14

HEAT

Responses 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 (where no heat energy is lost to the surroundings), 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 the substance and the temperature of the substance. 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 the 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, 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, so large quantities of energy can be moved from one place to another with relative simplicity by water. And the water will give off a large amount of energy as it cools.

6. The water on the cloth jacket will evaporate. Evaporation is a cooling process since energy is required to change the liquid water to vapor. As water evaporates from the moist cloth, the canteen surface is cooled.

$\boxed{7.}$ Steam at 100°C contains more thermal energy than water at 100°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°C, 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 have 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 pasta will not cook faster if the water is boiling faster. The rate at which the pasta cooks depends on the temperature at which it is cooking, and the boiling water is the same temperature whether it is boiling fast or slow.

10. Even though the temperature is high in the upper atmosphere, which means that the gas particles are moving very fast, the density of gas particles is very low. There would be relatively very few collisions of high-temperature gas particles with the animal, so very little warming of the animal would occur. Instead, the animal would radiate heat to the rarified atmosphere. The emissivity of the animal is much greater than that of the rarified atmosphere, so the animal will lose much more energy by radiation than it can gain from the atmosphere.

$\boxed{11.}$ Snow consists of crystals with tiny air pockets in between the flakes. Air is a good insulator, so when the Arctic explorers covered themselves with snow they were using its low thermal conductivity to keep heat from leaving their bodies. (In a similar fashion, down comforters keep you warm because of all the air trapped in between the feathers.) Snow would also protect the explorers from the very cold wind and prevent heat loss by convection.

12. 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, so for equal masses of sand and water, the sand will cool more than the water warms as their temperatures move toward 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, 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.

13. 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.

14. 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.

15. 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 toward 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.

16. 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, so a lower rate of losing body heat.

17. 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, 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 fan circulating air around that heat sink as well, so that heated air can continually be replaced with cool air to promote more cooling.

18. 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, due to the large specific heat of 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 toward the land.

19. 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, 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.

20. Air is a poorer conductor of heat than water by roughly a factor of 20, 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, 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, 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.

21. 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, 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.

22. 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°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 so there is less insulation than in a more mature baby, and low food consumption to replace lost energy. Also, the smaller the child, the larger the surface-area-to-volume ratio, which leads to relatively more heat being lost through the body surface area than for an older, larger baby.

23. 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 hot, humid air from close to the body and replaces it with cooler, less humid air, so that evaporation can continue.

24. (*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.

25. 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, so the sensation of heating is much less.

26. 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.

27. Shiny surfaces have low values of ε, the emissivity. Thus, the net rate of heat flow from the person to the surroundings (outside the blanket) will be low, since most of the heat is reflected by the blanket back to the person, and the person will stay warmer. The blanket will also prevent energy loss due to wind (convection) and will insulate the person, reducing heat transfer by conduction.

28. Cities situated on the ocean have less extreme temperatures 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.

29. The specific heat of water is large, so water is able to absorb a lot of heat energy with just a small temperature change. This helps to keep the temperature of the cup lower, preventing it from burning. Without the water, the cup's temperature would increase quickly, and then it would burn.

30. The air just outside the window will be somewhat warmed by conduction of heat energy through the window to the air. On a windy day, convection removes that warmer air from near the outside surface of the window. This increases the rate of heat conduction through the window, thus making the window feel colder than on a day with no wind.

Responses to MisConceptual Questions

1. (*c*) A common misconception is that "cold" flows from the ice into the tea. When the ice is placed in the tea, the ice has less kinetic energy per molecule than the tea, so in molecular collisions between the tea and ice, energy transfers from the tea into the ice. This energy transfer cools the tea as it melts the ice and then heats up the ice. The transfer of energy from the warmer tea to the colder ice is called "heat."

2. (*c*) Students frequently interpret having more ice with being colder. However, whenever ice and water are mixed together and are in thermal equilibrium they will be at the melting/freezing point of the water. Therefore, the two containers will be at the same temperature.

3. (*a*) When two objects are in thermal equilibrium, heat does not transfer between them. This occurs when the two objects are at the same temperature. Internal energy is an extrinsic property that depends upon the amount of the substance present. Therefore, two gases in thermal equilibrium with each other would have different internal energies if one consisted of one mole of gas and the other consisted of two moles of gas. Heat is a transfer of energy between objects that are not in thermal equilibrium. Heat is not a property of an object.

4. (*c*) Phase changes occur at specific temperatures (melting point, boiling point, or sublimation point) while heat is being added to or removed from the material. During the phase change the temperature remains constant. The thermal energy at this temperature is equal to the intermolecular binding energy. These energies are much lower than the energy necessary to break the molecules apart into their atoms or to change the chemical composition of the molecules.

5. (*a*) A common misconception is that as heat is added to water the temperature will always rise. However, Fig. 14–5 shows that heat is added to water at its melting and boiling points without the temperature changing. At these temperatures the water is undergoing a phase change.

6. (*d*) Heat is able to transfer through a vacuum by radiation, but heat requires a medium to transfer by conduction and by convection. Therefore, the vacuum in a thermos prevents heat loss by conduction and convection.

7. (*c*) Students often think that heat is a substance or a property of a material. When two materials are at different temperatures (that is, they have different average kinetic energies per molecule), energy can transfer from the hot object to the cold object. This transfer of energy is called heat.

8. (*d*) Radiation is emitted by all objects not at absolute zero. Very hot objects, such as the Sun, emit radiation in the visible spectrum, so they appear to be glowing. If the temperature of an object is less than that of its surroundings, it has a net gain in energy as it absorbs more radiation than it emits. However, it is still emitting radiation. The amount of radiation emitted is independent of the object's specific heat.

9. (*c*) The problem does not specify the initial temperatures of the ice and water. If the ice and water are both initially at 0°C, then none of the ice will melt, since heat will not transfer between them. Alternatively, if the ice is at 0°C and the water is at 100°C, then the water can provide $Q = mc\Delta T = (0.010\text{ kg})(4186\text{ J/kg}\cdot\text{C}°)(100\text{C}°) = 4186\text{ J}$ of heat as it cools to 0°C. The ice only needs $Q = mL = (0.010\text{ kg})(333\text{ kJ/kg}) = 3330\text{ J}$ to melt completely, so in this case all the ice would melt. Since the water could provide more heat than needed, you need to know the initial temperatures of the ice and water to determine just how much of the ice would melt.

10. (*d*) As the two objects are in thermal contact, the heat given off by the hot object will equal the heat absorbed by the cold object. The objects have the same specific heat, so the heat transfer is proportional to the product of the mass of each object and its change in temperature. The object with the smaller mass will then have the larger temperature change.

11. (*d*) The specific heat of an object is a measure of how much heat is required to change its temperature. Water has a high specific heat (much higher than air), so its temperature remains fairly constant even though the surrounding air may experience large temperature fluctuations.

12. (*a*) The two objects absorb the same amount of heat from the stove. From Eq. 14–2, given that the masses are the same, the object with the higher specific heat will experience the smaller temperature increase and will therefore be cooler.

Solutions to Problems

In solving these problems, the authors did not always follow the rules of significant figures rigidly. We tended to take quoted temperatures as correct to the number of digits shown, especially where other values might indicate that.

1. The kilocalorie is the heat needed to raise 1 kg of water by 1 C°. Use this relation to find the change in the temperature.

$$(8200\text{ J})\left(\frac{1\text{ kcal}}{4186\text{ J}}\right)\frac{(1\text{ kg})(1\text{C}°)}{1\text{ kcal}}\left(\frac{1}{3.0\text{ kg}}\right)=0.653\text{C}°$$

Thus, the final temperature is $10.0°\text{C}+0.653°\text{C}\approx\boxed{10.7°\text{C}}$.

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

$$(34.0\text{ kg})(95°\text{C}-15°\text{C})\frac{1\text{ kcal}}{(1\text{ kg})(1\text{ C}°)}\left(\frac{4186\text{ J}}{1\text{ kcal}}\right)=1.139\times10^{7}\text{ J}\approx\boxed{1.1\times10^{7}\text{ J}}$$

3. Find the mass of warmed water from the volume of water and its density of 1025 kg/m^3. Then use the fact that 1 kcal of energy raises 1 kg of water by $1\text{C}°$ and that the water warms by $25\text{C}°$.

$$V = At = \frac{m}{\rho} \quad\to\quad m = \rho At = (1025\text{ kg/m}^3)(1.0\text{ m}^2)(0.5\times10^{-3}\text{ m}) = 0.5125\text{ kg}$$

$$(0.5125\text{ kg})(25\text{ C}°)\frac{(1\text{ kcal})}{(1\text{ kg})(1\text{ C}°)}=12.8\text{ kcal};\;\; 12.8\text{ kcal}\left(\frac{1\text{ bar}}{300\text{ kcal}}\right)= 0.043\text{ bars}\approx\boxed{0.04\text{ bars}}$$

4. (*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 impossible to feed yourself in the United States on this amount of money.

5. On page 79 of the textbook, the conversion $1\text{ lb}=4.44822\text{ N}$ is given. We use that value.

$$1\text{ Btu}=(1\text{ lb})(1\text{ F}^\circ)\left(\frac{4.44822\text{ N}}{1\text{ lb}}\right)\left(\frac{1\text{ kg}}{9.80\text{m/s}^2}\right)\left(\frac{5/9\text{ C}^\circ}{1\text{ F}^\circ}\right)\frac{1\text{ kcal}}{(1\text{ kg})(1\text{ C}^\circ)}=0.2522\text{ kcal}\approx\boxed{0.252\text{ kcal}}$$

$$0.2522\text{ kcal}\left(\frac{4186\text{ J}}{1\text{ kcal}}\right)=\boxed{1056\text{ J}}$$

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

$$Q=\tfrac{1}{2}mv_0^2=\tfrac{1}{2}(1300\text{ kg})\left[(95\text{ km/h})\left(\frac{1\text{ m/s}}{3.6\text{ km/h}}\right)\right]^2=4.526\times10^4\text{ J}\approx\boxed{4.5\times10^4\text{ J}}$$

$$4.526\times10^4\text{ J}\left(\frac{1\text{ kcal}}{4186\text{ J}}\right)=108.1\text{ kcal}\approx\boxed{110\text{ kcal}}$$

7. The energy input is causing a certain rise in temperature, which can be expressed as a number of joules per hour per C°. Convert that to mass using the definition of kcal, relates mass to heat energy.

$$\left(\frac{3.2\times10^7\text{ J/h}}{30\text{ C}^\circ}\right)\left(\frac{1\text{ kcal}}{4186\text{ J}}\right)\frac{(1\text{ kg})(1\text{ C}^\circ)}{1\text{ kcal}}=254.8\text{ kg/h}\approx\boxed{250\text{ kg/h}}$$

8. The wattage rating is 375 joules per second. Note that 1 L of water has a mass of 1 kg.

$$\left((2.5\times10^{-1}\text{ L})\left(\frac{1\text{ kg}}{1\text{ L}}\right)(60\text{ C}^\circ)\right)\frac{1\text{ kcal}}{(1\text{ kg})(1\text{ C}^\circ)}\left(\frac{4186\text{ J}}{\text{kcal}}\right)\left(\frac{1\text{ s}}{375\text{ J}}\right)=167\text{ s}\approx\boxed{170\text{ s}=2.8\text{ min}}$$

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

$$Q=mc\Delta T=\left[(18\text{ L})\left(\frac{1\times10^{-3}\text{ m}^3}{1\text{ L}}\right)\left(\frac{1.0\times10^3\text{ kg}}{1\text{ m}^3}\right)\right](4186\text{ J/kg}\cdot\text{C}^\circ)(95^\circ\text{C}-15^\circ\text{C})=\boxed{6.0\times10^6\text{ J}}$$

10. The specific heat can be calculated from Eq. 14–2.

$$Q=mc\Delta T\quad\rightarrow\quad c=\frac{Q}{m\Delta T}=\frac{1.35\times10^5\text{ J}}{(4.1\text{ kg})(37.2^\circ\text{C}-18.0^\circ\text{C})}=1715\text{ J/kg}\cdot\text{C}^\circ\approx\boxed{1700\text{ J/kg}\cdot\text{C}^\circ}$$

11. (*a*) The heat absorbed can be calculated from Eq. 14–2. Note that 1 L of water has a mass of 1 kg.

$$Q = mc\Delta T = \left[(1.0\ \text{L})\left(\frac{1\times10^{-3}\ \text{m}^3}{1\ \text{L}}\right)\left(\frac{1.0\times10^{3}\ \text{kg}}{1\ \text{m}^3}\right)\right](4186\ \text{J/kg}\cdot\text{C}^\circ)(100^\circ\text{C} - 20^\circ\text{C})$$
$$= 3.349\times10^5\ \text{J} \approx \boxed{3.3\times10^5\ \text{J}}$$

(*b*) Power is the rate of energy usage.

$$P = \frac{\Delta E}{\Delta t} = \frac{Q}{\Delta t} \quad\rightarrow\quad \Delta t = \frac{Q}{P} = \frac{3.349\times10^5\ \text{J}}{60\ \text{W}} = 5582\ \text{s} \approx \boxed{5600\ \text{s}} \approx 93\ \text{min}$$

12. 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.

$$m_{\text{Cu}} : m_{\text{Al}} : m_{\text{H}_2\text{O}} = \frac{Q}{c_{\text{Cu}}\Delta T} : \frac{Q}{c_{\text{Al}}\Delta T} : \frac{Q}{c_{\text{H}_2\text{O}}\Delta T} = \frac{1}{c_{\text{Cu}}} : \frac{1}{c_{\text{Al}}} : \frac{1}{c_{\text{H}_2\text{O}}} = \frac{1}{390} : \frac{1}{900} : \frac{1}{4186}$$
$$= \frac{4186}{390} : \frac{4186}{900} : \frac{4186}{4186} = \boxed{10.7 : 4.65 : 1}$$

13. The heat must warm both the water and the pot to 100°C. The heat is also the power times the time. The temperature change is 89 C°.

$$Q = Pt = (m_{\text{Al}}c_{\text{Al}} + m_{\text{H}_2\text{O}}c_{\text{H}_2\text{O}})\Delta T_{\text{H}_2\text{O}} \quad\rightarrow$$
$$t = \frac{(m_{\text{Al}}c_{\text{Al}} + m_{\text{H}_2\text{O}}c_{\text{H}_2\text{O}})\Delta T_{\text{H}_2\text{O}}}{P} = \frac{[(0.28\ \text{kg})(900\ \text{J/kg}\cdot\text{C}^\circ) + (0.75\ \text{kg})(4186\ \text{J/kg}\cdot\text{C}^\circ)](89\ \text{C}^\circ)}{750\ \text{W}}$$
$$= 402\ \text{s} \approx \boxed{4.0\times10^2\ \text{s} = 6.7\ \text{min}}$$

14. The heat lost by the copper must be equal to the heat gained by the aluminum and the water. The aluminum and water have the same temperature change.

$$m_{\text{Cu}}c_{\text{Cu}}(T_{\text{i Cu}} - T_{\text{eq}}) = m_{\text{Al}}c_{\text{Al}}(T_{\text{eq}} - T_{\text{i Al}}) + m_{\text{H}_2\text{O}}c_{\text{H}_2\text{O}}(T_{\text{eq}} - T_{\text{i H}_2\text{O}})$$
$$(0.265\ \text{kg})(390\ \text{J/kg}\cdot\text{C}^\circ)(245^\circ\text{C} - T_{\text{eq}}) = \begin{bmatrix}(0.145\ \text{kg})(900\ \text{J/kg}\cdot\text{C}^\circ)\\ +(0.825\ \text{kg})(4186\ \text{J/kg}\cdot\text{C}^\circ)\end{bmatrix}(T_{\text{eq}} - 12.0^\circ\text{C})$$
$$T_{\text{eq}} = 18.532^\circ\text{C} \approx \boxed{18.5^\circ\text{C}}$$

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

$$m_{\text{glass}}c_{\text{glass}}(T_{\text{eq}} - T_{\text{glass}}) = m_{\text{H}_2\text{O}}c_{\text{H}_2\text{O}}(T_{\text{H}_2\text{O}} - T_{\text{eq}})$$
$$(31.5\ \text{g})(0.20\ \text{cal/g}\cdot\text{C}^\circ)(41.8^\circ\text{C} - 23.6^\circ\text{C}) = (135\ \text{g})(1.00\ \text{cal/g}\cdot\text{C}^\circ)(T_{\text{H}_2\text{O}} - 41.8^\circ\text{C})$$
$$T_{\text{H}_2\text{O}} = \boxed{42.6^\circ\text{C}}$$

16. 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.

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

$$(0.40\text{ kg})(450\text{ J/kg}\cdot\text{C}^\circ)(T_{\text{i shoe}} - 25.0^\circ\text{C}) = (0.30\text{ kg})(450\text{ J/kg}\cdot\text{C}^\circ)(25.0\text{ C}^\circ - 20.0\text{ C}^\circ) + (1.25\text{ kg})(4186\text{ J/kg}\cdot\text{C}^\circ)(25.0\text{ C}^\circ - 20.0\text{ C}^\circ)$$

$$T_{\text{i shoe}} = 174^\circ\text{C} \approx \boxed{170^\circ\text{C}}$$

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

$$m_{\text{Fe}}c_{\text{Fe}}(T_{\text{i Fe}} - T_{\text{eq}}) = m_{\text{Al}}c_{\text{Al}}(T_{\text{eq}} - T_{\text{i Al}}) + m_{\text{gly}}c_{\text{gly}}(T_{\text{eq}} - T_{\text{i gly}})$$

$$(0.290\text{ kg})(450\text{ J/kg}\cdot\text{C}^\circ)(142\text{ C}^\circ) = (0.095\text{ kg})(900\text{ J/kg}\cdot\text{C}^\circ)(28\text{ C}^\circ) + (0.250\text{ kg})c_{\text{gly}}(28\text{ C}^\circ)$$

$$c_{\text{gly}} = 2305\text{ J/kg}\cdot\text{C}^\circ \approx \boxed{2300\text{ J/kg}\cdot\text{C}^\circ}$$

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

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

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

(*c*) For 45 kg of water: $C = mc = (45\text{ kg})(4186\text{ J/kg}\cdot\text{C}^\circ) = \boxed{1.9\times10^5\text{ J/C}^\circ}$

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

$$\text{KE} = Q \quad \rightarrow \quad 8\left(\tfrac{1}{2}m_{\text{hammer}}\,v_{\text{hammer}}^2\right) = m_{\text{nail}}c_{\text{Fe}}\Delta T \quad \rightarrow$$

$$\Delta T = \frac{8\left(\tfrac{1}{2}m_{\text{hammer}}\,v_{\text{hammer}}^2\right)}{m_{\text{nail}}c_{\text{Fe}}} = \frac{4(1.20\text{ kg})(7.5\text{m/s})^2}{(0.014\text{ kg})(450\text{ J/kg}\cdot\text{C}^\circ)} = 42.86\text{ C}^\circ \approx \boxed{43\text{ C}^\circ}$$

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

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

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

$$= \frac{\begin{bmatrix}(0.105\text{ kg})(900\text{ J/kg}\cdot\text{C}^\circ) + (0.185\text{ kg})(4186\text{ J/kg}\cdot\text{C}^\circ)\\ +(0.017\text{ kg})(840\text{ J/kg}\cdot\text{C}^\circ)\end{bmatrix}(35.0^\circ\text{C} - 10.5^\circ\text{C})}{(0.215\text{ kg})(330^\circ\text{C} - 35.0^\circ\text{C})}$$

$$= 341.16\text{ J/kg}\cdot\text{C}^\circ \approx \boxed{341\text{ J/kg}\cdot\text{C}^\circ}$$

21. The heat released by the 10 grams of fudge cookies in the burning process is equal to the heat absorbed by the aluminum and water.

$$Q_{\substack{100\text{ g}\\ \text{cookies}}} = (m_{\text{Al}}c_{\text{Al}} + m_{\text{H}_2\text{O}}c_{\text{H}_2\text{O}})\Delta T$$

$$= [(0.615\text{ kg} + 0.524\text{ kg})(0.22\text{ kcal/kg}\cdot\text{C}^\circ) + (2.00\text{ kg})(1.00\text{ kcal/kg}\cdot\text{C}^\circ)](36.0^\circ\text{C} - 15.0^\circ\text{C})$$

$$= 47.26\text{ kcal} \approx 47.3\text{ kcal}$$

Since this is the energy content of 10 grams, the content of 100 grams would be 10 times this, or $\boxed{473\,\text{kcal}}$.

22. 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.

$$Q = mL_V \quad \rightarrow \quad m = \frac{Q}{L_V} = \frac{3.40\times10^5\ \text{J}}{2.1\times10^5\ \text{J/kg}} = \boxed{1.6\ \text{kg}}$$

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

$$Q = Q_{\text{heat}} + Q_{\text{melt}} = mc\Delta T + mL_F$$
$$= (23.50\ \text{kg})(230\ \text{J/kg}\cdot\text{C}^\circ)(961^\circ\text{C} - 25^\circ\text{C}) + (23.50\ \text{kg})(0.88\times10^5\ \text{J/kg}) = \boxed{7.1\times10^6\ \text{J}}$$

24. 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.

$$Q = mL_V \quad \rightarrow \quad m = \frac{Q}{L_V} = \frac{185\ \text{kcal}}{585\ \text{kcal/kg}} = \boxed{0.316\ \text{kg}} = 316\ \text{mL}$$

25. The heat lost by the steam condensing and then cooling to 30°C must be equal to the heat gained by the ice melting and then warming to 30°C.

$$m_{\text{steam}}[L_V + c_{H_2O}(T_{\text{isteam}} - T_{\text{eq}})] = m_{\text{ice}}[L_F + c_{H_2O}(T_{\text{eq}} - T_{\text{iice}})]$$
$$m_{\text{steam}} = m_{\text{ice}}\frac{[L_F + c_{H_2O}(T_{\text{eq}} - T_{\text{iice}})]}{[L_V + c_{H_2O}(T_{\text{isteam}} - T_{\text{eq}})]} = (1.00\ \text{kg})\frac{[3.33\times10^5\ \text{J/kg} + (4186\ \text{J/kg}\cdot\text{C}^\circ)(30^\circ\text{C})]}{[22.6\times10^5\ \text{J/kg} + (4186\ \text{J/kg}\cdot\text{C}^\circ)(30^\circ\text{C})]}$$
$$= \boxed{0.18\ \text{kg}}$$

26. 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, so none is used to raise the temperature of the nitrogen. The boiling point of the nitrogen is $77\ \text{K} = -196^\circ\text{C}$.

$$m_{\text{ice}}c_{\text{ice}}\left(T_{\substack{\text{ice}\\ \text{initial}}} - T_{\substack{\text{ice}\\ \text{final}}}\right) = m_{\text{nitrogen}}L_V \quad \rightarrow$$

$$m_{\text{nitrogen}} = \frac{m_{\text{ice}}c_{\text{ice}}\left(T_{\substack{\text{ice}\\ \text{initial}}} - T_{\substack{\text{ice}\\ \text{final}}}\right)}{L_V} = \frac{(2.8\times10^{-2}\ \text{kg})(2100\ \text{J/kg}\cdot\text{C}^\circ)(0^\circ\text{C} - -196^\circ\text{C})}{200\times10^3\ \text{J/kg}} = \boxed{5.8\times10^{-2}\ \text{kg}}$$

27. (*a*) The energy absorbed from the body must warm the snow to the melting temperature, melt the snow, and then warm the melted snow to the final temperature.

$$Q_a = Q_{\substack{\text{warm}\\ \text{snow}}} + Q_{\text{melt}} + Q_{\substack{\text{warm}\\ \text{liquid}}} = mc_{\text{snow}}\Delta T_1 + mL_F + mc_{\text{liquid}}\Delta T_2 = m[c_{\text{snow}}\Delta T_1 + L_F + c_{\text{liquid}}\Delta T_2]$$
$$= (1.0\ \text{kg})[(2100\ \text{J/kg}\cdot\text{C}^\circ)(15\ \text{C}^\circ) + (3.33\times10^5\ \text{J/kg}) + (4186\ \text{J/kg}\cdot\text{C}^\circ)(37\ \text{C}^\circ)]$$
$$= \boxed{5.2\times10^5\ \text{J}}$$

(*b*) The energy absorbed from the body only has to warm the melted snow to the final temperature.

$$Q_b = Q_{\substack{\text{heat}\\ \text{liquid}}} = mc_{\text{liquid}}\Delta T_2 = (1.0\text{ kg})(4186\text{ J/kg}\cdot\text{C}°)(35\text{ C}°) = \boxed{1.5\times 10^5\text{ J}}$$

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

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

$$t_1 = \frac{(m_{\text{Fe}}c_{\text{Fe}} + m_{\text{H}_2\text{O}}c_{\text{H}_2\text{O}})\Delta T}{P} = \frac{[(180\text{ kg})(450\text{ J/kg}\cdot\text{C}°) + (730\text{ kg})(4186\text{ J/kg}\cdot\text{C}°)](82\text{ C}°)}{5.8\times 10^7\text{ J/h}}$$

$$= 4.435\text{ h} \approx \boxed{4.4\text{ h}}$$

(*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.

$$Q_2 = Pt_2 = m_{\text{H}_2\text{O}}L_{\text{V}} \quad \rightarrow \quad t_2 = \frac{m_{\text{H}_2\text{O}}L_{\text{V}}}{P} = \frac{(730\text{ kg})(22.6\times 10^5\text{ J/kg})}{5.8\times 10^7\text{ J/h}} = 28\,445\text{ h}$$

Thus, the total time is $t_1 + t_2 = 4.435\text{ h} + 28.445\text{ h} = 32.88\text{ h} \approx \boxed{33\text{ h}}$.

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.

$$m_{\text{Al}}c_{\text{Al}}(T_{\text{Al}} - T_{\text{eq}}) = m_{\text{H}_2\text{O}}c_{\text{H}_2\text{O}}(T_{\text{H}_2\text{O}} - T_{\text{eq}}) = m_{\text{Hg}}[L_{\text{F}} + c_{\text{Hg}}(T_{\text{eq}} - T_{\text{melt}})]$$

$$L_{\text{F}} = \frac{m_{\text{Al}}c_{\text{Al}}(T_{\text{Al}} - T_{\text{eq}}) + m_{\text{H}_2\text{O}}c_{\text{H}_2\text{O}}(T_{\text{H}_2\text{O}} - T_{\text{eq}})}{m_{\text{Hg}}} = c_{\text{Hg}}(T_{\text{eq}} - T_{\text{melt}})$$

$$= \frac{[(0.620\text{ kg})\times(900\text{ J/kg}\cdot\text{C}°) + (0.400\text{ kg})\times(4186\text{ J/kg}\cdot\text{C}°)](12.80°\text{C} - 5.06°\text{C})]}{1.00\text{ kg}}$$

$$-(138\text{ J/kg}\cdot\text{C}°)[5.06°\text{C} - (-39.0°\text{C})]$$

$$= \boxed{1.12\times 10^4\text{ J/kg}}$$

30. 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.

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

$$m_{\text{ice}} = \frac{[(0.085\text{ kg})(900\text{ J/kg}\cdot\text{C}°)(3.0\text{ C}°) + (0.31\text{ kg})(4186\text{ J/kg}\cdot\text{C}°)(3.0\text{ C}°)]}{[(2100\text{ J/kg}\cdot\text{C}°)(8.5\text{ C}°) + 3.3\times 10^5\text{ J/kg} + (4186\text{ J/kg}\cdot\text{C}°)(17\text{ C}°)]} = \boxed{9.8\times 10^{-3}\text{ kg}}$$

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

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

$$m_{\text{ice}} = \frac{\frac{1}{2}m_{\text{bullet}}v^2}{L_{\text{F}}} = \frac{\frac{1}{2}(5.5\times 10^{-2}\text{ kg})(250\text{ m/s})^2}{3.33\times 10^5\text{ J/kg}} = \boxed{5.2\times 10^{-3}\text{ kg}} = 5.2\text{ g}$$

32. The heat conduction rate is given by Eq. 14–5.

$$\frac{Q}{t} = kA\frac{T_1 - T_2}{\ell} = (380\text{ J/s}\cdot\text{m}\cdot\text{C}°)\pi(1.0\times 10^{-2}\text{ m})^2\frac{(460°\text{C} - 22°\text{C})}{0.56\text{ m}} = \boxed{93\text{ W}}$$

33. (*a*) The power radiated is given by Eq. 14–6. The temperature of the tungsten is $273\text{ K} + 25\text{ K} = 298\text{ K}$.

$$\frac{\Delta Q}{\Delta t} = \varepsilon\sigma A T^4 = (0.35)(5.67\times10^{-8}\ \text{W/m}^2\cdot\text{K}^4)4\pi(0.19\ \text{m})^2(298\ \text{K})^4 = \boxed{71\ \text{W}}$$

(*b*) The net flow rate of energy is given by Eq. 14–7. The temperature of the surroundings is 268 K.

$$\frac{\Delta Q}{\Delta t} = \varepsilon\sigma A\left(T_1^4 - T_1^4\right) = (0.35)\left(5.67\times10^{-8}\ \text{W/m}^2\cdot\text{K}^4\right)4\pi\,(0.19\ \text{m})^2\left[(298\ \text{K})^4 - (268\ \text{K})^4\right]$$
$$= \boxed{25\ \text{W}}$$

34. Eq. 14–8 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 by its density.

$$\Delta Q = mL_\text{F} = \rho V L_\text{F} = \rho A(\Delta x)L_\text{F} \qquad \frac{\Delta Q}{\Delta t} = (1000\text{W/m}^2)\varepsilon A\cos\theta \ \rightarrow$$
$$\Delta t = \frac{\rho A(\Delta x)L_\text{F}}{(1000\ \text{W/m}^2)\varepsilon A\cos\theta} = \frac{\rho(\Delta x)L_\text{F}}{(1000\ \text{W/m}^2)\varepsilon\cos\theta}$$
$$= \frac{(9.17\times10^2\ \text{kg/m}^3)(1.0\times10^{-2}\ \text{m})(3.33\times10^5\ \text{J/kg})}{(1000\ \text{W/m}^2)(0.050)\cos 35^\circ} = \boxed{7.5\times10^4\ \text{s}} \approx 21\ \text{h}$$

35. The distance can be calculated from the heat conduction rate, given by Eq. 14–5. The rate is given as a power (150 W = 150 J/s).

$$\frac{Q}{t} = P = kA\frac{T_1 - T_2}{\ell} \ \rightarrow\ \ell = kA\frac{T_1 - T_2}{P} = (0.2\ \text{J/s}\cdot\text{m}\cdot\text{C}^\circ)(1.5\ \text{m}^2)\frac{0.50\ \text{C}^\circ}{150\ \text{W}} = \boxed{1.0\times10^{-3}\ \text{m}}$$

$\boxed{36.}$ This is a heat transfer by conduction, so Eq. 14–5 is applicable.

$$\frac{Q}{t} = P = kA\frac{T_1 - T_2}{\ell} = (0.84\ \text{J/s}\cdot\text{m}\cdot\text{C}^\circ)(16\ \text{m}^2)\frac{30^\circ\text{C} - 10^\circ\text{C}}{0.14\ \text{m}} = 1920\ \text{W}$$

It would take 19.2 lightbulbs, so $\boxed{20\ \text{bulbs}}$ are needed to maintain the temperature difference.

37. This is an example of heat conduction. The temperature difference can be calculated by Eq. 14–5.

$$\frac{Q}{t} = P = kA\frac{T_1 - T_2}{\ell} \ \rightarrow\ \Delta T = \frac{P\ell}{kA} = \frac{(95\ \text{W})(5.0\times10^{-4}\ \text{m})}{(0.84\ \text{J/s}\cdot\text{m}\cdot\text{C}^\circ)4\pi(3.0\times10^{-2}\ \text{m})^2} = \boxed{5.0\ \text{C}^\circ}$$

38. This is an example of heat conduction. The heat conducted is the heat released by the melting ice, $Q = m_\text{ice}L_\text{F}$. 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. 14–5.

$$\frac{Q}{t} = kA\frac{T_1 - T_2}{\ell} \ \rightarrow\ t = \frac{m_\text{ice}L_\text{F}\ell}{kA\Delta T}$$
$$= \frac{(8.2\ \text{kg})(3.33\times10^5\ \text{J/kg})(1.5\times10^{-2}\ \text{m})}{2(0.023\ \text{J/s}\cdot\text{m}\cdot\text{C}^\circ)[2(0.25\ \text{m})(0.35\ \text{m}) + 2(0.25\ \text{m})(0.55\ \text{m}) + 2(0.35\ \text{m})(0.55\ \text{m})](34\ \text{C}^\circ)}$$
$$= 3.136\times10^4\text{s} \approx \boxed{3.1\times10^4\ \text{s}} \approx 8.7\ \text{h}$$

39. For the temperature at the joint to remain constant, the heat flow in the rods must be the same. Note that the cross-sectional areas and lengths are the same. Use Eq. 14–5 for heat conduction.

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

$$T_{\text{middle}} = \frac{k_{\text{Cu}}T_{\text{hot}} + k_{\text{Al}}T_{\text{cool}}}{k_{\text{Cu}} + k_{\text{Al}}} = \frac{(380\text{ J/s}\cdot\text{m}\cdot\text{C}^\circ)(205^\circ\text{C}) + (200\text{ J/s}\cdot\text{m}\cdot\text{C}^\circ)(0.0^\circ\text{C})}{380\text{ J/s}\cdot\text{m}\cdot\text{C}^\circ + 200\text{ J/s}\cdot\text{m}\cdot\text{C}^\circ} = 134.3^\circ\text{C} \approx \boxed{130^\circ\text{ C}}$$

40. 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.

$$\frac{Q}{t} = k_1A\frac{T_1 - T_x}{\ell_1} = k_2A\frac{T_x - T_2}{\ell_2} \rightarrow \frac{Q}{t}\frac{\ell_1}{k_1A} = T_1 - T_x;\ \frac{Q}{t}\frac{\ell_2}{k_2A} = T_x - T_2$$

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

$$\frac{Q}{t}\frac{\ell_1}{k_1A} + \frac{Q}{t}\frac{\ell_2}{k_2A} = T_1 - T_x + T_x - T_2 \rightarrow \frac{Q}{t}\left(\frac{\ell_1}{k_1} + \frac{\ell_2}{k_2}\right)\frac{1}{A} = T_1 - T_2 \rightarrow$$

$$\frac{Q}{t} = A\frac{(T_1 - T_2)}{\left(\frac{\ell_1}{k_1} + \frac{\ell_2}{k_2}\right)} = A\frac{(T_1 - T_2)}{(R_1 + R_2)}$$

The R-value for the brick needs to be calculated, using the definition of R given on page 402 of the textbook.

$$R = \frac{\ell}{k} = \frac{4\text{ in.}\left(\frac{1\text{ ft}}{12\text{ in.}}\right)}{0.84\frac{\text{J}}{\text{s}\cdot\text{m}\cdot\text{C}^\circ}\left(\frac{1\text{ Btu}}{1055\text{ J}}\right)\left(\frac{1\text{ m}}{3.281\text{ ft}}\right)\left(\frac{5\text{ C}^\circ}{9\text{ F}^\circ}\right)\left(\frac{3600\text{ s}}{1\text{ h}}\right)} = 0.69\text{ft}^2\cdot\text{h}\cdot\text{F}^\circ/\text{Btu}$$

$$\frac{Q}{t} = A\frac{(T_1 - T_2)}{(R_1 + R_2)} = (195\text{ ft}^2)\frac{(35\text{ F}^\circ)}{(0.69 + 19)\text{ft}^2\cdot\text{h}\cdot\text{F}^\circ/\text{Btu}} = 347\text{ Btu/h} \approx \boxed{350\text{ Btu/h}}$$

This is about 100 watts.

$\boxed{41.}$ (*a*) Use Eq. 14–6 for total power radiated.

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

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

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

$$\frac{P}{A} = \frac{Q/t}{4\pi R_{\text{Sun-Earth}}^2} = \frac{3.195\times10^{26}\text{ W}}{4\pi(1.5\times10^{11}\text{ m})^2} = 1.130\times10^3\text{ W/m}^2 \approx \boxed{1100\text{ W/m}^2}$$

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

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

43. 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).

$$mL_F + mc_{H_2O}(T_{eq} - 0) = mL_V + mc_{H_2O}(100°C - T_{eq})$$

$$T_{eq} = \frac{L_V - L_F}{2c_{H_2O}} + 50°C = \frac{2260\text{ kJ/kg} - 333\text{ kJ/kg}}{2(4.186\text{ kJ/kg}\cdot C°)} + 50°C = 280°C$$

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 needed to melt a kilogram of ice and warm it to 100°C.

$$Q = mL_F + mc_{H_2O}(T_{eq} - 0) = (1\text{ kg})[333\text{ kJ/kg} + (4.186\text{ kJ/kg}\cdot C°)(100\text{ C°})] = 751.6\text{ kJ}$$

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

$$Q = mL_V \quad \rightarrow \quad m = \frac{Q}{L_V} = \frac{751.6\text{ kJ}}{2260\text{ kJ/kg}} = 0.333\text{ kg}$$

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.

44. Use the heat conduction rate equation, Eq. 14–5.

(*a*) $$\frac{Q}{t} = kA\frac{T_1 - T_2}{\ell} = (0.025\text{ J/s}\cdot\text{m}\cdot C°)(0.95\text{ m}^2)\frac{[34°C - (-18°C)]}{3.5\times10^{-2}\text{ m}} = 35.3\text{ W} \approx \boxed{35\text{ W}}$$

(*b*) $$\frac{Q}{t} = kA\frac{T_1 - T_2}{\ell} = (0.56\text{ J/s}\cdot\text{m}\cdot C°)(0.95\text{ m}^2)\frac{[34°C - (-18°C)]}{5.0\times10^{-3}\text{ m}} = 5533\text{ W} \approx \boxed{5500\text{ W}}$$

45. The temperature rise can be calculated from Eq. 14–2.

$$Q = mc\Delta T \quad \rightarrow \quad \Delta T = \frac{Q}{mc} = \frac{(0.80)(200\text{ kcal/h})(0.75\text{ h})}{(70\text{ kg})(0.83\text{ kcal/kg}\cdot C°)} = 2.065\text{ C°} \approx \boxed{2\text{ C°}}$$

46. For an estimate of the heat conduction rate, use Eq. 14–5.

$$\frac{Q}{t} = kA\frac{T_1 - T_2}{\ell} = (0.2\text{ J/s}\cdot\text{m}\cdot C°)(1.5\text{ m}^2)\frac{(37°C - 34°C)}{4.0\times10^{-2}\text{ m}} = 22.5\text{ W} \approx \boxed{20\text{ W}}$$

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

47. We are told that 80% of the cyclist's energy goes toward evaporation. The energy needed for evaporation 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.

$$0.80Q_{rider} = m_{H_2O}L_V \rightarrow Q_{rider} = \frac{m_{H_2O}L_V}{0.80} = \frac{(9.0\text{ kg})(585\text{ kcal/kg})}{0.8} = 6581\text{ kcal} \approx \boxed{6.6\times10^3\text{ kcal}}$$

48. 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.

$$2.0\times10^5\text{ MJ} = 0.70(30\times10^6\text{ MJ/kg})(m\text{ kg}) \quad \rightarrow \quad m = \frac{2.0\times10^5\text{ MJ}}{0.70(30\text{ MJ/kg})} = \boxed{9500\text{ kg}}$$

49. 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.

$$\tfrac{1}{2}\text{PE} = Q \quad \rightarrow \quad \tfrac{1}{2}(mgh) = mc_{\text{marble}}\Delta T \quad \rightarrow \quad \Delta T = \frac{\tfrac{1}{2}gh}{c_{\text{marble}}} = \frac{0.50(9.80\text{ m/s}^2)(120\text{ m})}{860\text{ J/kg}\cdot\text{C}^\circ} = \boxed{0.68\text{ C}^\circ}$$

50. 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.

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

$$(2.3\text{ kg})(130\text{ J/kg}\cdot\text{C}^\circ)(T_{\text{i Pb}} - 32.0^\circ\text{C}) = (2.5\text{ kg})(4186\text{ J/kg}\cdot\text{C}^\circ)(12.0\text{ C}^\circ) \quad \rightarrow$$

$$T_{\text{i Pb}} = 452^\circ\text{C} \approx \boxed{450^\circ\text{C}}$$

51. (*a*) The energy required to raise the temperature of the water is given by Eq. 14–2.

$$Q = mc\Delta T \quad \rightarrow$$

$$\frac{Q}{\Delta t} = mc\frac{\Delta T}{\Delta t} = (0.250\text{ kg})\left(4186\frac{\text{J}}{\text{kg}\cdot\text{C}^\circ}\right)\left(\frac{80\text{ C}^\circ}{105\text{ s}}\right) = 797\text{ W} \approx \boxed{800\text{ W (2 significant figures)}}$$

(*b*) After 105 s, the water is at 100°C. So for the remaining 15 s the energy input will boil the water. Use the heat of vaporization.

$$Q = mL_{\text{V}} \quad \rightarrow \quad m = \frac{Q}{L_{\text{V}}} = \frac{(\text{Power})\Delta t}{L_{\text{V}}} = \frac{(797\text{ W})(15\text{ s})}{2260\text{ J/g}} = \boxed{5.3\text{ g}}$$

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

$$\text{KE}_{\text{lost}} = Q \quad \rightarrow \quad \tfrac{1}{2}m(\upsilon_{\text{i}}^2 - \upsilon_{\text{f}}^2) = mc\Delta T \quad \rightarrow \quad \Delta T = \frac{\upsilon_{\text{i}}^2 - \upsilon_{\text{f}}^2}{2c} = \frac{(22\text{ m/s})^2 - (12\text{ m/s})^2}{2(1200\text{ J/kg}\cdot\text{C}^\circ)} = \boxed{0.14\text{ C}^\circ}$$

53. (*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, so it all passes through this 30-m layer. This is a heat conduction problem, so Eq. 14–5 is appropriate. The radius of the Earth is about 6.38×10^6 m.

$$\frac{Q}{t} = kA\frac{T_1 - T_2}{\ell} \quad \rightarrow \quad Q_{\text{interior}} = kA\frac{T_1 - T_2}{\ell}t = (0.80\text{ J/s}\cdot\text{m}\cdot\text{C}^\circ)4\pi R_{\text{Earth}}^2\frac{1.0\text{ C}^\circ}{30\text{ m}}\left[1\text{ h}\left(\frac{3600\text{ s}}{\text{h}}\right)\right]$$

$$= 4.910\times10^{16}\text{ J} \approx \boxed{4.9\times10^{16}\text{ J}}$$

(*b*) The cross-sectional area of the Earth, perpendicular to the Sun, is a circle of radius R_{Earth}, so it has an area of πR_{Earth}^2. Multiply this area by the solar constant of 1350 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.

$$Q_{\text{Sun}} = \pi R_{\text{Earth}}^2(1350\text{ W/m}^2)\left[1\text{ h}\left(\frac{3600\text{ s}}{\text{h}}\right)\right] = 6.215\times10^{20}\text{ J}$$

$$\frac{Q_{\text{Sun}}}{Q_{\text{interior}}}=\frac{\pi R_{\text{Earth}}^2(1350\text{ W/m}^2)\left[1\text{ h}\left(\frac{3600\text{ s}}{\text{day}}\right)\right]}{(0.80\text{ J/s}\cdot\text{m}\cdot\text{C°})4\pi R_{\text{Earth}}^2\frac{1.0\text{ C°}}{30\text{ m}}\left[1\text{ h}\left(\frac{3600\text{ s}}{\text{h}}\right)\right]}=\frac{(1350\text{ W/m}^2)}{(0.80\text{ J/s}\cdot\text{m}\cdot\text{C°})4\left(\frac{1.0\text{ C°}}{30\text{ m}}\right)}$$

$$=1.266\times10^4$$

So $\boxed{Q_{\text{Sun}}\approx1.3\times10^4\;Q_{\text{interior}}}$.

54. 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.

$$\tfrac{1}{2}m\upsilon_{\text{i}}^2=mc_{\text{Fe}}(T_{\text{melt}}-T_{\text{i}})+mL_{\text{F}}\quad\rightarrow$$

$$\upsilon_{\text{i}}=\sqrt{2[c_{\text{Fe}}(T_{\text{melt}}-T_{\text{i}})+L_{\text{F}}]}=\sqrt{2[(450\text{ J/kg}\cdot\text{C°})(1538\text{°C}-(-105\text{°C}))+2.89\times10^5\text{ J/kg}]}$$

$$=\boxed{1430\text{ m/s}}$$

55. We assume that the lightbulb emits energy by radiation, so Eq. 14–7 applies. Use the data for the 75-W bulb to calculate the product $\varepsilon\sigma A$ for the bulb, and then calculate the temperature of the 150-W bulb.

$$(Q/t)_{75\text{ W}}=\sigma A\left(T_{75\text{ W}}^4-T_{\text{room}}^4\right)\quad\rightarrow$$

$$\varepsilon\sigma A=\frac{(Q/t)_{75\text{ W}}}{\left(T_{75\text{ W}}^4-T_{\text{room}}^4\right)}=\frac{(0.90)(75\text{ W})}{[(273+75)\text{K}]^4-[(273+18)\text{K}]^4}=9.006\times10^{-9}\text{ W/K}^4$$

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

$$T_{150\text{ W}}=\left[\frac{(Q/t)_{150\text{ W}}}{e\sigma A}+T_{\text{room}}^4\right]^{1/4}=\left[\frac{(0.90)(150\text{ W})}{(9.006\times10^{-9}\text{ W/K}^4)}+(291\text{ K})^4\right]^{1/4}$$

$$=386\text{ K}=113\text{°C}\approx\boxed{110\text{°C}}$$

56. 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, $Q=mc\Delta T$.

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

$$t=\frac{mc\Delta T}{P}=\frac{(65\text{ kg})(3470\text{ J/kg}\cdot\text{C°})(36.6\text{°C}-35.6\text{°C})}{200\text{ W}}=1128\text{ s}\approx\boxed{1100\text{ s}}=19\text{ min}$$

57. 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 to 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.

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

$$\left(1000\text{ W/m}^2\right)\varepsilon A_{\text{absorb}}\cos\theta=\varepsilon\sigma A_{\text{radiate}}\left(T_1^4-T_2^4\right)+\frac{m_{\text{H}_2\text{O}}L_{\text{evaporation}}}{\Delta t}\quad\rightarrow$$

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

$$= (0.85)\left(40\times10^{-4}\ \text{m}^2\right)\frac{\left(1000\ \text{W/m}^2\right)(1) - 2\left(5.67\times10^{-8}\ \text{W/m}^2\cdot\text{K}^4\right)\left[(308\ \text{K})^4 - (297\ \text{K})^4\right]}{\left(2.45\times10^6\ \text{J/kg}\right)}$$

$$= 1.196\times10^{-6}\ \text{kg/s}\left(\frac{1000\ \text{g}}{1\ \text{kg}}\right)\left(\frac{3600\ \text{s}}{1\ \text{h}}\right) = \boxed{4.3\ \text{g/h}}$$

58. (*a*) The amount of heat energy required is given by Eq. 14–2. One liter of water has a mass of 1 kg.

$$Q = mc\Delta T = (245\ \text{kg})(4186\ \text{J/kg}\cdot\text{C°})(45\text{°C} - 10\text{°C}) = 3.589\times10^7\ \text{J} \approx \boxed{3.6\times10^7\ \text{J}}$$

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

$$Q = Pt \rightarrow t = \frac{Q}{P} = \frac{3.589\times10^7\ \text{J}}{9.5\times10^3\ \text{W}} = 3778\ \text{s} \approx \boxed{3800\ \text{s}} \approx 63\ \text{min}$$

59. We model the heat loss as conductive, so that, using Eq. 14–5, $\frac{Q}{t} = \frac{kA}{\ell}\Delta T \rightarrow Q = \alpha t\Delta T$, where α describes the average heat conductivity properties of the house, such as insulation materials and surface area of the conducting surfaces. It could have units of $\text{J/h}\cdot\text{°C}$. We see that the heat loss is proportional to the product of elapsed time and the temperature difference. We assume that the proportionality constant α does not vary during the day, so that, for example, heating by direct sunlight through windows is not considered. We also assume that α is independent of temperature, so it is the same during both the day and the night.

$$Q_{\substack{\text{turning}\\\text{down}}} = (\alpha\ \text{J/h}\cdot\text{C°})(15\ \text{h})(22\text{°C} - 8\text{°C}) + (\alpha\ \text{J/h}\cdot\text{C°})(9\ \text{h})(16\text{°C} - 0\text{°C}) = 354\alpha\ \text{J}$$

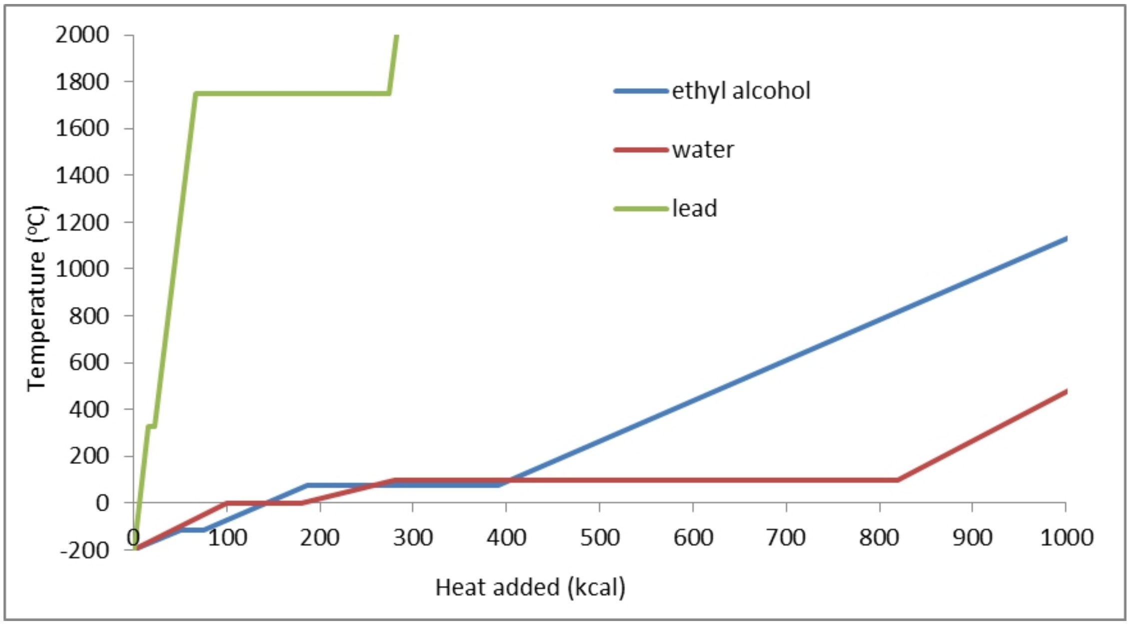
$$Q_{\substack{\text{not turning}\\\text{down}}} = (\alpha\ \text{J/h}\cdot\text{C°})(15\ \text{h})(22\text{°C} - 8\text{°C}) + (\alpha\ \text{J/h}\cdot\text{C°})(9\ \text{h})(22\text{°C} - 0\text{°C}) = 408\alpha\ \text{J}$$

$$\frac{\Delta Q}{Q_{\substack{\text{turning}\\\text{down}}}} = \frac{408\alpha\ \text{J} - 354\alpha\ \text{J}}{354\alpha\ \text{J}} = 0.1525 \approx \boxed{15,}$$

Keeping the thermostat "up" in this model requires about 15% more heat than turning it down.

Solutions to Search and Learn Problems

1.



We chose a starting temperate of $-200°\mathrm{C}$, so that all three substances would be in the solid state. Lead has small specific and latent heats, so the temperature of lead increases rapidly as a function of input heat. Water has the largest specific and latent heats and therefore has the smallest temperature increase. There is no temperature range for which water, lead, and ethyl alcohol are all liquid. All three are solids at temperatures below $-114°\mathrm{C}$. All three are gases for temperatures above 1750°C.

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

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

(*b*) Use Eq. 14–7 to calculate the rate of heat output by radiation, and assume that the temperature of space is 0 K. The whole sphere is radiating heat back into space, so we use the full surface area of the Earth, $4\pi R_{\text{Earth}}^2$.

$$\frac{Q}{t} = \varepsilon\sigma A T^4 \quad\rightarrow\quad T = \left(\frac{Q}{t}\frac{1}{\varepsilon\sigma A}\right)^{1/4}$$

$$= \left[(1.73\times10^{17}\ \text{J/s})\frac{1}{(1.0)(5.67\times10^{-8}\ \text{W/m}^2\cdot\text{K}^4)4\pi(6.38\times10^6\ \text{m})^2}\right]^{1/4} = \boxed{278\ \text{K} = 5°\text{C}}$$

3. (*a*) To calculate heat transfer by conduction, use Eq. 14–5 for all three areas—walls, roof, and windows. Each area has the same temperature difference.

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

$$= \left[\frac{(0.023\ \text{J/s}\cdot\text{m}\cdot\text{C}^\circ)(410\ \text{m}^2)}{0.195\ \text{m}} + \frac{(0.1\ \text{J/s}\cdot\text{m}\cdot\text{C}^\circ)(250\ \text{m}^2)}{0.055\ \text{m}} + \frac{(0.84\ \text{J/s}\cdot\text{m}\cdot\text{C}^\circ)(33\ \text{m}^2)}{6.5\times10^{-3}\ \text{m}} \right](38\ \text{C}^\circ)$$

$$= 1.812\times10^5\ \text{W} \approx \boxed{1.8\times10^5\ \text{W}}$$

(*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, $Q_{\substack{\text{raise}\\\text{temp}}} = m_{\text{air}}c_{\text{air}}(\Delta T)_{\text{warming}}$. 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, if we assume the outside temperature is still $-15°\text{C}$, varies from $30\ \text{C}^\circ$ to $38\ \text{C}^\circ$. We will estimate the average temperature difference as $34\,\text{C}^\circ$ and scale the answer from part (*a*) accordingly.

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

$$= \left(1.29\frac{\text{kg}}{\text{m}^3}\right)(750\text{m}^3)\left(0.24\frac{\text{kcal}}{\text{kg}\cdot\text{C}^\circ}\right)\left(\frac{4186\ \text{J}}{\text{kcal}}\right)(8°\text{C})$$

$$+\left(1.812\times10^5\frac{\text{J}}{\text{s}}\right)\left(\frac{34°\text{C}}{38°\text{C}}\right)(1800\ \text{s}) = 2.996\times10^8\ \text{J} \approx \boxed{3.0\times10^8\ \text{J}}$$

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

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

$$Q_{\text{gas}} = \frac{1}{0.9}\left(\frac{Q}{t}\right)_{\text{conduction}} t_{\text{month}} = \frac{1}{0.9}(1.812\times10^5\ \text{J/s})(30\ \text{days})\left(\frac{24\ \text{h}}{1\ \text{day}}\right)\left(\frac{3600\ \text{s}}{1\ \text{h}}\right) = 5.219\times10^{11}\ \text{J}$$

$$5.276\times10^{11}\ \text{J}\left(\frac{1\ \text{kg}}{5.4\times10^7\ \text{J}}\right)\left(\frac{\$0.080}{\text{kg}}\right) = \$773.12 \approx \boxed{\$770}$$

As an extra comment, almost 90% of the heat loss is through the windows. Investing in insulated window drapes and double-paned windows in order to reduce the thermal conductivity of the windows could mean major savings for this homeowner.