37^{o}C$, there will be a large evaporative effect. A significant increase in evaporation occurs at incubator temperatures, and that evaporation of moisture from the baby will cool the baby dramatically. Thus an incubator must have not only a high temperature but also a high humidity. Other factors might include radiative energy loss, blood vessels being close to the skin surface and so there is less insulation than a more mature baby, and low food consumption to replace lost energy.

24. Shiny surfaces absorb very little of the radiation that is incident on them – they reflect it back towards the source. Thus the liner is silvered to reduce radiation energy transfer (both into and away from the substance in the thermos). The (near) vacuum between its two walls reduces the energy transfer by conduction. Vacuum is a very poor conductor of heat.

25. The overall R-value of the wall plus window is lower than R_1 and higher than R_2. The rate of heat transfer through the entire wall + window area will increase, but the total area and the temperature difference has not changed. Thus, since $\frac{Q}{t}=\frac{A}{R_{\text{effective}}}\left(T_1-T_2\right)$, for the rate to increase means the R-value had to drop from its original value. However, the rate of heat transfer will be lower than if the wall was totally glass, and so the final R-value must be higher than that of the glass.

26. (*a*) (1) Ventilation around the edges is cooling by convection.
(2) Cooling through the frame is cooling by conduction.
(3) Cooling through the glass panes is cooling by conduction and radiation.
(*b*) Heavy curtains can reduce all three heat losses. The curtains will prevent air circulation around the edges of the windows, thus reducing the convection cooling. The curtains are more opaque than the glass, preventing the electromagnetic waves responsible for radiation heat transfer from reaching the glass. And the curtains provide another layer of insulation between the outdoors and the warm interior of the room, lowering the rate of conduction.

27. The thermal conductivity of the wood is about 2000 times less than that of the aluminum. Thus it takes a long time for energy from the wood to flow into your hand. Your skin temperature rises very slowly due to contact with the wood compared to contact with the aluminum, and so the sensation of heating is much less.

28. The Earth cools primarily by radiation. The clouds act as “insulation” in that they absorb energy from the radiating Earth, and reradiate some of it back to the Earth, reducing the net amount of radiant energy loss.

29. The emergency blanket is shiny (having a low emissivity) so that it reflects a person’s radiated energy back to them, keeping them warmer. Also, like any blanket, it can insulate and so reduce heat transfer by conduction.

30. Cities situated on the ocean have less temperature extremes because the oceans are a heat reservoir. Due to ocean currents, the temperature of the ocean in a locale will be fairly constant during a season. In the winter, the ocean temperature remains above freezing. Thus if the air and land near the ocean get colder than the oceans, the oceans will release thermal energy, moderating the temperature of the nearby region. Likewise, in the warm seasons, the ocean temperatures will be cooler than the surrounding land mass, which heats up more easily than the water. Then the oceans will absorb thermal energy from the surrounding areas, again moderating the temperature.

Solutions to Problems

1. The kcal is the heat needed to raise 1 kg of water by 1 C°. Use the definition to find the heat needed.

$$\left(30.0\text{ kg}\right)\left(95^\circ\text{C}-15^\circ\text{C}\right)\frac{1\text{ kcal}}{\left(1\text{kg}\right)\left(1\text{C}^\circ\right)}\left(\frac{4186\text{ J}}{1\text{ kcal}}\right)=\boxed{1.0\times10^{7}\text{ J}}$$

2. The kcal is the heat needed to raise 1 kg of water by 1 C°. Use that definition to find the temperature change. Then the final temperature can be found.

$$\left(\frac{7700\text{ J}}{3.0\text{ kg}}\right)\left(\frac{1\text{ kcal}}{4186\text{ J}}\right)\frac{(1\text{kg})(1\text{C}^{\circ})}{1\text{ kcal}} = 0.61\text{C}^{\circ} \quad\rightarrow\quad \text{Final Temperature} = \boxed{10.6^{\circ}\text{C}}$$

3. (*a*) $2500\text{ Cal}\left(\frac{4.186\times10^{3}\text{ J}}{1\text{ Cal}}\right) = \boxed{1.0\times10^{7}\text{ J}}$

(*b*) $2500\text{ Cal}\left(\frac{1\text{ kWh}}{860\text{ Cal}}\right) = \boxed{2.9\text{ kWh}}$

(*c*) At 10 cents per day, the food energy costs $\boxed{\$0.29\text{ per day}}$. It would be practically impossible to feed yourself in the United States on this amount of money.

4. Assume that we are at the surface of the Earth so that 1 kg has a weight of 2.20 lb.

$$1\text{Btu} = (1\text{ lb})(1^{\circ}\text{F})\left(\frac{0.454\text{ kg}}{1\text{ lb}}\right)\left(\frac{5/9^{\circ}\text{ C}}{1^{\circ}\text{F}}\right)\frac{1\text{ kcal}}{(1\text{ kg})(1\text{C}^{\circ})} = \boxed{0.252\text{ kcal}}$$

$$0.252\text{ kcal}\left(\frac{4186\text{ J}}{1\text{ kcal}}\right) = \boxed{1055\text{ J}}$$

5. The energy input is causing a certain rise in temperature, expressible as a number of Joules per hour per C°. Convert that to mass using the definition of kcal.

$$\left(\frac{3.2\times10^{7}\text{ J/h}}{35\text{ C}^{\circ}}\right)\left(\frac{1\text{ kcal}}{4186\text{ J}}\right)\frac{(1\text{kg})(1\text{C}^{\circ})}{1\text{ kcal}} = \boxed{2.2\times10^{2}\text{ kg/h}}$$

6. The wattage rating is Joules per second. Note that 1 L of water has a mass of 1 kg.

$$\left[(2.50\times10^{-1}\text{L})\left(\frac{1\text{ kg}}{1\text{ L}}\right)(40\text{C}^{\circ})\right]\frac{1\text{ kcal}}{(1\text{ kg})(1\text{C}^{\circ})}\left(\frac{4186\text{ J}}{\text{kcal}}\right)\left(\frac{1\text{ s}}{350\text{ J}}\right) = \boxed{1.2\times10^{2}\text{s} = 2.0\text{ min}}$$

7. The energy generated by using the brakes must equal the car's initial kinetic energy, since its final kinetic energy is 0.

$$Q = \tfrac{1}{2}mv_0^2 = \tfrac{1}{2}(1.2\times10^{3}\text{kg})\left[(95\text{km/h})\left(\frac{1\text{m/s}}{3.6\text{km/h}}\right)\right]^2\left(\frac{1\text{ kcal}}{4186\text{ J}}\right) = \boxed{1.0\times10^{2}\text{kcal}}$$

8. The heat absorbed can be calculated from Eq. 14-2. Note that 1 L of water has a mass of 1 kg.

$$Q = mc\Delta T = \left[(16\text{ L})\left(\frac{1\times10^{-3}\text{m}^3}{1\text{ L}}\right)\left(\frac{1.0\times10^{3}\text{kg}}{1\text{ m}^3}\right)\right](4186\text{ J/kg}\bullet\text{C}^{\circ})(90^{\circ}\text{C} - 20^{\circ}\text{C}) = \boxed{4.7\times10^{6}\text{ J}}$$

9. The specific heat can be calculated from Eq. 14-2.

$$Q = mc\Delta T \quad\rightarrow\quad c = \frac{Q}{m\Delta T} = \frac{1.35\times10^{5}\text{ J}}{(5.1\text{ kg})(31.5^{\circ}\text{C} - 18.0^{\circ}\text{C})} = 1961\text{ J/kg}\bullet\text{C}^{\circ} \approx \boxed{2.0\times10^{3}\text{ J/kg}\bullet\text{C}^{\circ}}$$

10. The heat absorbed by all three substances is given by Eq. 14-2, $Q = mc\Delta T$. Thus the amount of mass can be found as $m = \dfrac{Q}{c\Delta T}$. The heat and temperature change are the same for all three substances.

$$m_{\text{Cu}} : m_{\text{Al}} : m_{\text{H}_2\text{O}} = \frac{Q}{c_{\text{Cu}}\Delta T} : \frac{Q}{c_{\text{Al}}\Delta T} : \frac{Q}{c_{\text{H}_2\text{O}}\Delta T} = \frac{1}{c_{\text{Cu}}} : \frac{1}{c_{\text{Al}}} : \frac{1}{c_{\text{H}_2\text{O}}} = \frac{1}{390} : \frac{1}{900} : \frac{1}{4186}$$

$$= \frac{4186}{390} : \frac{4186}{900} : \frac{4186}{4186} = \boxed{10.7 : 4.65 : 1}$$

11. The heat gained by the glass thermometer must be equal to the heat lost by the water.

$$m_{\text{glass}} c_{\text{glass}} \left(T_{\text{eq}} - T_{i\ \text{glass}}\right) = m_{\text{H}_2\text{O}} c_{\text{H}_2\text{O}} \left(T_{i\,\text{H}_2\text{O}} - T_{\text{eq}}\right)$$

$$(35\ \text{g})\left(0.20\,\text{cal/g}\bullet\text{C}^\circ\right)\left(39.2^\circ\text{C} - 21.6^\circ\text{C}\right) = (135\ \text{g})\left(1.00\,\text{cal/g}\bullet\text{C}^\circ\right)\left(T_{i\,\text{H}_2\text{O}} - 39.2^\circ\text{C}\right)$$

$$T_{i\,\text{H}_2\text{O}} = \boxed{40.1^\circ\text{C}}$$

12. The heat lost by the copper must be equal to the heat gained by the aluminum and the water.

$$m_{\text{Cu}} c_{\text{Cu}} \left(T_{i\text{Cu}} - T_{\text{eq}}\right) = m_{\text{Al}} c_{\text{Al}} \left(T_{\text{eq}} - T_{i\text{Al}}\right) + m_{\text{H}_2\text{O}} c_{\text{H}_2\text{O}} \left(T_{\text{eq}} - T_{i\,\text{H}_2\text{O}}\right)$$

$$(0.245\ \text{kg})\left(390\,\text{J/kg}\bullet\text{C}^\circ\right)\left(285^\circ\text{C} - T_{\text{eq}}\right) = \begin{bmatrix} (0.145\ \text{kg})\left(900\,\text{J/kg}\bullet\text{C}^\circ\right) \\ +(0.825\ \text{kg})\left(4186\,\text{J/kg}\bullet\text{C}^\circ\right) \end{bmatrix}\left(T_{\text{eq}} - 12.0^\circ\text{C}\right)$$

$$T_{\text{eq}} = \boxed{19.1^\circ\text{C}}$$

13. The heat lost by the horseshoe must be equal to the heat gained by the iron pot and the water. Note that 1 L of water has a mass of 1 kg.

$$m_{\text{shoe}} c_{\text{Fe}} \left(T_{i\text{shoe}} - T_{\text{eq}}\right) = m_{\text{pot}} c_{\text{Fe}} \left(T_{\text{eq}} - T_{i\text{pot}}\right) + m_{\text{H}_2\text{O}} c_{\text{H}_2\text{O}} \left(T_{\text{eq}} - T_{i\,\text{H}_2\text{O}}\right)$$

$$(0.40\ \text{kg})\left(450\,\text{J/kg}\bullet\text{C}^\circ\right)\left(T_{i\text{shoe}} - 25.0^\circ\text{C}\right) = (0.30\ \text{kg})\left(450\,\text{J/kg}\bullet\text{C}^\circ\right)\left(25.0\text{C}^\circ - 20.0\text{C}^\circ\right)$$
$$+ (1.35\ \text{kg})\left(4186\,\text{J/kg}\bullet\text{C}^\circ\right)\left(25.0\text{C}^\circ - 20.0\text{C}^\circ\right)$$

$$T_{i\text{shoe}} = 186^\circ\text{C} \approx \boxed{190^\circ\text{C}}$$

14. The heat lost by the substance must be equal to the heat gained by the aluminum, water, and glass.

$$m_{\text{x}} c_{\text{x}} \left(T_{i\text{x}} - T_{\text{eq}}\right) = m_{\text{Al}} c_{\text{Al}} \left(T_{\text{eq}} - T_{i\text{Al}}\right) + m_{\text{H}_2\text{O}} c_{\text{H}_2\text{O}} \left(T_{\text{eq}} - T_{i\,\text{H}_2\text{O}}\right) + m_{\text{glass}} c_{\text{glass}} \left(T_{\text{eq}} - T_{i\text{glass}}\right)$$

$$c_{\text{x}} = \frac{m_{\text{Al}} c_{\text{Al}} \left(T_{\text{eq}} - T_{i\text{Al}}\right) + m_{\text{H}_2\text{O}} c_{\text{H}_2\text{O}} \left(T_{\text{eq}} - T_{i\,\text{H}_2\text{O}}\right) + m_{\text{glass}} c_{\text{glass}} \left(T_{\text{eq}} - T_{i\text{glass}}\right)}{m_{\text{x}} \left(T_{i\text{x}} - T_{\text{eq}}\right)}$$

$$= \frac{\left[(0.105\ \text{kg})\left(900\,\text{J/kg}\bullet\text{C}^\circ\right) + (0.165\ \text{kg})\left(4186\,\text{J/kg}\bullet\text{C}^\circ\right) + (0.017\ \text{kg})\left(840\,\text{J/kg}\bullet\text{C}^\circ\right)\right]\left(22.5\text{C}^\circ\right)}{(0.215\ \text{kg})\left(330^\circ\text{C} - 35.0^\circ\text{C}\right)}$$

$$= \boxed{2.84 \times 10^2\ \text{J/kg}\bullet\text{C}^\circ}$$

15. The heat must warm both the water and the pot to 100°C. The heat is also the power times the time.

$$Q = Pt = \left(m_{\mathrm{Al}}c_{\mathrm{Al}} + m_{\mathrm{H_2O}}c_{\mathrm{H_2O}}\right)\Delta T_{\mathrm{H_2O}} \rightarrow$$

$$t = \frac{\left(m_{\mathrm{Al}}c_{\mathrm{Al}} + m_{\mathrm{H_2O}}c_{\mathrm{H_2O}}\right)\Delta T_{\mathrm{H_2O}}}{P} = \frac{\left[(0.36\text{ kg})(900\,\mathrm{J/kg{\bullet}C^o}) + (0.75\text{ kg})(4186\,\mathrm{J/kg{\bullet}C^o})\right](92\mathrm{C^o})}{750\text{ W}}$$

$$= \boxed{425\text{ s}} \approx 7\text{ min}$$

16. The heat released by the 15 grams of candy in the burning is equal to the heat absorbed by the bomb, calorimeter, and water.

$$Q_{15} = \left[\left(m_{\mathrm{bomb}} + m_{\mathrm{cup}}\right)c_{\mathrm{Al}} + m_{\mathrm{H_2O}}c_{\mathrm{H_2O}}\right]\Delta T$$

$$= \left[(0.725\text{ kg} + 0.624\text{ kg})(0.22\,\mathrm{kcal/kg{\bullet}C^o}) + (2.00\text{ kg})(1.00\,\mathrm{kcal/kg{\bullet}C^o})\right](53.5^\circ\mathrm{C} - 15.0^\circ\mathrm{C})$$

$$= 88.43\text{ kcal}$$

The heat released by 75 grams of the candy would be 5 times that released by the 15 grams.

$$Q_{75} = 5Q_{15} = 5(88.43\text{ kcal}) = 440\text{ kcal} = \boxed{440\text{ Cal}}$$

17. The heat lost by the iron must be the heat gained by the aluminum and the glycerin.

$$m_{\mathrm{Fe}}c_{\mathrm{Fe}}\left(T_{i\,\mathrm{Fe}} - T_{\mathrm{eq}}\right) = m_{\mathrm{Al}}c_{\mathrm{Al}}\left(T_{\mathrm{eq}} - T_{i\,\mathrm{Al}}\right) + m_{\mathrm{gly}}c_{\mathrm{gly}}\left(T_{\mathrm{eq}} - T_{i\,\mathrm{gly}}\right)$$

$$(0.290\text{ kg})(450\,\mathrm{J/kg{\bullet}C^o})(142\mathrm{C^o}) = (0.095\text{ kg})(900\,\mathrm{J/kg{\bullet}C^o})(28\mathrm{C^o}) + (0.250\text{ kg})c_{\mathrm{gly}}(28\mathrm{C^o})$$

$$c_{\mathrm{gly}} = \boxed{2.3\times10^3\,\mathrm{J/kg{\bullet}C^o}}$$

18. We assume that all of the kinetic energy of the hammer goes into heating the nail.

$$KE = Q \rightarrow 10\left(\tfrac{1}{2}m_{\mathrm{hammer}}v_{\mathrm{hammer}}^2\right) = m_{\mathrm{nail}}c_{\mathrm{Fe}}\Delta T \rightarrow$$

$$\Delta T = \frac{10\left(\frac{1}{2}m_{\mathrm{hammer}}v_{\mathrm{hammer}}^2\right)}{m_{\mathrm{nail}}c_{\mathrm{Fe}}} = \frac{5(1.20\text{ kg})(6.5\,\mathrm{m/s})^2}{(0.014\text{ kg})(450\,\mathrm{J/kg{\bullet}C^o})} = 40.24\,\mathrm{C^o} \approx \boxed{4.0\times10^1\,\mathrm{C^o}}$$

19. 65% of the original potential energy of the aluminum goes to heating the aluminum.

$$0.65PE = Q \rightarrow 0.65m_{\mathrm{Al}}gh = m_{\mathrm{Al}}c_{\mathrm{Al}}\Delta T \rightarrow$$

$$\Delta T = \frac{0.65gh}{c_{\mathrm{Al}}} = \frac{0.65(9.80\,\mathrm{m/s^2})(45\text{ m})}{(900\,\mathrm{J/kg{\bullet}C^o})} = \boxed{0.32\,\mathrm{C^o}}$$

20. (*a*) Since $Q = mc\Delta T$ and $Q = C\Delta T$, equate these two expressions for Q and solve for C.

$$Q = mc\Delta T = C\Delta T \rightarrow \boxed{C = mc}$$

(*b*) For 1.0 kg of water: $C = mc = (1.0\text{ kg})(4186\,\mathrm{J/kg{\bullet}C^o}) = \boxed{4.2\times10^3\,\mathrm{J/C^o}}$

(*c*) For 25 kg of water: $C = mc = (25\text{ kg})(4186\,\mathrm{J/kg{\bullet}C^o}) = \boxed{1.0\times10^5\,\mathrm{J/C^o}}$

21. The silver must be heated to the melting temperature and then melted.

$$Q = Q_{\mathrm{heat}} + Q_{\mathrm{melt}} = mc\Delta T + mL_{\mathrm{fusion}}$$

$$= (16.50\text{ kg})(230\,\mathrm{J/kg{\bullet}C^o})(961^\circ\mathrm{C} - 20^\circ\mathrm{C}) + (16.50\text{ kg})(0.88\times10^5\,\mathrm{J/kg}) = \boxed{5.0\times10^6\,\mathrm{J}}$$

22. Assume that the heat from the person is only used to evaporate the water. Also, we use the heat of vaporization at room temperature (585 kcal/kg), since the person's temperature is closer to room temperature than 100°C.

$$Q = mL_{\text{vap}} \quad \rightarrow \quad m = \frac{Q}{L_{\text{vap}}} = \frac{180\text{ kcal}}{585\text{ kcal/kg}} = 0.308\text{ kg} \approx \boxed{0.31\text{ kg}} = 310\text{ mL}$$

23. The oxygen is all at the boiling point, so any heat added will cause oxygen to evaporate (as opposed to raising its temperature). We assume that all the heat goes to the oxygen, and none to the flask.

$$Q = mL_{\text{vap}} \quad \rightarrow \quad m = \frac{Q}{L_{\text{vap}}} = \frac{2.80\times10^5\text{ J}}{2.1\times10^5\text{ J/kg}} = \boxed{1.3\text{ kg}}$$

24. Assume that all of the heat lost by the ice cube in cooling to the temperature of the liquid nitrogen is used to boil the nitrogen, and so none is used to raise the temperature of the nitrogen. The boiling point of the nitrogen is $77\text{ K} = -196^\circ\text{C}$.

$$m_{\text{ice}}c_{\text{ice}}\left(T_{i\text{ ice}} - T_{f\text{ ice}}\right) = m_{\text{nitrogen}}L_{\text{vap}} \quad \rightarrow$$

$$m_{\text{nitrogen}} = \frac{m_{\text{ice}}c_{\text{ice}}\left(T_{i\text{ ice}} - T_{f\text{ ice}}\right)}{L_{\text{vap}}} = \frac{\left(3.0\times10^{-2}\text{ kg}\right)\left(2100\text{ J/kg}\cdot\text{C}^\circ\right)\left(0^\circ\text{C} - -196^\circ\text{C}\right)}{200\times10^3\text{ J/kg}} = \boxed{6.2\times10^{-2}\text{ kg}}$$

25. The heat lost by the aluminum and 310 g of liquid water must be equal to the heat gained by the ice in warming in the solid state, melting, and warming in the liquid state.

$$m_{\text{Al}}c_{\text{Al}}\left(T_{i\text{Al}} - T_{\text{eq}}\right) + m_{\text{H}_2\text{O}}c_{\text{H}_2\text{O}}\left(T_{i\text{H}_2\text{O}} - T_{\text{eq}}\right) = m_{\text{ice}}\left[c_{\text{ice}}\left(T_{\text{melt}} - T_{i\text{ ice}}\right) + L_{\text{fusion}} + c_{\text{H}_2\text{O}}\left(T_{\text{eq}} - T_{\text{melt}}\right)\right]$$

$$m_{\text{ice}} = \frac{\left(0.095\text{ kg}\right)\left(900\text{ J/kg}\cdot\text{C}^\circ\right)\left(3.0\text{C}^\circ\right) + \left(0.31\text{ kg}\right)\left(4186\text{ J/kg}\cdot\text{C}^\circ\right)\left(3.0\text{C}^\circ\right)}{\left[\left(2100\text{ J/kg}\cdot\text{C}^\circ\right)\left(8.5\text{C}^\circ\right) + 3.3\times10^5\text{ J/kg} + \left(4186\text{ J/kg}\cdot\text{C}^\circ\right)\left(17\text{C}^\circ\right)\right]} = \boxed{9.90\times10^{-3}\text{kg}}$$

26. (*a*) The heater must heat both the boiler and the water at the same time.

$$Q_1 = Pt_1 = \left(m_{\text{Fe}}c_{\text{Fe}} + m_{\text{H}_2\text{O}}c_{\text{H}_2\text{O}}\right)\Delta T \quad \rightarrow$$

$$t_1 = \frac{\left(m_{\text{Fe}}c_{\text{Fe}} + m_{\text{H}_2\text{O}}c_{\text{H}_2\text{O}}\right)\Delta T}{P} = \frac{\left[\left(230\text{ kg}\right)\left(450\text{ J/kg}\cdot\text{C}^\circ\right) + \left(830\text{ kg}\right)\left(4186\text{ J/kg}\cdot\text{C}^\circ\right)\right]\left(82\text{C}^\circ\right)}{5.2\times10^7\text{ J/h}}$$

$$= 5.642\text{ h} \approx \boxed{5.6\text{ h}}$$

(*b*) Assume that after the water starts to boil, all the heat energy goes into boiling the water, and none goes to raising the temperature of the iron or the steam.

$$Q_2 = Pt_2 = m_{\text{H}_2\text{O}}L_{\text{vap}} \quad \rightarrow \quad t_2 = \frac{m_{\text{H}_2\text{O}}L_{\text{vap}}}{P} = \frac{\left(830\text{ kg}\right)\left(22.6\times10^5\text{ J/kg}\right)}{5.2\times10^7\text{ J/h}} = 36.073\text{ h}$$

Thus the total time is $t_1 + t_2 = 5.642\text{ h} + 36.073\text{ h} = 41.72\text{ h} \approx \boxed{42\text{ h}}$

27. We assume that the cyclist's energy is only going to evaporation, not any heating. Then the energy needed is equal to the mass of the water times the latent heat of vaporization for water. Note that 1 L of water has a mass of 1 kg. Also, we use the heat of vaporization at room temperature (585 kcal/kg), since the cyclist's temperature is closer to room temperature than 100°C.

$$Q = m_{\text{H}_2\text{O}}L_{\text{vap}} = \left(8.0\text{ kg}\right)\left(585\text{ kcal/kg}\right) = \boxed{4.7\times10^3\text{kcal}}$$

28. The heat lost by the steam condensing and then cooling to 20°C must be equal to the heat gained by the ice melting and then warming to 20°C.

$$m_{\text{steam}}\left[L_{\text{vap}}+c_{H_2O}\left(T_{i\,\text{steam}}-T_{\text{eq}}\right)\right]=m_{\text{ice}}\left[L_{\text{fus}}+c_{H_2O}\left(T_{\text{eq}}-T_{i\,\text{ice}}\right)\right]$$

$$m_{\text{steam}}=m_{\text{ice}}\frac{\left[L_{\text{fus}}+c_{H_2O}\left(T_{\text{eq}}-T_{i\,\text{ice}}\right)\right]}{\left[L_{\text{vap}}+c_{H_2O}\left(T_{i\,\text{steam}}-T_{\text{eq}}\right)\right]}=(1.00\text{ kg})\frac{\left[3.33\times10^5\text{ J/kg}+\left(4186\text{ J/kg}\bullet\text{C}^\circ\right)\left(20\text{C}^\circ\right)\right]}{\left[22.6\times10^5\text{ J/kg}+\left(4186\text{ J/kg}\bullet\text{C}^\circ\right)\left(80\text{C}^\circ\right)\right]}$$

$$=\boxed{1.61\times10^{-1}\text{kg}}$$

29. The heat lost by the aluminum and the water must equal the heat needed to melt the mercury and to warm the mercury to the equilibrium temperature.

$$m_{\text{Al}}c_{\text{Al}}\left(T_{i\,\text{Al}}-T_{\text{eq}}\right)+m_{H_2O}c_{H_2O}\left(T_{i\,H_2O}-T_{\text{eq}}\right)=m_{\text{Hg}}\left[L_{\text{fusion}}+c_{\text{Hg}}\left(T_{\text{eq}}-T_{\text{melt}}\right)\right]$$

$$L_{\text{fusion}}=\frac{m_{\text{Al}}c_{\text{Al}}\left(T_{i\,\text{Al}}-T_{\text{eq}}\right)+m_{H_2O}c_{H_2O}\left(T_{i\,H_2O}-T_{\text{eq}}\right)}{m_{\text{Hg}}}-c_{\text{Hg}}\left(T_{\text{eq}}-T_{\text{melt}}\right)$$

$$=\frac{\left[(0.620\text{ kg})\left(900\text{ J/kg}\bullet\text{C}^\circ\right)+(0.400\text{ kg})\left(4186\text{ J/kg}\bullet\text{C}^\circ\right)\right]\left(12.80^\circ\text{C}-5.06^\circ\text{C}\right)}{1.00\text{ kg}}$$

$$-\left(138\text{ J/kg}\bullet\text{C}^\circ\right)\left[5.06^\circ\text{C}-\left(-39.0^\circ\text{C}\right)\right]$$

$$=\boxed{1.12\times10^4\text{ J/kg}}$$

30. Assume that the kinetic energy of the bullet was all converted into heat which melted the ice.

$$\tfrac{1}{2}m_{\text{bullet}}v^2=Q=m_{\text{ice}}L_{\text{fusion}}\quad\rightarrow$$

$$m_{\text{ice}}=\frac{\frac{1}{2}m_{\text{bullet}}v^2}{L_{\text{fusion}}}=\frac{\frac{1}{2}\left(7.0\times10^{-2}\text{kg}\right)(250\text{ m/s})^2}{3.33\times10^5\text{ J/kg}}=\boxed{6.6\times10^{-3}\text{kg}}=6.6\text{ g}$$

31. Assume that all of the melted ice stays at 0°C, so that all the heat is used in melting ice, and none in warming water. The available heat is half of the original kinetic energy

$$\tfrac{1}{2}\left(\tfrac{1}{2}m_{\text{skater}}v^2\right)=Q=m_{\text{ice}}L_{\text{fusion}}\quad\rightarrow$$

$$m_{\text{ice}}=\frac{\frac{1}{4}m_{\text{skater}}v^2}{L_{\text{fusion}}}=\frac{\frac{1}{4}(54.0\text{ kg})(6.4\text{ m/s})^2}{3.33\times10^5\text{ J/kg}}=\boxed{1.7\times10^{-3}\text{kg}}=1.7\text{ g}$$

32. The kinetic energy of the bullet is assumed to warm the bullet and melt it.

$$\tfrac{1}{2}mv^2=Q=mc_{\text{Pb}}\left(T_{\text{melt}}-T_i\right)+mL_{\text{fusion}}\quad\rightarrow$$

$$v=\sqrt{2\left[c_{\text{Pb}}\left(T_{\text{melt}}-T_i\right)+L_{\text{fusion}}\right]}=\sqrt{2\left[\left(130\text{ J/kg}\bullet\text{C}^\circ\right)\left(327^\circ\text{C}-20^\circ\text{C}\right)+\left(0.25\times10^5\text{ J/kg}\right)\right]}$$

$$=\boxed{3.6\times10^2\text{ m/s}}$$

33. The heat conduction rate is given by Eq. 14-4.

$$\frac{Q}{t}=kA\frac{T_1-T_2}{l}=\left(200\text{ J/s}\bullet\text{m}\bullet\text{C}^\circ\right)\pi\left(1.0\times10^{-2}\text{ m}\right)^2\frac{\left(460^\circ\text{C}-22^\circ\text{C}\right)}{0.33\text{ m}}=\boxed{83\text{ W}}$$

34. The heat conduction rate is given by Eq. 14-4.

$$\frac{Q}{t}=kA\frac{T_1-T_2}{l}=\left(0.84\,\text{J/s}\bullet\text{m}\bullet\text{C}^\circ\right)\left(3.0\text{ m}^2\right)\frac{\left[15.0^\circ\text{C}-\left(-5^\circ\text{C}\right)\right]}{3.2\times10^{-3}\text{ m}}=\boxed{1.6\times10^4\text{ W}}$$

35. (*a*) The power radiated is given by Eq. 14-5. The temperature of the tungsten is $273\,\text{K}+25\,\text{K}=298\,\text{K}$.

$$\frac{\Delta Q}{\Delta t}=e\sigma AT^4=\left(0.35\right)\left(5.67\times10^{-8}\text{ W/m}^2\bullet\text{K}^4\right)4\pi\left(0.22\text{ m}\right)^2\left(298\text{ K}\right)^4=\boxed{95\text{ W}}$$

(*b*) The net flow rate of energy is given by Eq. 14-6. The temperature of the surroundings is 268 K.

$$\frac{\Delta Q}{\Delta t}=e\sigma A\left(T_1^4-T_1^4\right)=\left(0.35\right)\left(5.67\times10^{-8}\text{ W/m}^2\bullet\text{K}^4\right)4\pi\left(0.22\text{ m}\right)^2\left[\left(298\text{ K}\right)^4-\left(268\text{ K}\right)^4\right]$$

$$=\boxed{33\text{ W}}$$

36. The distance can be calculated from the heat conduction rate, given by Eq. 14-4. The rate is given as a power (200 W = 200 J/s).

$$\frac{Q}{t}=P=kA\frac{T_1-T_2}{l}\quad\rightarrow\quad l=kA\frac{T_1-T_2}{P}=\left(0.2\,\text{J/s}\bullet\text{m}\bullet\text{C}^\circ\right)\left(1.5\text{ m}^2\right)\frac{0.50\,\text{C}^\circ}{200\text{ W}}=\boxed{8\times10^{-4}\text{m}}$$

37. This is a heat transfer by conduction, and so Eq. 14-4 is applicable.

$$\frac{Q}{t}=P=kA\frac{T_1-T_2}{l}=\left(0.84\,\text{J/s}\bullet\text{m}\bullet\text{C}^\circ\right)\left(16\,\text{m}^2\right)\frac{30^\circ\text{C}-10^\circ\text{C}}{0.12\text{ m}}=2.24\times10^3\,\text{W}$$

If we assume that all of the energy from the light bulbs goes into this conduction, then:

$$2.24\times10^3\,\text{W}\left(\frac{1\text{ bulb}}{100\text{ W}}\right)=22.4\text{ bulbs}\ \text{ and so }\ \boxed{23\text{ bulbs}}\ \text{ are needed.}$$

38. Eq. 14-7 gives the heat absorption rate for an object facing the Sun. The heat required to melt the ice is the mass of the ice times the latent heat of fusion for the ice. The mass is found by multiplying the volume of ice times its density.

$$\Delta Q=mL_f=\rho VL_f=\rho A\left(\Delta x\right)L_f\qquad\frac{\Delta Q}{\Delta t}=\left(1000\,\text{W/m}^2\right)eA\cos\theta\quad\rightarrow$$

$$\Delta t=\frac{\rho A\left(\Delta x\right)L_f}{\left(1000\,\text{W/m}^2\right)eA\cos\theta}=\frac{\rho\left(\Delta x\right)L_f}{\left(1000\,\text{W/m}^2\right)e\cos\theta}$$

$$=\frac{\left(9.17\times10^2\text{ kg/m}^3\right)\left(1.0\times10^{-2}\text{m}\right)\left(3.33\times10^5\text{ J/kg}\right)}{\left(1000\,\text{W/m}^2\right)\left(0.050\right)\cos30^\circ}=\boxed{7.1\times10^4\text{s}}=20\text{ h}$$

39. For the temperature at the joint to remain constant, the heat flow in both rods must be the same. Note that the cross-sectional areas and lengths are the same. Use Eq. 14-4 for heat conduction.

$$\left(\frac{Q}{t}\right)_{\text{Cu}}=\left(\frac{Q}{t}\right)_{\text{Al}}\quad\rightarrow\quad k_{\text{Cu}}A\frac{T_{\text{hot}}-T_{\text{middle}}}{l}=k_{\text{Al}}A\frac{T_{\text{middle}}-T_{\text{cool}}}{l}\quad\rightarrow$$

$$T_{\text{middle}}=\frac{k_{\text{Cu}}T_{\text{hot}}+k_{\text{Al}}T_{\text{cool}}}{k_{\text{Cu}}+k_{\text{Al}}}=\frac{\left(380\,\text{J/s}\bullet\text{m}\bullet\text{C}^\circ\right)\left(250^\circ\text{C}\right)+\left(200\,\text{J/s}\bullet\text{m}\bullet\text{C}^\circ\right)\left(0.0^\circ\text{C}\right)}{380\,\text{J/s}\bullet\text{m}\bullet\text{C}^\circ+200\,\text{J/s}\bullet\text{m}\bullet\text{C}^\circ}=\boxed{1.6\times10^2\ ^\circ\text{C}}$$

40. (*a*) The cross-sectional area of the Earth, perpendicular to the Sun, is a circle of radius R_{Earth}, and so has an area of πR_{Earth}^2. Multiply this area times the solar constant to get the rate at which the Earth is receiving solar energy.

$$\frac{Q}{t} = \pi R_{\text{Earth}}^2 \left(\text{solar constant}\right) = \pi\left(6.38\times10^6\,\text{m}\right)^2\left(1350\,\text{W/m}^2\right) = \boxed{1.73\times10^{17}\,\text{W}}$$

(*b*) Use Eq. 14-5 to calculate the rate of heat output by radiation.

$$\frac{Q}{t} = e\sigma AT^4 \quad \rightarrow$$

$$T = \left(\frac{Q}{t}\frac{1}{\varepsilon\sigma A}\right)^{1/4} = \left[\left(1.7\times10^{17}\,\text{J/s}\right)\frac{1}{(1.0)\left(5.67\times10^{-8}\,\text{W/m}^2\bullet\text{K}^4\right)4\pi\left(6.38\times10^6\,\text{m}\right)^2}\right]^{1/4}$$

$$= \boxed{278\text{ K} = 5^{\circ}\text{C}}$$

41. This is an example of heat conduction, and the temperature difference can be calculated by Eq. 14-4.

$$\frac{Q}{t} = P = kA\frac{T_1 - T_2}{l} \quad \rightarrow \quad \Delta T = \frac{Pl}{kA} = \frac{(95\text{ W})\left(1.0\times10^{-3}\,\text{m}\right)}{\left(0.84\,\text{J/s}\bullet\text{m}\bullet\text{C}^{\circ}\right)4\pi\left(3.0\times10^{-2}\,\text{m}\right)^2} = \boxed{10\,\text{C}^{\circ}}$$

42. The conduction rates through the two materials must be equal. If they were not, the temperatures in the materials would be changing. Call the temperature at the boundary between the materials T_x.

$$\frac{Q}{t} = k_1A\frac{T_1 - T_x}{l_1} = k_2A\frac{T_x - T_2}{l_2} \quad \rightarrow \quad \frac{Q}{t}\frac{l_1}{k_1A} = T_1 - T_x \;\; ; \;\; \frac{Q}{t}\frac{l_2}{k_2A} = T_x - T_2$$

Add these two equations together, and solve for the heat conduction rate.

$$\frac{Q}{t}\frac{l_1}{k_1A} + \frac{Q}{t}\frac{l_2}{k_2A} = T_1 - T_x + T_x - T_2 \quad \rightarrow \quad \frac{Q}{t}\left(\frac{l_1}{k_1} + \frac{l_2}{k_2}\right)\frac{1}{A} = T_1 - T_2 \quad \rightarrow$$

$$\frac{Q}{t} = A\frac{(T_1 - T_2)}{\left(\frac{l_1}{k_1} + \frac{l_2}{k_2}\right)} = A\frac{(T_1 - T_2)}{(R_1 + R_2)} = \left(240\text{ ft}^2\right)\frac{\left(12\,\text{F}^{\circ}\right)}{(1+19)\,\text{ft}^2\bullet\text{h}\bullet\text{F}^{\circ}/\text{Btu}} = 144\,\text{Btu/h} \approx \boxed{1.4\times10^2\text{ Btu/h}}$$

This is about 42 Watts.

43. (*a*) We assume that $T_2 > T_1$. The conduction rates through the three materials must be equal. If they were not, the temperatures in the materials would be changing. Call the temperature at the boundary between the air and the left-most piece of glass, T_x, and the temperature at the boundary between the air and the right-most piece of glass, T_y. Write the conduction rate for each material separately, and solve for the temperature differences.

$$\frac{Q}{t} = k_1A\frac{T_x - T_1}{l_1} = k_2A\frac{T_y - T_x}{l_2} = k_3A\frac{T_2 - T_y}{l_3} \quad \rightarrow$$

$$\frac{Q}{t}\frac{l_1}{k_1A} = T_x - T_1 \;\; ; \;\; \frac{Q}{t}\frac{l_2}{k_2A} = T_y - T_x \;\; ; \;\; \frac{Q}{t}\frac{l_3}{k_3A} = T_2 - T_y$$

Add these three equations together, and solve for the heat conduction rate.

$$\frac{Q}{t}\frac{l_1}{k_1 A}+\frac{Q}{t}\frac{l_2}{k_2 A}+\frac{Q}{t}\frac{l_3}{k_3 A}=T_x-T_1+T_y-T_x+T_2-T_y \;\rightarrow\; \frac{Q}{t}\left(\frac{l_1}{k_1}+\frac{l_2}{k_2}+\frac{l_3}{k_3}\right)\frac{1}{A}=T_2-T_1 \;\rightarrow$$

$$\boxed{\frac{Q}{t}=A\frac{(T_2-T_1)}{(l_1/k_1+l_2/k_2+l_3/k_3)}}$$

(*b*) For *n* materials placed next to one another, the expression would be

$$\frac{Q}{t}=A\frac{(T_2-T_1)}{\sum_{i=1}^{n} l_i/k_i}= \;\rightarrow\; \boxed{\frac{Q}{t}=A\frac{(T_2-T_1)}{\sum_{i=1}^{n} R_i}}$$

44. This is an example of heat conduction. The heat conducted is the heat released by the melting ice, $Q=m_{\rm ice}L_{\rm fusion}$. The area through which the heat is conducted is the total area of the six surfaces of the box, and the length of the conducting material is the thickness of the Styrofoam. We assume that all of the heat conducted into the box goes into melting the ice, and none into raising the temperature inside the box. The time can then be calculated by Eq. 14-4.

$$\frac{Q}{t}=kA\frac{T_1-T_2}{l} \;\rightarrow\; t=\frac{m_{\rm ice}L_{\rm fusion}l}{kA\Delta T}$$

$$=\frac{(11.0\text{ kg})(3.33\times10^5\text{ J/kg})(1.5\times10^{-2}\text{ m})}{2(0.023\text{ J/s}\bullet\text{m}\bullet\text{C}^\circ)[2(0.25\text{ m})(0.35\text{ m})+2(0.25\text{ m})(0.55\text{ m})+2(0.35\text{ m})(0.55\text{ m})](32\text{ C}^\circ)}$$

$$=\boxed{4.5\times10^4\text{ s}}\approx 12\text{ h}$$

45. The heat needed to warm the liquid can be calculated by Eq. 14-2.

$$Q=mc\Delta T=(0.20\text{ kg})(1.00\text{ kcal/kg}\bullet\text{C}^\circ)(37^\circ\text{C}-5^\circ\text{C})=6.4\text{ kcal}=\boxed{6.4\text{ C}}$$

46. Since 30% of the heat generated is lost up the chimney, the heat required to heat the house is 70% of the heat provided by the coal.

$$2.0\times10^5\text{ MJ}=0.70(30\times10^6\text{ MJ/kg})(m\text{ kg}) \;\rightarrow\; m=\frac{2.0\times10^5\text{ MJ}}{0.70(30\text{ MJ/kg})}=\boxed{9.5\times10^3\text{ kg}}$$

47. The heat released can be calculated by Eq. 14-2. To find the mass of the water, use the density (of pure water).

$$Q=mc\Delta T=\rho Vc\Delta T=(1.0\times10^3\text{ kg/m}^3)(1.0\times10^3\text{ m})^3(4186\text{ J/kg}\bullet\text{C}^\circ)(1\text{C}^\circ)=\boxed{4\times10^{15}\text{ J}}$$

48. We assume that the initial kinetic energy of the bullet all goes into heating the wood and the bullet.

$$\tfrac{1}{2}m_{\rm bullet}v_i^2=Q=m_{\rm bullet}c_{\rm lead}\Delta T_{\rm lead}+m_{\rm wood}c_{\rm wood}\Delta T_{\rm wood} \;\rightarrow$$

$$v_i=\sqrt{\frac{(m_{\rm bullet}c_{\rm lead}+m_{\rm wood}c_{\rm wood})\Delta T}{\tfrac{1}{2}m_{\rm bullet}}}$$

$$=\sqrt{\frac{[(0.015\text{ kg})(130\text{ J/kg}\bullet\text{C}^\circ)+(1.05\text{ kg})(1700\text{ J/kg}\bullet\text{C}^\circ)](0.020\text{ C}^\circ)}{\tfrac{1}{2}(0.015\text{ kg})}}=\boxed{69\text{ m/s}}$$

49. (*a*) Use Eq. 14-5 for total power radiated.

$$\frac{Q}{t} = e\sigma AT^4 = e\sigma 4\pi R_{\text{Sun}}^2 T^4 = (1.0)\left(5.67\times10^{-8}\ \text{W/m}^2\bullet\text{K}^4\right)4\pi\left(7.0\times10^8\,\text{m}\right)^2(5500\ \text{K})^4$$

$$= 3.195\times10^{26}\,\text{W} \approx \boxed{3.2\times10^{26}\,\text{W}}$$

(*b*) Assume that the energy from the Sun is distributed symmetrically over a spherical surface with the Sun at the center.

$$\frac{P}{A} = \frac{Q/t}{4\pi R_{\text{Sun-Earth}}^2} = \frac{3.195\times10^{26}\,\text{W}}{4\pi\left(1.5\times10^{11}\,\text{m}\right)^2} = 1.130\times10^3\ \text{W/m}^2 \approx \boxed{1.1\times10^3\ \text{W/m}^2}$$

50. The temperature rise can be calculated from Eq. 14-2.

$$Q = mc\Delta T \quad \rightarrow \quad \Delta T = \frac{Q}{mc} = \frac{(0.80)(200\,\text{kcal/h})(1.00\ \text{h})}{(70\ \text{kg})\left(0.83\,\text{kcal/kg}\bullet\text{C}^\circ\right)} = \boxed{2.8\,\text{C}^\circ}$$

51. We assume that the starting speed of the boulder is zero, and that 50% of the original potential energy of the boulder goes to heating the boulder.

$$\tfrac{1}{2}PE = Q \quad \rightarrow \quad \tfrac{1}{2}(mgh) = mc_{\text{marble}}\Delta T \quad \rightarrow \quad \Delta T = \frac{\tfrac{1}{2}gh}{c_{\text{marble}}} = \frac{0.50\left(9.8\,\text{m/s}^2\right)(140\ \text{m})}{860\,\text{J/kg}\bullet\text{C}^\circ} = \boxed{0.80\,\text{C}^\circ}$$

52. The heat lost by the lead must be equal to the heat gained by the water. Note that 1 L of water has a mass of 1 kg.

$$m_{\text{Pb}}c_{\text{Pb}}\left(T_{\text{i Pb}} - T_{\text{eq}}\right) = m_{\text{H}_2\text{O}}c_{\text{H}_2\text{O}}\left(T_{\text{eq}} - T_{i\,\text{H}_2\text{O}}\right)$$

$$(2.3\ \text{kg})\left(130\,\text{J/kg}\bullet\text{C}^\circ\right)\left(T_{\text{i Pb}} - 28.0^\circ\text{C}\right) = (2.5\ \text{kg})\left(4186\,\text{J/kg}\bullet\text{C}^\circ\right)\left(8.0\,\text{C}^\circ\right) \quad \rightarrow$$

$$T_{\text{i Pb}} = 308^\circ\text{C} \approx \boxed{310^\circ\text{C}}$$

53. Use the heat conduction rate equation, Eq. 14-4.

(*a*) $$\frac{Q}{t} = kA\frac{T_1 - T_2}{l} = \left(0.025\,\text{J/s}\bullet\text{m}\bullet\text{C}^\circ\right)\left(1.2\,\text{m}^2\right)\frac{\left[34^\circ\text{C} - \left(-20^\circ\text{C}\right)\right]}{3.5\times10^{-2}\,\text{m}} = \boxed{46\ \text{W}}$$

(*b*) $$\frac{Q}{t} = kA\frac{T_1 - T_2}{l} = \left(0.56\,\text{J/s}\bullet\text{m}\bullet\text{C}^\circ\right)\left(1.2\,\text{m}^2\right)\frac{\left[34^\circ\text{C} - \left(-20^\circ\text{C}\right)\right]}{5.0\times10^{-3}\,\text{m}} = \boxed{7.3\times10^3\ \text{W}}$$

54. We assume that all of the heat provided by metabolism goes into evaporating the water. For the energy required for the evaporation of water, we use the heat of vaporization at room temperature (585 kcal/kg), since the runner's temperature is closer to room temperature than 100°C.

$$2.5\ \text{h}\left(\frac{950\ \text{kcal}}{1\ \text{h}}\right)\left(\frac{\text{kg H}_2\text{O}}{585\ \text{kcal}}\right) = \boxed{4.1\ \text{kg}}$$

55. For an estimate of the heat conduction rate, use Eq. 14-4.

$$\frac{Q}{t} = kA\frac{T_1 - T_2}{l} = \left(0.2\,\text{J/s}\bullet\text{m}\bullet\text{C}^\circ\right)\left(1.5\,\text{m}^2\right)\frac{\left(37^\circ\text{C} - 34^\circ\text{C}\right)}{4.0\times10^{-2}\,\text{m}} = 22.5\,\text{W} \approx \boxed{20\ \text{W}}$$

This is only about 10% of the cooling capacity that is needed for the body. Thus convection cooling is clearly necessary.

56. (*a*) To calculate heat transfer by conduction, use Eq. 14-4 for all three areas – walls, roof, and windows. Each area has the same temperature difference.

$$\frac{Q_{\text{conduction}}}{t}=\left[\left(\frac{kA}{l}\right)_{\text{walls}}+\left(\frac{kA}{l}\right)_{\text{roof}}+\left(\frac{kA}{l}\right)_{\text{windows}}\right](T_1-T_2)$$

$$=\left[\frac{\left(0.023\,\text{J/s}\bullet\text{m}\bullet\text{C}^\circ\right)\left(410\,\text{m}^2\right)}{1.75\times10^{-1}\,\text{m}}+\frac{\left(0.12\,\text{J/s}\bullet\text{m}\bullet\text{C}^\circ\right)\left(280\,\text{m}^2\right)}{6.5\times10^{-2}\,\text{cm}}+\frac{\left(0.84\,\text{J/s}\bullet\text{m}\bullet\text{C}^\circ\right)\left(33\,\text{m}^2\right)}{6.5\times10^{-3}\,\text{m}}\right]\left(33\,\text{C}^\circ\right)$$

$$=1.596\times10^5\,\text{W}\approx\boxed{1.6\times10^5\,\text{W}}$$

(*b*) The energy being added must both heat the air and replace the energy lost by conduction, as considered above. The heat required to raise the temperature is given by Eq. 14-2, $Q_{\substack{\text{raise}\\\text{temp}}}=m_{\text{air}}c_{\text{air}}\left(\Delta T\right)_{\text{warming}}$. The mass of the air can be found from the density of the air times its volume. The conduction heat loss is proportional to the temperature difference between the inside and outside, which varies from 20C$^\circ$ to 33C$^\circ$. We will estimate the average temperature difference as 26.5°C and scale the answer from part (a) accordingly.

$$Q_{\text{added}}=Q_{\substack{\text{raise}\\\text{temp}}}+Q_{\text{conduction}}=\rho_{\text{air}}Vc_{\text{air}}\left(\Delta T\right)_{\text{warming}}+\left(\frac{Q_{\text{conduction}}}{t}\right)(1800\text{ s})$$

$$=\left(1.29\frac{\text{kg}}{\text{m}^3}\right)\left(750\text{m}^3\right)\left(0.24\frac{\text{kcal}}{\text{kg}\bullet\text{C}^\circ}\right)\left(\frac{4186\text{ J}}{\text{kcal}}\right)\left(13^\circ\text{C}\right)$$

$$+\left(1.596\times10^5\frac{\text{J}}{\text{s}}\right)\left(\frac{26.5^\circ\text{C}}{33^\circ\text{C}}\right)(1800\text{ s})=\boxed{2.4\times10^8\,\text{J}}$$

(*c*) We assume a month is 30 days.

$$0.9Q_{\text{gas}}=\left(\frac{Q}{t}\right)_{\text{conduction}}t_{\text{month}}\quad\rightarrow$$

$$Q_{\text{gas}}=\frac{1}{0.9}\left(\frac{Q}{t}\right)_{\text{conduction}}t_{\text{month}}=\frac{1}{0.9}\left(1.596\times10^5\text{ J/s}\right)(30\text{ d})\left(\frac{24\text{ h}}{1\text{ d}}\right)\left(\frac{3600\text{ s}}{1\text{ h}}\right)=4.596\times10^{11}\,\text{J}$$

$$4.6\times10^{11}\,\text{J}\left(\frac{1\text{ kg}}{5.4\times10^7\,\text{J}}\right)\left(\frac{\$0.080}{\text{kg}}\right)=\boxed{\$680}$$

57. (*a*) The bullet will gain an amount of heat equal to 50% of its loss of kinetic energy. Initially assume that the phase of the bullet does not change, so that all of the heat causes a temperature increase.

$$\tfrac{1}{2}\left[\tfrac{1}{2}m\left(v_i^2-v_f^2\right)\right]=Q=mc_{\text{Pb}}\Delta T\quad\rightarrow\quad\Delta T=\frac{\tfrac{1}{4}\left(v_i^2-v_f^2\right)}{c_{\text{Pb}}}=\frac{\left(220\,\text{m/s}\right)^2-\left(160\,\text{m/s}\right)^2}{4\left(130\,\text{J/kg}\bullet\text{C}^\circ\right)}=\boxed{44\,\text{C}^\circ}$$

(*b*) The final temperature of the bullet would be about 64°C, which is not above the melting temperature of lead, which is 327°C. Thus $\boxed{\text{none of the bullet will melt}}$.

58. (*a*) The rate of absorbing heat for an object facing the Sun is given by Eq. 14-7. The rise in temperature is related to the absorbed heat by Eq. 14-2. We assume that all absorbed heat raises the temperature of the leaf.

$$\Delta Q = mc\Delta T \qquad \frac{\Delta Q}{\Delta t} = \left(1000\ \mathrm{W/m^2}\right) eA\cos\theta \quad \rightarrow$$

$$\frac{\Delta T}{\Delta t} = \frac{\left(1000\ \mathrm{W/m^2}\right) eA\cos\theta}{mc} = \frac{\left(1000\ \mathrm{W/m^2}\right)(0.85)\left(40\ \mathrm{cm^2}\right)\left(\dfrac{1\ \mathrm{m^2}}{1\times10^4\ \mathrm{cm^2}}\right)(1)}{\left(4.5\times10^{-4}\ \mathrm{kg}\right)\left(0.80\ \mathrm{kcal/kg{\bullet}C^o}\right)\left(\dfrac{4186\ \mathrm{J}}{1\ \mathrm{kcal}}\right)} = \boxed{2.3\ \mathrm{C^o/s}}$$

(*b*) We assume that the rate of heat loss by radiation must equal the rate of heat absorption of solar energy. Note that the area of the leaf that radiates is twice the area that absorbs heat energy.

$$\left(\frac{\Delta Q}{\Delta t}\right)_{\substack{\text{Solar}\\ \text{heating}}} = \left(\frac{\Delta Q}{\Delta t}\right)_{\text{radiation}} \rightarrow \left(1000\ \mathrm{W/m^2}\right) eA_{\text{absorb}}\cos\theta = e\sigma A_{\text{radiate}}\left(T_1^4 - T_2^4\right) \rightarrow$$

$$T_1 = \left[\frac{\left(1000\ \mathrm{W/m^2}\right)\cos\theta}{2\sigma} + T_2^4\right]^{1/4} = \left[\frac{\left(1000\ \mathrm{W/m^2}\right)(1)}{2\left(5.67\times10^{-8}\ \mathrm{W/m^2{\bullet}K^4}\right)} + \left(293\ \mathrm{K}\right)^4\right]^{1/4}$$

$$= 357\ \mathrm{K} = \boxed{84^\circ\mathrm{C}}$$

This is very hot, which indicates that the leaf must lose energy by other means than just radiation.

(*c*) The leaf can also lose heat by $\boxed{\text{conduction}}$ to the cooler air around it; by $\boxed{\text{convection}}$, as the wind continually moves cooler air over the surface of the leaf; and $\boxed{\text{evaporation}}$ of water.

59. The rate of energy absorption from the Sun must be equal to the rate of losing energy by radiation plus the rate of losing energy by evaporation if the leaf is to maintain a steady temperature. The latent heat of evaporation is taken be the value at 20°C, which is 2450 kJ/kg. Also note that the area of the leaf that radiates is twice the area that absorbs heat energy.

$$\left(\frac{\Delta Q}{\Delta t}\right)_{\substack{\text{Solar}\\ \text{heating}}} = \left(\frac{\Delta Q}{\Delta t}\right)_{\text{radiation}} + \left(\frac{\Delta Q}{\Delta t}\right)_{\text{evaporation}} \rightarrow$$

$$\left(1000\ \mathrm{W/m^2}\right) eA_{\text{absorb}}\cos\theta = e\sigma A_{\text{radiate}}\left(T_1^4 - T_2^4\right) + \frac{m_{\mathrm{H_2O}} L_{\text{evaporation}}}{\Delta t} \rightarrow$$

$$\frac{m_{\mathrm{H_2O}}}{\Delta t} = eA_{\text{absorb}} \frac{\left(1000\ \mathrm{W/m^2}\right)\cos\theta - 2\sigma\left(T_1^4 - T_2^4\right)}{L_{\text{evaporation}}}$$

$$= (0.85)\left(40\times10^{-4}\ \mathrm{m^2}\right)\frac{\left(1000\ \mathrm{W/m^2}\right)(1) - 2\left(5.67\times10^{-8}\ \mathrm{W/m^2{\bullet}K^4}\right)\left[\left(308\ \mathrm{K}\right)^4 - \left(293\ \mathrm{K}\right)^4\right]}{\left(2.45\times10^6\ \mathrm{J/kg}\right)}$$

$$= 1.1\times10^{-6}\ \mathrm{kg/s} = \boxed{4.1\ \mathrm{g/h}}$$

60. Assume that the final speed of the meteorite, as it completely melts, is 0, and that all of its initial kinetic energy was used in heating the iron to the melting point and then melting the iron.

$$\tfrac{1}{2}mv_i^2 = mc_{\mathrm{Fe}}\left(T_{\text{melt}} - T_i\right) + mL_{\text{fusion}} \rightarrow$$

$$v_i = \sqrt{2\left[c_{\mathrm{Fe}}\left(T_{\text{melt}} - T_i\right) + L_{\text{fusion}}\right]} = \sqrt{2\left[\left(450\ \mathrm{J/kg{\bullet}C^o}\right)\left(1808^\circ\mathrm{C} - -125^\circ\mathrm{C}\right) + 2.89\times10^5\ \mathrm{J/kg}\right]}$$

$$= \boxed{1.52\times10^3\ \mathrm{m/s}}$$

61. (*a*) We consider just the 30 m of crust immediately below the surface of the Earth, assuming that all the heat from the interior gets transferred to the surface, and so it all passes through this 30 m layer. This is a heat conduction problem, and so Eq. 14-4 is appropriate. The radius of the Earth is about $6.38\times10^{6}\,\mathrm{m}$.

$$\frac{Q}{t}=kA\frac{T_1-T_2}{l}\quad\rightarrow$$

$$Q_{\text{interior}}=kA\frac{T_1-T_2}{l}t=\left(0.80\,\mathrm{J/s{\bullet}m{\bullet}C^{o}}\right)4\pi R_{\text{Earth}}^{2}\frac{1.0\,\mathrm{C^{o}}}{30\ \mathrm{m}}\left[1\ \text{day}\left(\frac{86,400\ \mathrm{s}}{\text{day}}\right)\right]$$

$$=1.179\times10^{18}\,\mathrm{J}\approx\boxed{1.2\times10^{18}\,\mathrm{J}}$$

(*b*) The cross-sectional area of the Earth, perpendicular to the Sun, is a circle of radius R_{Earth}, and so has an area of πR_{Earth}^{2}. Multiply this area times the solar constant of $1350\,\mathrm{W/m^{2}}$ to get the amount of energy incident on the Earth from the Sun per second, and then convert to energy per day.

$$Q_{\text{Sun}}=\pi R_{\text{Earth}}^{2}\left(1350\,\mathrm{W/m^{2}}\right)\left[1\ \text{day}\left(\frac{86,400\ \mathrm{s}}{\text{day}}\right)\right]=1.492\times10^{22}\,\mathrm{J}$$

Thus $\frac{Q_{\text{interior}}}{Q_{\text{Sun}}}=\frac{1.179\times10^{18}\,\mathrm{J}}{1.492\times10^{22}\,\mathrm{J}}=7.902\times10^{-5}$, or $\boxed{Q_{\text{Sun}}=1.3\times10^{4}Q_{\text{interior}}}$.

62. Assume that the loss of kinetic energy is all turned into heat which changes the temperature of the squash ball.

$$KE_{\text{lost}}=Q\quad\rightarrow\quad\tfrac{1}{2}m\left(v_i^2-v_f^2\right)=mc\Delta T\quad\rightarrow\quad\Delta T=\frac{v_i^2-v_f^2}{2c}=\frac{\left(22\,\mathrm{m/s}\right)^2-\left(12\,\mathrm{m/s}\right)^2}{2\left(1200\,\mathrm{J/kg{\bullet}C^{o}}\right)}=\boxed{0.14\,\mathrm{C^{o}}}$$

63. The heat gained by the ice (to melt it and warm it) must be equal to the heat lost by the steam (in condensing and cooling).

$$mL_{\text{F}}+mc_{\mathrm{H_2O}}\left(T_{\text{eq}}-0\right)=mL_{\text{V}}+mc_{\mathrm{H_2O}}\left(100^{\circ}\mathrm{C}-T_{\text{eq}}\right)$$

$$T_{\text{eq}}=\frac{L_{\text{V}}-L_{\text{F}}}{2c_{\mathrm{H_2O}}}+50^{\circ}\mathrm{C}=\frac{2260\,\mathrm{kJ/kg}-333\,\mathrm{kJ/kg}}{2\left(4.186\,\mathrm{kJ/kg{\bullet}C^{o}}\right)}+50^{\circ}\mathrm{C}=280^{\circ}\mathrm{C}$$

This answer is not possible. Because this answer is too high, the steam must not all condense, and none of it must cool below 100°C. Calculate the energy need to melt a kilogram of ice and warm it to 100°C.

$$Q=mL_{\text{F}}+mc_{\mathrm{H_2O}}\left(T_{\text{eq}}-0\right)=\left(1\,\mathrm{kg}\right)\left[333\,\mathrm{kJ/kg}+\left(4.186\,\mathrm{kJ/kg{\bullet}C^{o}}\right)\left(100\mathrm{C^{o}}\right)\right]=751.6\,\mathrm{kJ}$$

Calculate the mass of steam that needs to condense in order to provide this much energy.

$$Q=mL_{\text{V}}\quad\rightarrow\quad m=\frac{Q}{L_{\text{V}}}=\frac{751.6\,\mathrm{kJ}}{2260\,\mathrm{kJ/kg}}=0.333\,\mathrm{kg}$$

Thus one-third of the original steam mass must condense to liquid at 100°C in order to melt the ice and warm the melted ice to 100°C. The final mixture will be at 100°C, with 1/3 of the total mass as steam, and 2/3 of the total mass as water.

64. The body's metabolism (blood circulation in particular) provides cooling by convection. If the metabolism has stopped, then heat loss will be by conduction and radiation, at a rate of 200 W, as given. The change in temperature is related to the body's heat loss by Eq. 14-2, $Q = mc\Delta T$.

$$\frac{Q}{t} = P = \frac{mc\Delta T}{t} \rightarrow$$

$$t = \frac{mc\Delta T}{P} = \frac{(70\text{ kg})(3470\text{ J/kg}\cdot\text{C}^\circ)(36.6^\circ\text{C} - 35.6^\circ\text{C})}{200\text{ W}} = \boxed{1200\text{ s}} = 20\text{ min}$$

65. (*a*) The amount of heat energy required is given by Eq. 14-2. 1 L of water has a mass of 1 kg.

$$Q = mc\Delta T = (185\text{ kg})(4186\text{ J/kg}\cdot\text{C}^\circ)(50^\circ\text{C} - 10^\circ\text{C}) = 3.098\times10^7\text{ J} \approx \boxed{3.1\times10^7\text{ J}}$$

(*b*) The heat energy is the power input times the time.

$$Q = Pt \rightarrow t = \frac{Q}{P} = \frac{3.098\times10^7\text{ J}}{9.5\times10^3\text{ W}} = 3260\text{ s} \approx \boxed{3.3\times10^3\text{ s}} = 54\text{ min}$$

66. We assume that the light bulb emits energy by radiation, and so Eq. 14-6 applies. Use the data for the 60-W bulb to calculate the product $e\sigma A$ for the bulb, and then calculate the temperature of the 150-W bulb.

$$(Q/t)_{60\text{ W}} = e\sigma A\left(T_{60\text{ W}}^4 - T_{\text{room}}^4\right) \rightarrow$$

$$e\sigma A = \frac{(Q/t)_{60\text{ W}}}{\left(T_{60\text{ W}}^4 - T_{\text{room}}^4\right)} = \frac{(0.90)(60\text{ W})}{[(273+65)\text{K}]^4 - [(273+18)\text{K}]^4} = 9.182\times10^{-9}\text{ W/K}^4$$

$$(Q/t)_{150\text{ W}} = e\sigma A\left(T_{150\text{ W}}^4 - T_{\text{room}}^4\right) \rightarrow$$

$$T_{150\text{ W}} = \left[\frac{(Q/t)_{150\text{ W}}}{e\sigma A} + T_{\text{room}}^4\right]^{1/4} = \left[\frac{(0.90)(150\text{ W})}{(9.182\times10^{-9}\text{ W/K}^4)} + (291\text{ K})^4\right]^{1/4}$$

$$= 385\text{ K} = 112^\circ\text{C} \approx \boxed{110^\circ\text{C}}$$