Section 1 Temperature, Heat, and Thermal Energy: Practice Problems

1. When you turn on the hot water to wash dishes, the water pipes heat up. How much heat is absorbed by a copper water pipe with a mass of 2.3 kg when its temperature is raised from 20.0°C to 80.0°C?

SOLUTION:

$$\begin{aligned} Q &= mC\Delta T \\ &= (2.3\ \text{kg})(385\ \text{J/(kg}\cdot\text{K)}) \\ &\quad (80.0°\text{C} - 20.0°\text{C}) \\ &= 5.3\times10^{4}\ \text{J} \end{aligned}$$

2. Electric power companies sell electrical energy by the kWh, where 1 kWh = 3.6×10^{6} J. Suppose that it costs $0.15 per kWh to run an electric water heater in your neighborhood. How much does it cost to heat 75 kg of water from 15°C to 43°C to fill a bathtub?

SOLUTION:

$$\begin{aligned} Q &= mC\Delta T \\ &= (75\ \text{kg})(4180\ \text{J/(kg}\cdot\text{K)}) \\ &\quad (43°\text{C} - 15°\text{C}) \\ &= 8.8\times10^{6}\ \text{J} \end{aligned}$$

$$\frac{8.8\times10^{6}\ \text{J}}{3.6\times10^{6}\ \text{J/kWh}} = 2.4\ \text{kWh}$$

$$(2.4\ \text{kWh})(\$0.15\ \text{per kWh}) = \$0.36$$

3. **Challenge** A car engine's cooling system contains 20.0 L of water (1 L of water has a mass of 1 kg).

a. What is the change in the temperature of the water if 836.0 kJ of thermal energy is added?
b. Suppose that it is winter, and the car's cooling system is filled with methanol. The density of methanol is 0.80 g/cm^3. What would be the increase in temperature of the methanol if it absorbed 836.0 kJ of thermal energy?
c. Which coolant, water or methanol, would better remove thermal energy from the car engine? Explain.

SOLUTION:
a.

$$Q = mC\Delta T$$
$$\Delta T = \frac{Q}{mC} = \frac{(8.36\times10^5\ \text{J})}{(20.0\ \text{kg})(4180\ \text{J/(kg·K)})} = 10.0\ \text{K}$$

b. The mass of methanol would be 0.80 times the mass of 20.0 L of water, or 16 kg.

$$Q = mC\Delta T$$
$$\Delta T = \frac{Q}{mC} = \frac{8.36\times10^5\ \text{J}}{(16\ \text{kg})(2450\ \text{J/(kg·K)})} = 21\ \text{K}$$

c. For temperatures above 0°C, water is the better coolant because it can absorb heat without changing its temperature as much as methanol does.

4. A 1.00×10^{2}-g aluminum block at 100.0°C is placed in 1.00×10^{2} g of water at 10.0°C. The final temperature of the mixture is 26.0°C. What is the specific heat of the aluminum?

SOLUTION:

$$m_W C_W (T_f - T_W) + m_{Al} C_{Al} (T_f - T_{Al}) = 0$$

$$\begin{aligned} C_{Al} &= \frac{m_W C_W (T_f - T_W)}{m_{Al} (T_{Al} - T_f)} \\ &= \frac{(0.100\ \text{kg})[4180\ \text{J/(kg}\cdot{}^\circ\text{C)}](26.0^\circ\text{C} - 10.0^\circ\text{C})}{(0.100\ \text{kg})(100.0^\circ\text{C} - 26.0^\circ\text{C})} \\ &= 9.04\times10^{2}\ \text{J/(kg}\cdot{}^\circ\text{C)} \end{aligned}$$

5. Three metal fishing weights, each with a mass of 1.00×10^{2} g and at a temperature of 100.0°C, are placed in 1.00×10^{2} g of water at 35.0°C. The final temperature of the mixture is 45.0°C. What is the specific heat of the metal in the weights?

SOLUTION:

$$m_W C_W (T_f - T_W) + m_M C_M (T_f - T_M) = 0$$

$$\begin{aligned} C_M &= \frac{m_W C_W (T_f - T_W)}{m_M (T_M - T_f)} \\ &= \frac{(0.1000\ \text{kg})[4180\ \text{J/(kg}\cdot{}^\circ\text{C)}](45.0^\circ\text{C} - 35.0^\circ\text{C})}{(0.300\ \text{kg})(100.0^\circ\text{C} - 45.0^\circ\text{C})} \\ &= 2.53\times10^{2}\ \text{J/(kg}\cdot{}^\circ\text{C)} \end{aligned}$$

6. A 2.00×10^2-g sample of water at 80.0°C is mixed with 2.00×10^2 g of water at 10.0°C in a calorimeter. What is the final temperature of the mixture?

SOLUTION:

$$m_A C_A (T_f - T_{Ai}) + m_B C_B (T_f - T_{Bi}) = 0$$

Since $m_A = m_B$ and $C_A = C_B$, there is cancellation in this particular case so that

$$T_f = \frac{T_{Ai} + T_{Bi}}{2}$$

$$= \frac{80.0°C + 10.0°C}{2}$$

$$= 45.0°C$$

7. A 1.50×10^2-g piece of glass at a temperature of 70.0°C is placed in a container with 1.00×10^2 g of water initially at a temperature of 16.0°C. What is the equilibrium temperature of the water?

SOLUTION:

$$m_W C_W (T_f - T_{Wi}) + m_A C_A (T_f - T_{Ai}) = 0$$

$$T_f = \frac{m_W C_W T_{Wi} + m_G C_G T_{Gi}}{m_W C_W + m_G C_G}$$

$$= \frac{(0.10\ kg)(4180\ J/(kg \cdot K))(16.0°C) + (0.15\ kg)(840\ J/(kg \cdot K))(70.0°C)}{} = 28.5°C$$

$$= \frac{\quad}{(0.10\ \text{kg})(4180\ \text{J/(kg·K)}) + (0.15\ \text{kg})(840\ \text{J/(kg·K)})}$$

8. **Challenge** A 4.00×10^2-g sample of water at 15.0°C is mixed with 4.00×10^2 g of water at 85.0°C. After the system reaches thermal equilibrium, 4.00×10^2 g of methanol at 15°C is added. Assume there is no thermal energy lost to the surroundings. What is the final temperature of the mixture?

SOLUTION:

Step 1:

$$m_A C_A (T_f - T_{Ai}) + m_B C_B (T_f - T_{Bi}) = 0$$

Since in this particular case, $m_A = m_B$, the masses cancel and

$$T_f = \frac{c_A T_{Ai} + c_B T_{Bi}}{c_A + c_B}$$

$$= \frac{(4180\ \text{J/(kg·K)})(15.0°\text{C}) + (4180\ \text{J/(kg·K)})(85.0°\text{C})}{4180\ \text{J/(kg·K)} + 4180\ \text{J/(kg·K)}} = 50.0°\text{C}$$

Step 2:

$$m_W C_W (T_f - T_{Wi}) + m_M C_M (T_f - T_{Mi}) = 0$$

$$T_f = \frac{m_W c_W T_{Wi} + m_M c_M T_{Mi}}{m_W c_W + m_M c_M}$$

$$= \frac{(0.800\ \text{kg})(4180\ \text{J/(kg·K)})(50.0°\text{C}) + (0.400\ \text{kg})(2450\ \text{J/(kg·K)})(85.0°\text{C})}{(0.800\ \text{kg})(4180\ \text{J/(kg·K)}) + (0.400\ \text{kg})(2450\ \text{J/(kg·K)})} = 57.9°\text{C}$$

Section 1 Temperature, Heat, and Thermal Energy: Review

9. **MAIN IDEA** The hard tile floor of a bathroom always feels cold to bare feet even though the rest of the room is warm. Is the floor colder than the rest of the room?

SOLUTION:

The floor is usually at the same temperature as the rest of the room, but the tile conducts heat more efficiently than most materials, so it conducts heat from a person's feet, making them feel cold.

Chapter 12 Practice Problems, Review, and Assessment

10. **Temperature** Make the following conversions:

a. 5°C to kelvins
b. 34 K to degrees Celsius
c. 212°C to kelvins
d. 316 K to degrees Celsius

SOLUTION:
a. 278 K

b. –239°C

c. 485 K

d. 43°C

11. **Units** Are the units the same for heat, (*Q*) and specific heat (*C*)? Explain.

SOLUTION:
No. Heat is measured in joules (J) and specific heat is measured in joules per kilograms-kelvin, J/(kg·K).

12. **Types of Energy** Describe the mechanical energy and the thermal energy of a bouncing basketball.

SOLUTION:
The basketball has kinetic energy when it is in motion and gravitational potential energy when it is above the ground. Some kinetic energy is transformed into thermal energy and sound energy when the basketball hits the ground. Its thermal energy depends on the total energy of its particles.

13. **Thermal Energy** Could the thermal energy of a bowl of hot water equal that of a bowl of cold water? Explain your answer.

SOLUTION:
Thermal energy is the measure of the total energy of all the molecules in an object. The temperature (hot or cold) measures the amount of energy per molecule. If the bowls are identical and contain the same amount of water, they have the same number of molecules, but the bowl of hot water has more total thermal energy. However, if the cold water mass is slightly more than that of the hot water, the two energies could be equal.

14. **Cooling** On a dinner plate, a baked potato always stays hot longer than any other food. Why?

SOLUTION:
A potato has a large specific heat and conducts heat poorly, so it loses its thermal energy slowly.

15. **Heat and Food** It takes much longer to bake a whole potato than potatoes that have been cut into pieces. Why?

SOLUTION:
Potatoes do not conduct thermal energy well. Increasing surface area by cutting a potato into small parts increases the thermal energy flow into the potato.

16. **Cooking** Stovetop pans are made from metals such as copper, iron, and aluminum. Why are these materials used?

SOLUTION:
They are good thermal conductors and have relatively low specific heats.

17. **Specific Heat** If you take a plastic spoon out of a cup of hot cocoa and put it in your mouth, you are not likely to burn your tongue. However, you could very easily burn your tongue if you put the hot cocoa in your mouth. Why?

SOLUTION:
The plastic spoon has a lower specific heat than the cocoa, so it does not transmit much thermal energy to your tongue.

18. **Critical Thinking** As water heats in a pot on a stove, it might produce some mist above its surface right before the water begins to roll. What is happening?

SOLUTION:

Some of the water molecules are evaporating at the surface of the liquid. When the warm molecules contact the cold air above the pot, the molecules condense into liquid water again, forming a mist above the pot.

Section 2 Changes of State and Thermodynamics: Practice Problems

19. How much thermal energy is absorbed by 1.00×10^{2} g of ice at –20.0°C to become water at 0.0°C?

SOLUTION:

$$Q = mC\Delta T + mH_f$$
$$= (0.100\ \text{kg})(2060\ \text{J/kg}\cdot{}^\circ\text{C})(20.0^\circ\text{C}) + (0.100\ \text{kg})(3.34\times10^{5}\ \text{J/kg})$$
$$= 3.75\times10^{4}\ \text{J}$$

20. A 2.00×10^{2}-g sample of water at 60.0°C is heated to water vapor at 140.0°C. How much thermal energy is absorbed?

SOLUTION:

$$Q = mC_{\text{water}}\Delta T + mH_{\text{v}} + mC_{\text{vapor}}\Delta T$$
$$= (0.200\ \text{kg})(4180\ \text{J/kg}\cdot{}^\circ\text{C})(100.0^\circ\text{C} - 60.0^\circ\text{C}) + (0.200\ \text{kg})(2.26\times10^{6}\ \text{J/kg}) + (0.200\ \text{kg})(2020\ \text{J/kg}\cdot{}^\circ\text{C})(140.0^\circ\text{C} - 100.0^\circ\text{C})$$
$$= 502\ \text{kJ}$$

Chapter 12 Practice Problems, Review, and Assessment

21. Use the graph in **Figure 15** to calculate the heat of fusion and heat of vaporization of water.

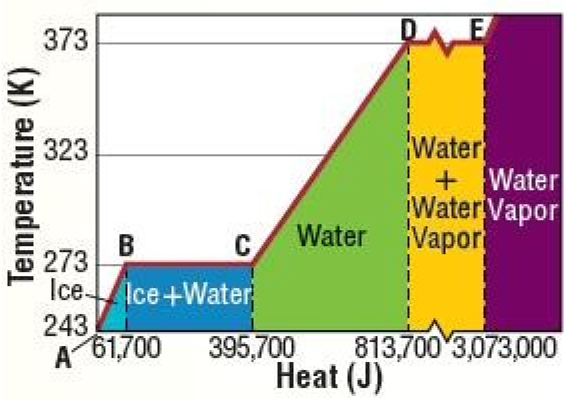

Figure 15

SOLUTION:

H_f **= 395,700 J – 61,700 J = 334,000 J**

H_v **= 3,073,000 J – 813,700 J = 2,259,000 J**

22. A steel plant operator wishes to change 100 kg of 25°C iron into molten iron (melting point = 1538°C). How much thermal energy must be added?

SOLUTION:

$$\begin{aligned} Q &= Q_{\text{heat iron}} + Q_{\text{melt iron}} \\ &= mC_{\text{iron}}\Delta T + mH_{\text{f iron}} \\ &= (100 \text{ kg})(450 \text{ J/(kg}\cdot{}^\circ\text{C)})(1538^\circ\text{C} - 25^\circ\text{C}) + (100 \text{ kg})(2.66\times10^5 \text{ J/kg}) \\ &= 9.5\times10^7 \text{ J} \end{aligned}$$

23. **Challenge** How much thermal energy is needed to change 3.00×10^2 g of ice at –30.0°C to water vapor at 130.0° C?

SOLUTION:

$$\begin{aligned}Q &= mC_{ice}\Delta T + mH_f + mC_{water}\Delta T + mH_v + mC_{vapor}\Delta T\\ &= (0.300\text{ kg})(2060\text{ J/kg•°C})(0.0°\text{C} - (-30.0°\text{C}))\\ &\quad + (0.300\text{ kg})(3.34\times10^5\text{ J/kg})\\ &\quad + (0.300\text{ kg})(4180\text{ J/kg•°C})(100.0°\text{C} - 0.0°\text{C})\\ &\quad + (0.300\text{ kg})(2.26\times10^6\text{ J/kg})\\ &\quad + (0.300\text{ kg})(2020\text{ J/kg•°C})(130.0°\text{C} - 100.0°\text{C})\\ &= 9.40\times10^2\text{ kJ}\end{aligned}$$

24. A gas balloon absorbs 75 J of thermal energy. The balloon expands but stays at the same temperature. How much work did the balloon do in expanding?

SOLUTION:

$\Delta U = Q - W$

Since the balloon did not change temperature, $\Delta U = 0$.

Therefore, $Q = W$.

Thus, the balloon did 75 J of work in expanding.

25. A drill bores a small hole in a 0.40-kg block of aluminum and heats the aluminum by 5.0°C. How much work did the drill do in boring the hole?

SOLUTION:

$\Delta U = Q - W_{block}$**; since** $W_{drill} = -W$

and assume no heat added to drill:

$\Delta U = 0 + W_{drill} = mC\Delta T$

$W_{drill} = (0.40\text{ kg})(897\text{ J/kg•°C})(5.0°\text{C})$

$= 1.8\times10^3$ J

26. How many times would you have to drop a 0.50-kg bag of lead shot from a height of 1.5 m to heat the shot by 1.0°C?

SOLUTION:

$$\Delta U = mC\Delta T$$
$$= (0.50\text{ kg})(130\text{ J/kg}\cdot{}^\circ\text{C})(1.0^\circ\text{C})$$
$$= 65\text{ J}$$

Each time the bag is raised its potential energy is

$$PE = mgh$$
$$= (0.50\text{ kg})(9.8\text{ N/kg})(1.5\text{ m})$$
$$= 7.4\text{ J}$$

When the bag hits the ground this energy is (mostly) transmitted as work on the lead shot.

The number of drops is

$$\frac{65\text{ J}}{7.4\text{ J}} = 9\text{ drops}$$

27. When you stir a cup of tea, you do about 0.050 J of work each time you circle the spoon in the cup. How many times would you have to stir the spoon to heat a 0.15-kg cup of tea by 2.0°C?

SOLUTION:

$$\Delta U = mc\Delta T$$
$$= (0.15\text{ kg})(4180\text{ J/kg}\cdot{}^\circ\text{C})(2.0^\circ\text{C})$$
$$= 1.3\times10^{3}\text{ J}$$

The number of stirs is

$$\frac{1.3\times10^{3}\text{ J}}{0.050\text{ J}} = 2.6\times10^{4}\text{ stirs}$$

28. **Challenge** An expansion valve does work on 100 g of water. The system is isolated, and all of the work is used to convert the 90°C water into water vapor at 110°C. How much work does the expansion valve do on the water?

SOLUTION:

$$W = \Delta U = mc_w\Delta T_w + mH_v + mc_s\Delta T_s$$
$$= (0.1\text{ kg})(4180\text{ J/kg}\cdot°\text{C})(100 - 90°\text{C})$$
$$+ (0.1\text{ kg})(2.26\times10^6\text{ J/kg})$$
$$+ (0.1\text{ kg})(2020\text{ J/kg}\cdot°\text{C})(110 - 100°\text{C})$$
$$= 200\text{ kJ}$$

Section 2 Changes of State and Thermodynamics: Review

29. **MAIN IDEA** Describe the energy transformations and transfers made by a heat engine, and explain why operating a heat engine causes an increase in entropy.

SOLUTION:

Some of the thermal energy from the hot reservoir is used to do work (transformation to mechanical energy) and some is transferred to the cold reservoir. Entropy is increased whenever thermal energy flows from a warmer object to a cooler object.

30. **Heat of Vaporization** Old heating systems sent water vapor into radiators in each room of a house. In the radiators, the water vapor condensed to water. Analyze this process and explain how it heated a room.

SOLUTION:

The condensing steam released its heat of vaporization into the room and was then circulated back to the boiler.

31. **Heat of Fusion** How much thermal energy is needed to change 50.0 g of ice at –20.0°C to water at 10.0°C?

SOLUTION:

$$Q = mC_{\text{ice}}\Delta T + mH_v + mC_{\text{water}}\Delta T$$
$$= (0.0500\text{ kg})(2060\text{ J/kg}\cdot°\text{C})(0.0°\text{C} - (-20.0°\text{C}))$$
$$+ (0.0500\text{ kg})(3.34\times10^5\text{ J/kg})$$
$$+ (0.0500\text{ kg})(4180\text{ J/kg}\cdot°\text{C})(10.0°\text{C} - 0.0°\text{C})$$
$$= 20.8\text{ kJ}$$

32. **Heat of Vaporization** How much energy is needed to heat 1.0 kg of mercury metal from 10.0°C to its boiling point (357°C) and vaporize it completely? For mercury, C = 140 J/(kg·°C) and $H_v = 3.06\times10^5$ J/kg.

SOLUTION:

$$\begin{aligned} Q &= mC_{Hg}\Delta T + mH_v \\ &= (1.0\text{ kg})(140\text{ J/kg}\cdot°\text{C})(357°\text{C} - 10.0°\text{C}) \\ &\quad + (1.0\text{ kg})(3.06\times10^5\text{ J/kg}) \\ &= 3.5\times10^5\text{ J} \end{aligned}$$

33. **Mechanical Energy and Thermal Energy** A man uses a 320-kg hammer moving at 5.0 m/s to smash a 3.0-kg block of lead against a 450-kg rock. When he measured the temperature of the lead block he found that it had increased by 5.0°C. Explain how this happened.

SOLUTION:

Part of the kinetic energy of the hammer is absorbed as thermal energy by the lead block. The hammer's energy is

$$\frac{1}{2}mv^2 = \frac{1}{2}(320\text{ kg})(5.0\text{ m/s})^2 = 4.0\text{ kJ.}$$

The change in thermal energy of the block is

$$\begin{aligned} \Delta U &= mC\Delta T \\ &= (3.0\text{ kg})(130\text{ J/kg}\cdot°\text{C})(5.0°\text{C}) \\ &= 2.0\text{ kJ} \end{aligned}$$

Hence, about half of the hammer's energy went to the lead block.

34. **Mechanical Energy and Thermal Energy** James Joule carefully measured the difference in temperature of water at the top and the bottom of a waterfall. Why did he expect a difference?

SOLUTION:

The water at the top has gravitational potential energy that is dissipated into thermal energy when the water splashes at the bottom. The water should be hotter at the bottom, but not by much.

35. **Mechanical Energy and Thermal Energy** For the waterfall in **Figure 23,** calculate the temperature difference between the water at the top and the bottom of the fall. Assume that the potential energy of the water is all converted to thermal energy.

Figure 23

SOLUTION:

$$PE_{\text{gravity}} = Q_{\text{absorbed by water}}$$
$$mgh = mC\Delta T$$
$$\Delta T = \frac{gh}{C} = \frac{(9.8\ \text{N/kg})(125.0\ \text{m})}{4180\ \text{J/kg}\cdot{}^\circ\text{C}}$$
$$= 0.293^\circ\text{C rise in temperature at the bottom}$$

36. **Entropy** Evaluate why heating a home with natural gas results in increased entropy.

SOLUTION:

The gas releases heat, *Q*, at its combustion temperature, *T*. The natural gas molecules break up and combust with oxygen. The thermal energy is distributed in many new ways, and the natural gas molecules cannot readily be reassembled.

37. **Critical Thinking** Many outdoor amusement parks and zoos have systems that spray a fine mist of water, which evaporates quickly. Explain why this process cools the surrounding air.

SOLUTION:

When the water evaporates, it absorbs thermal energy from the air.

Chapter Assessment
Section 1 Temperature, Heat, and Thermal Energy: Mastering Concepts

38. **BIG IDEA** Explain the differences among the mechanical energy of a ball, its thermal energy, and its temperature.

SOLUTION:

The mechanical energy is the sum of the potential and kinetic energies of the ball considered as one mass. The thermal energy is the sum of the potential and kinetic energies of the individual particles that make up the mass of the ball. The temperature is a measure of the average kinetic energy of the particles of the ball.

39. Can temperature be assigned to a vacuum? Explain.

SOLUTION:

No, there are no particles that have energy in a vacuum.

40. Do all of the molecules or atoms in a liquid have the same speed?

SOLUTION:

No. There is a distribution of velocities of the atoms or molecules.

41. Is your body a good judge of temperature? On a cold winter day, a metal doorknob feels much colder to your hand than a wooden door does. Explain why this is true.

SOLUTION:

Your skin measures thermal energy flow to or from itself. The metal doorknob absorbs thermal energy from your skin faster than the wooden door, so it feels colder even if the door and the knob are at the same temperature.

42. When thermal energy is transferred from a warmer object to a colder object it is in contact with, do the two have the same temperature changes?

SOLUTION:

The two objects will change temperatures depending on their masses and specific heats and will eventually reach the same temperature. The temperature changes are not necessarily the same for each.

Chapter Assessment
Section 1 Temperature, Heat, and Thermal Energy: Mastering Problems

43. How much thermal energy is needed to raise the temperature of 50.0 g of water from 4.5°C to 83.0°C? (Level 1)

SOLUTION:

$$Q = mC\Delta T$$
$$= (0.0500\text{ kg})(4180\text{ J/kg}\cdot{}^\circ\text{C})(83.0^\circ\text{C} - 4.5^\circ\text{C})$$
$$= 1.64 \times 10^4\text{ J}$$

44. **Coffee Cup** A glass coffee cup is at room temperature. It is then plunged into hot dishwater, as shown in **Figure 24.** If the temperature of the cup reaches that of the dishwater, how much thermal energy does the cup absorb? Assume that the mass of the dishwater is large enough so that its temperature does not change appreciably. (Level 1)

Figure 24

SOLUTION:

$$Q = mC\Delta T$$
$$= (4.00 \times 10^{-1}\text{ kg})(840\text{ J/kg}\cdot{}^\circ\text{C})(80.0^\circ\text{C} - 20.0^\circ\text{C})$$
$$= 2.02 \times 10^4\text{ J}$$

45. A 1.00×10^{2}-g mass of tungsten at 100.0°C is placed in 2.00×10^{2} g of water at 20.0°C. The mixture reaches equilibrium at 21.2°C. Calculate the specific heat of tungsten. (Level 1)

SOLUTION:

$\Delta Q_T + \Delta Q_W = 0$

Where T stands for tungsten and W stands for water.

or $m_T C_T \Delta T_T = -m_W C_W \Delta T_W$

$$C_T = \frac{-m_W C_W \Delta T_W}{m_T \Delta T_T}$$

$$= \frac{-(0.200\text{ kg})(4180\text{ J/kg•K})(21.2°\text{C} - 20.0°\text{C})}{(0.100\text{ kg})(21.2°\text{C} - 100.0°\text{C})}$$

$$= 127\text{ J/kg•K}$$

46. A 6.0×10^{2}-g sample of water at 90.0°C is mixed with 4.00×10^{2}-g of water at 22.0°C. Assume that there is no thermal energy lost to the container or surroundings. What is the final temperature of the mixture? (Level 1)

SOLUTION:

$$T_f = \frac{m_A C_A \Delta T_{AI} + m_B C_B \Delta T_{BI}}{m_A C_A + m_B C_B}$$

but $C_A = C_B$ **because both liquids are water, and the C's will divide out.**

$$T_f = \frac{m_A T_{AI} + m_B T_{BI}}{m_A + m_B}$$

$$= \frac{(6.0\times10^{2}\text{ g})(90.0°\text{C}) + (4.00\times10^{2}\text{ g})(22.0°\text{C})}{6.0\times10^{2}\text{ g} + 4.00\times10^{2}\text{ g}}$$

$$= 63°\text{C}$$

47. A 5.00×10^2-g block of metal absorbs 5016 J of thermal energy when its temperature changes from 20.0°C to 30.0°C. Calculate the specific heat of the metal. (Level 1)

SOLUTION:

$$Q = mC\Delta T$$

$$\text{so } C = \frac{Q}{m\Delta T}$$

$$= \frac{5016\text{ J}}{(5.00\times10^{-1}\text{ kg})(30.0°\text{C} - 20.0°\text{C})}$$

$$= 1.00\times10^3\text{ J/kg}\bullet°\text{C}$$

$$= 1.00\times10^3\text{ J/kg}\bullet\text{K}$$

48. The kinetic energy of a compact car moving at 100 km/h is 2.9×10^5 J. To get an idea of the amount of energy needed to heat water, how many liters of water would 2.9×10^5 J of energy warm from room temperature (20.0°C) to boiling (100.0°C)? (Level 2)

SOLUTION:

$$Q = mC\Delta T = \rho VC\Delta T$$

where ρ is the density of the material

$$\text{So, } V = \frac{Q}{\rho C\Delta T}$$

$$= \frac{2.9\times10^5\text{ J}}{(1.00\text{ kg/L})(4180\text{ J/kg}\bullet°\text{C})(100.0°\text{C} - 20.0°\text{C})}$$

$$= 0.87\text{ L}$$

49. **Car Engine** A 2.50×10^2-kg cast-iron car engine contains water as a coolant. Suppose that the engine's temperature is 35.0°C when it is shut off, and the air temperature is 10.0°C. The heat given off by the engine and water in it as they cool to air temperature is 4.40×10^6 J. What mass of water is used to cool the engine? (Level 2)

SOLUTION:

$$Q = m_W C_W \Delta T + m_i C_i \Delta T$$

$$m_W = \frac{Q - m_i C_i \Delta T}{C_W \Delta T}$$

$$= \frac{(4.4\times10^6\ \text{J}) - ((2.50\times10^2\ \text{kg})(450\ \text{J/kg}\bullet{}^\circ\text{C})(35.0^\circ\text{C} - 10.0^\circ\text{C}))}{(4180\ \text{J/kg}\bullet{}^\circ\text{C})(35.0^\circ\text{C} - 10.0^\circ\text{C})}$$

$$= 15\ \text{kg}$$

50. **Water Heater** An electric immersion heater is used to heat a cup of water, as shown in **Figure 25.** The cup is made of glass and contains 250 g of water at 15°C. How much time is needed to bring the water to the boiling point? Assume that the temperature of the cup is the same as the temperature of the water at all times and that no thermal energy is lost to the air. (Level 2)

Figure 25

SOLUTION:

$Q = m_G C_G \Delta T_G + m_W C_W \Delta T_W$

but $\Delta T_G = \Delta T_W$, so

$Q = (m_G C_G + m_W C_W)\Delta T$

$= ((0.300\text{ kg})(840\text{ J/kg}\cdot°\text{C}) + (0.250\text{ kg})(4180\text{ J/kg}\cdot°\text{C}))(100.0°\text{C} - 15°\text{C})$

$= 1.1\times10^5\text{ J}$

Now $P = \frac{E}{t} = \frac{Q}{t}$, so

$t = \frac{Q}{P} = \frac{1.1\times10^5\text{ J}}{3.00\times10^2\text{ J/s}}$

= 370 s = 6.2 min

51. **Ranking Task** The following materials are each placed in identical containers holding equal amounts of room-temperature methanol. Rank the materials according to the amount of thermal energy they transfer to the methanol, from least to greatest. Specifically indicate any ties. (Level 2)

A. 50 g of aluminum at 30°C
B. 60 g of aluminum at 40°C
C. 50 g of glass at 30°C
D. 50 g of silver at 30°C
E. 50 g of zinc at 30°C

SOLUTION:

For each substance:

$$Q = mC(T_f - T_i)$$

But, $$T_f = \frac{mCT_i + m_m C_m T_{mi}}{mC + m_m C_m}$$

So, $$Q = mC\left(\frac{mCT_i + m_m C_m T_{mi}}{mC + m_m C_m} - T_i\right) = mC\left(\frac{m_m C_m T_{mi} - m_m C_m T_i}{mC + m_m C_m}\right)$$

$$= \left(\frac{(mC)(m_m C_m)}{mC + m_m C_m}\right)(T_{mi} - T_i)$$

Thus, D < E < C < A < B.

52. A piece of zinc at 71.0°C is placed in a container of water, as shown in **Figure 26.** What is the final temperature of the water and the zinc? (Level 1)

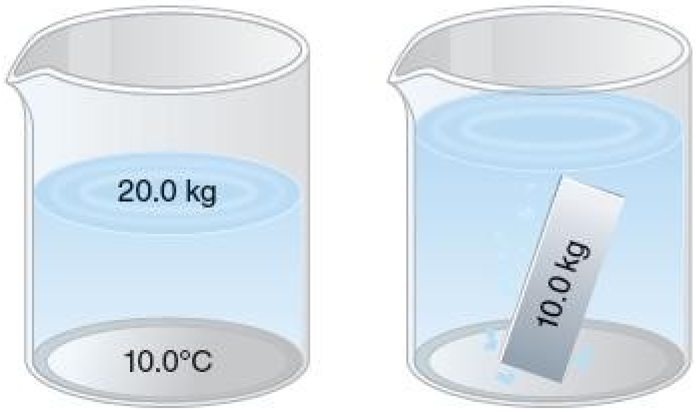

Figure 26

SOLUTION:

$$T_f = \frac{m_A C_A T_{Ai} + m_B C_B T_{Bi}}{m_A C_A + m_B C_B}$$

$$= \frac{(10.0\ \text{kg})(388\ \text{J/kg}\cdot\text{K})(71.0°\text{C}) + (20.0\ \text{kg})(4180\ \text{J/kg}\cdot\text{K})(10.0°\text{C})}{(10.0\ \text{kg})(388\ \text{J/kg}\cdot\text{K}) + (20.0\ \text{kg})(4180\ \text{J/kg}\cdot\text{K})}$$

$$= 12.7°\text{C}$$

Chapter Assessment
Section 2 Changes of State and Thermodynamics: Mastering Concepts

53. Can you add thermal energy to an object without increasing its temperature? Explain.

SOLUTION:
Yes. When you melt a solid or boil a liquid, you add thermal energy without changing the temperature.

54. When wax freezes, does it absorb or release energy?

SOLUTION:
When wax freezes, it releases energy.

55. Explain why water in a canteen that is surrounded by dry air stays cooler if it has a canvas cover that is kept wet.

SOLUTION:

When the water in the cover evaporates into the dry air, it must absorb an amount of thermal energy proportional to its heat of fusion. In doing so, it cools off the canteen. This works only if the air is dry; if the air is humid, then the water will not evaporate.

56. Which process occurs at the coils of a running air conditioner inside a house, vaporization or condensation? Explain.

SOLUTION:

Inside the house, the coolant is evaporating in the coils to absorb energy from the rooms.

Chapter Assessment
Section 2 Changes of State and Thermodynamics: Mastering Problems

57. Years ago, a block of ice with a mass of about 20.0 kg was used daily in a home icebox. The temperature of the ice was 0.0°C when it was delivered. As it melted, how much thermal energy did the ice absorb? (Level 1)

SOLUTION:

$$Q = mH_f$$
$$= (20.0\ \text{kg})(3.34 \times 10^5\ \text{J/kg})$$
$$= 6.68 \times 10^6\ \text{J}$$

58. A 40.0-g sample of chloroform is condensed from a vapor to a liquid at 61.6°C. It releases 9870 J of thermal energy. What is the heat of vaporization of chloroform? (Level 1)

SOLUTION:

$$Q = mH_v$$
$$H_v = \frac{Q}{m} = \frac{9870\ \text{J}}{0.0400\ \text{kg}}$$
$$= 2.47 \times 10^5\ \text{J/kg}$$

59. A 750-kg car moving at 23 m/s brakes to a stop. Assume that all the kinetic energy is transformed into thermal energy. The brakes contain about 15 kg of iron, which absorbs the energy. What is the increase in temperature of the brakes? (Level 1)

SOLUTION:

During braking, the kinetic energy of the car is converted into heat energy.

So,

$\Delta KE_C + Q_B = 0.0$, and $\Delta KE_C + m_B C_B \Delta T = 0.0$

so,

$$\Delta T = \frac{-\Delta KE_C}{m_B C_B} = -\frac{\frac{1}{2} m_C \left(v_f^2 - v_1^2\right)}{m_B C_B}$$

$$= -\frac{\frac{1}{2}(750\ \text{kg})\left(0.0^2 - (23\ \text{m/s})^2\right)}{(15\ \text{kg})(450\ \text{J/kg}\bullet{}^\circ\text{C})}$$

$$= 29^\circ\text{C}$$

60. How much thermal energy is added to 10.0 g of ice at –20.0°C to convert it to water vapor at 120.0°C? (Level 2)

SOLUTION:

Amount of heat needed to heat ice to 0.0°C:

$$Q = mC\Delta T$$
$$= (0.0100\text{ kg})(2060\text{ J/kg}\cdot{}^\circ\text{C})(0.0^\circ\text{C} - (-20.0^\circ\text{C}))$$
$$= 412\text{ J}$$

Amount of heat to melt ice:

$$Q = mH_v$$
$$= (0.0100\text{ kg})(3.34\times10^5\text{ J/kg})$$
$$= 3.34\times10^3\text{ J}$$

Amount of heat to heat water to 100.0°C:

$$Q = mC\Delta T$$
$$= (0.0100\text{ kg})(4180\text{ J/kg}\cdot\text{C})(100.0^\circ\text{C} - 0.0^\circ\text{C})$$
$$= 4.18\times10^3\text{ J}$$

Amount of heat to boil water:

$$Q = mH_v$$
$$= (0.0100\text{ kg})(2.26\times10^6\text{ J/kg})$$
$$= 2.26\times10^4\text{ J}$$

Amount of heat to heat steam to 120.0°C:

$$Q = mC\Delta T$$
$$= (0.0100\text{ kg})(2020\text{ J/kg}\cdot{}^\circ\text{C})(120.0^\circ\text{C} - 100.0^\circ\text{C})$$
$$= 404\text{ J}$$

The total heat is

$$Q = 412\text{ J} + 3.34\times10^3\text{ J} + 4.18\times10^3\text{ J}$$
$$+ 2.26\times10^4\text{ J} + 404\text{ J}$$
$$= 3.09\times10^4\text{ J}$$

61. A 4.2-g lead bullet moving at 275 m/s strikes a steel plate and comes to a stop. If all its kinetic energy is converted to thermal energy and none leaves the bullet, what is its temperature change? (Level 2)

SOLUTION:

Because the kinetic energy is converted to thermal energy, $\Delta KE + Q = 0$. So

$\Delta KE = -m_B C_B \Delta T$ and

$$\Delta T = -\frac{\Delta KE}{m_B C_B} = \frac{-\frac{1}{2} m_B \left(v_f^2 - v_i^2\right)}{m_B C_B}$$

and the mass of the bullet divides out so

$$\begin{aligned}\Delta T &= \frac{-\frac{1}{2}\left(v_f^2 - v_i^2\right)}{C_B} \\ &= \frac{-\frac{1}{2}\left((0.0\text{ m/s})^2 - (275\text{ m/s})^2\right)}{130\text{ J/kg}\cdot{}^\circ\text{C}} \\ &= 290^\circ\text{C}\end{aligned}$$

62. **Soft Drink** A soft drink from Australia is labeled *Low-Joule Cola*. The label says "100 mL yields 1.7 kJ." The can contains 375 mL of cola. Chandra drinks the cola and then wants to offset this input of food energy by climbing stairs. How high must Chandra climb if her mass is 65.0 kg? (Level 2)

SOLUTION:

Chandra gained $(3.75)(1.7\text{ kJ}) = 6.4\times10^3$ J of energy from the drink.

To conserve energy, $E + \Delta PE = 0$ or $6.4\times10^3\text{ J} = -mg\Delta h$ so,

$$\begin{aligned}\Delta h &= \frac{6.4\times10^3\text{ J}}{-mg} \\ &= \frac{6.4\times10^3\text{ J}}{(-65.0\text{ kg})(-9.8\text{ N/kg})} \\ &= 1.0\times10^1\text{ m}\end{aligned}$$

which is about three flights of stairs

Chapter Assessment: Applying Concepts

63. **Cooking** Sally is cooking pasta in a pot of boiling water. Will the pasta cook faster if the water is boiling vigorously or if it is boiling gently?

SOLUTION:

It should make no difference. Either way, the water is at the same temperature.

64. Which liquid would an ice cube cool faster, water or methanol? Explain.

SOLUTION:

Methanol, because it has a lower specific heat; for a given mass and heat transfer, it generates a bigger ΔT since $Q = mC?T$.

65. Equal masses of aluminum and lead are heated to the same temperature. The pieces of metal are placed on a block of ice. Which metal melts more ice? Explain.

SOLUTION:

The specific heat of aluminum is much greater than that of lead; therefore, it melts more ice.

66. Why do easily vaporized liquids, such as acetone and methanol, feel cool to the skin?

SOLUTION:

As they evaporate, they absorb their heat of vaporization from the skin.

67. Explain why fruit growers spray their trees with water to protect the fruit from freezing when frost is expected.

SOLUTION:

The water on the leaves will not freeze until it can release its heat of fusion. This process keeps the leaves warmer longer. The heat capacity of the ice slows down the cooling below 0°C.

68. Two blocks of lead have the same temperature. Block A has twice the mass of block B. They are dropped into identical cups of water of equal temperatures. Will the two cups of water have equal temperatures after equilibrium is achieved? Explain.

SOLUTION:

The cup with block A will be hotter because block A contains more thermal energy.

69. **Windows** Often architects design most windows of a house on the north side. How does putting windows on the south side affect the heating and cooling of the house?

SOLUTION:

In the northern hemisphere, the sunlight comes from the south. In most places, it is easier to heat a house in winter than to cool the house in summer, so north-facing windows make it easier to keep a house cool in the summer while still letting indirect light in and warming the house somewhat during the winter.

Chapter Assessment: Mixed Review

70. What is the efficiency of an engine that outputs 1800 J/s while burning gasoline to produce 5300 J/s? How much waste heat does the engine produce per second? (Level 1)

SOLUTION:

$$\text{Efficiency} = \frac{W}{Q_H} \times 100 = \frac{1800\text{ J}}{5300\text{ J}} \times 100$$
$$= 34\%$$

The waste heat is

$$5300\text{ J/s} - 1800\text{ J/s} = 3500\text{ J/s}$$

71. **Stamping Press** A metal stamping machine in a factory does 2100 J of work each time it stamps out a piece of metal. Assume that the work changes only the metal's thermal energy. Each stamped piece is then dipped in a 32.0-kg vat of water for cooling. By how many degrees does the vat heat up each time a piece of stamped metal is dipped into it? (Level 1)

SOLUTION:

If we assume the 2100 J of work from the machine is absorbed as thermal energy in the stamped piece, then the vat must absorb 2100 J in the form of heat from each piece. No work is done on the water, only heat is transferred. The change in temperature of the water is given by

$$\Delta U = mC\Delta T,$$

Therefore,

$$\Delta T = \frac{\Delta U}{mC}$$
$$= \frac{2100\text{ J}}{(32.0\text{ kg})(4180\text{ J/kg}\cdot{}^\circ\text{C})}$$
$$= 0.016^\circ\text{C}.$$

72. **Problem Posing** Complete this problem so that it must be solved using the concept listed below: "A beaker of water has a temperature of 35°C…." (Level 2)

a. specific heat
b. entropy

SOLUTION:

a. Answers will vary. Possible form of the correct answer would be: "…There is 1.0 kg of water in the beaker. A 5.0 g piece of 0-degree C zinc is placed in it. What is the final temperature of the zinc and water?"

b. Answers will vary. Possible form of the correct answer would be: "…If 75 J of thermal energy are added to it, how much does its entropy increase?"

73. A 1500-kg automobile comes to a stop from 25 m/s. All the energy of the automobile is deposited in the brakes. Assuming that the brakes are about 45 kg of aluminum, what is the change in temperature of the brakes? (Level 2)

SOLUTION:

The energy change in the car is

$$\Delta KE = \frac{1}{2}(1500\text{ kg})(25\text{ m/s})^2 = 4.7\times10^5\text{ J.}$$

If all of this energy is transferred as work to the brakes, then $\Delta U = \Delta KE = mC\Delta T$.

Therefore,

$$\Delta T = \frac{\Delta KE}{mC} = \frac{4.7\times10^5\text{ J}}{(45\text{ kg})(897\text{ J/kg}\cdot{}^\circ\text{C})} = 12^\circ\text{C}$$

74. **Iced Tea** To make iced tea, you brew the tea with hot water and then add ice. If you start with 1.0 L of 90°C tea, how much ice is needed to cool it to 0°C? Would it be better to let the tea cool to room temperature before adding the ice?
(Level 2)

SOLUTION:

Heat lost by the tea

$$Q = mC\Delta T$$
$$= (1.0\ \text{kg})(4180\ \text{J/kg}\cdot\text{K})(90°\text{C})$$
$$= 376\ \text{kJ}$$

Amount of ice melted

$$m = \frac{Q}{H_f}$$
$$= \frac{376\ \text{kJ}}{334\ \text{kJ}} = 1.1\ \text{kg}$$

Thus, you need slightly more ice than tea, but this ratio would make watery tea. Let the tea cool to room temperature before adding the ice.

75. A block of copper comes in contact with a block of aluminum and come to thermal equilibrium, as shown in **Figure 27.** What are the relative masses of the blocks? (Level 2)

Figure 27

SOLUTION:

The heat lost from the copper equals the heat gained by the aluminum. The Δ*T* for the copper is -40.0°C and the aluminum heats by +40.0°C. Therefore,

$$m_{\text{copper}} c_{\text{copper}} = m_{\text{aluminum}} c_{\text{aluminum}}$$

$$\text{so, } \frac{m_{\text{copper}}}{m_{\text{aluminum}}} = \frac{c_{\text{aluminum}}}{c_{\text{copper}}}$$

$$= \frac{897 \text{ J/kg·K}}{385 \text{ J/kg·K}} = 2.33$$

The copper block has 2.33 times as much mass as the aluminum block.

76. Two copper blocks, each with a mass of 0.35 kg, slide toward each other at the same speed and collide. The two blocks come to a stop together after the collision. Their temperatures increase by 0.20°C as a result of the collision. Assume that all kinetic energy is transformed into thermal energy. What was their speed before the collision? (Level 2)

SOLUTION:
The change in internal energy of the blocks is

$$\Delta U = mC\Delta T$$
$$= (0.70\text{ kg})(385\text{ J/kg}\cdot°\text{C})(0.20°\text{C})$$
$$= 54\text{ J}$$

Therefore, 54 J equals the kinetic energy of the blocks before the collision.

$$54\text{ J} = (2)\left(\frac{1}{2}\right)mv^2$$
$$\text{So, } v = \sqrt{\frac{54\text{ J}}{0.35\text{ kg}}}$$
$$= 12\text{ m/s}$$

77. A 2.2-kg block of ice slides across a rough floor. Its initial velocity is 2.5 m/s, and its final velocity is 0.50 m/s. How much of the ice block melted as a result of the work done by friction? (Level 3)

SOLUTION:
The work done by friction equals the negative of the change in kinetic energy of the block, assuming not too much of the block melted.

$$\Delta KE = \frac{1}{2}(2.2\text{ kg})(0.50\text{ m/s})^2 - \frac{1}{2}(2.2\text{ kg})(2.5\text{ m/s})^2$$
$$= -6.6\text{ J}$$

Therefore, +6.6 J is added to the ice. The amount of ice melted is given by

$$m = \frac{KE}{H_f}$$
$$= \frac{6.6\text{ J}}{3.34\times10^5\text{ J/kg}}$$
$$= 2.0\times10^{-5}\text{ kg}$$

Chapter Assessment: Thinking Critically

78. **Analyze and Conclude** Chemists use calorimeters to measure the heat produced by chemical reactions. Suppose a chemist dissolves 1.0×10^{22} molecules of a powdered substance into a calorimeter containing 0.50 kg of water. The molecules break up and release their binding energy to the water. The water temperature increases by 2.3°C. What is the binding energy per molecule for this substance?

SOLUTION:

The amount of energy added to the water is

$$\begin{aligned}\Delta U &= mC\Delta T\\ &= (0.50\text{ kg})(4180\text{ J/kg}\bullet{}^\circ\text{C})(2.3^\circ\text{C})\\ &= 4.8\text{ kJ}\end{aligned}$$

The energy per molecule is therefore,

$$\frac{4.8\text{ kJ}}{10^{22}\text{ molecules}} = 4.8\times10^{-19}\text{ J/molecule}$$

79. **Reverse Problem** Write a physics problem with real-life objects for which the following equation would be part of the solution:

$$75\text{ J/K} = \frac{m(4180\text{ J/kg}\bullet\text{K})(260\text{ K} - 250\text{ K})}{250\text{ K}}$$

SOLUTION:

Answers will vary, but a correct form of the answer is, "A certain amount of water is heated from 250 K to 260 K and its entropy increases by 75 J/K. What is the mass of the water?"

80. **Analyze and Conclude** A certain heat engine removes 50.0 J of thermal energy from a hot reservoir at temperature T_H = 545 K and expels 40.0 J of thermal energy to a colder reservoir at temperature T_C = 325 K. In the process, it also transfers entropy from one reservoir to the other.

a. Find the total entropy change of the reservoirs.
b. What would be the total entropy change in the reservoirs if T_C = 205 K?

SOLUTION:
a**. As the engine operates, it removes energy from the hot reservoir.**

Therefore, $\Delta S_H = \frac{Q_H}{T_H}$ **so that the entropy of the hot reservoir decreases.**

The entropy of the cold reservoir $\Delta S_T = \frac{Q_L}{T_C}$ **increases. The net increase in entropy of the reservoirs together is**

$$\begin{aligned}\Delta S_T &= \Delta S_C - \Delta S_H \\ &= \frac{Q_C}{T_C} - \frac{Q_H}{T_H}\end{aligned}$$

$$\begin{aligned}\Delta S_T &= \frac{40.0\text{ J}}{325\text{ K}} - \frac{50.0\text{ J}}{545\text{ K}} \\ &= 0.0313\text{ J/K}\end{aligned}$$

b.

$$\Delta S_T = \frac{40.0\text{ J}}{205\text{ K}} - \frac{50.0\text{ J}}{545\text{ K}} = 0.103\text{ J/K}$$

The total entropy change in the reservoirs, and in the universe, has increased approximately by a factor of three.

81. **Analyze and Conclude** During a game, the metabolism of basketball players often increases by as much as 30.0 W. How much perspiration must a player vaporize per hour to dissipate this extra thermal energy?

SOLUTION:
The amount of thermal energy to be dissipated in 1.00 h is

$$U = (30.0\ \text{J/s})(3600\ \text{s/h})(1\ \text{h})$$
$$= 1.08 \times 10^5\ \text{J}$$

The amount of water this energy, transmitted as heat, would vaporize is

$$m = \frac{Q}{H_v}$$
$$= \frac{1.08 \times 10^5\ \text{J}}{2.26 \times 10^6\ \text{J/kg}}$$
$$= 0.0478\ \text{kg}$$

82. **Apply Concepts** Most energy on Earth comes from the Sun. The Sun's surface temperature is approximately 10^4 K. What would be the effect on Earth if the Sun's surface temperature were 10^3 K?

SOLUTION:
Student answers will vary. Answers should reflect changing average temperature on Earth, different weather patterns, plant and animal species dying out, etc.

Chapter Assessment: Writing in Physics

83. Our understanding of the relationship between heat and energy was influenced by a brewer named James Prescott Joule and a soldier named Benjamin Thompson, Count Rumford. Investigate what experiments they did and evaluate whether it is fair that the unit of energy is called the joule and not the thompson.

SOLUTION:
In 1799, heat was thought to be a liquid that flowed from one object to another. However, Count Rumford thought that heat was caused by the motion of particles. He did not do any quantitative measurements and his ideas were not widely accepted.

In 1843, Joule, doing careful measurements, measured the change in temperature caused by adding heat or doing work on a quantity of water. He proved that heat is a flavor of energy and that energy is conserved. Joule deserves the credit and the eponymic unit.

84. Water has an unusually large specific heat and large heats of fusion and vaporization. The weather and ecosystems depend upon water in all three states. How would the world be different if water's thermodynamic properties were like other materials, such as methanol?

SOLUTION:

The large specific heat and large heats of fusion and vaporization mean that water, ice, and water vapor can store a lot of thermal energy without changing their temperatures too much. The implications are many. The oceans and large lakes moderate the temperature changes in nearby regions on a daily and seasonal basis. The day-to-night temperature variation near a lake is much smaller than the day-to-night temperature variation in the desert. The large heat of fusion of water controls the change of seasons in the far north and south. The absorption of energy by freezing water in the fall and its release in the spring slows the temperature changes in the atmosphere. Water absorbs and stores a lot of energy as it vaporizes. This energy can be used to drive meteorological events, such as thunderstorms and hurricanes.

Chapter Assessment: Cumulative Review

85. A rope is wound around a drum with a radius of 0.250 m and a moment of inertia of 2.25 $kg \cdot m^2$. The rope is connected to a 4.00-kg block. Find the linear acceleration of the block. Find the angular acceleration of the drum. Find the tension, F_T, in the rope. Find the angular velocity of the drum after the block has fallen 5.00 m.

SOLUTION:

Find the linear acceleration of the block.

Solve Newton's second law for the block: $mg - F_T = ma$, where the positive direction is downward and where F_T is the force of the rope on the drum.

Newton's second law for the drum is

$F_T\, r = I\alpha$ or $F_T\, r = Ia/r$.

That is, $F_T = Ia/r^2$.

Therefore, $mg - (I/r^2)a = ma$.

That is, $a = mg/(m + I/r^2) = g/10.0$
$= 0.98\ \text{m/s}^2$.

Find the angular acceleration of the drum.

$$\alpha = \frac{a}{r} = \frac{0.98\ \text{m/s}^2}{0.250\ \text{m}}$$
$$= 3.9\ \text{rad/s}^2$$

Find the tension, FT, in the rope.

$$F_T = \frac{I\alpha}{r}$$
$$= \frac{(2.25\ \text{kg•m}^2)(3.92\ \text{rad/s}^2)}{0.250\ \text{m}}$$
$$= 35.3\ \text{N}$$

Find the angular velocity of the drum after the block has fallen 5.00 m.

$$x = \frac{1}{2}at^2,$$
$$\text{so } t = \sqrt{\frac{2x}{a}} = \sqrt{\frac{2(5.00\ \text{m})}{(0.98\ \text{m/s}^2)}}$$
$$= 3.2\ \text{s}$$

Therefore,

$$\omega = \alpha t$$
$$= (3.92\ \text{rad/s}^2)(3.19\ \text{s})$$
$$= 13\ \text{rad/s}$$

86. A weight lifter raises a 180-kg barbell to a height of 1.95 m. How much work is done by the weight lifter in lifting the barbell?

SOLUTION:

$$\begin{aligned} W &= mgh \\ &= (180 \text{ kg})(9.8 \text{ N/kg})(1.95 \text{ m}) \\ &= 3.4\times10^{3} \text{ J} \end{aligned}$$

87. In a Greek myth, Sisyphus is fated to forever roll a huge rock up a hill. Each time he reaches the top, the rock rolls back to the bottom. If the rock has a mass of 215 kg, the hill is 33 m in height, and Sisyphus can produce an average power of 0.2 kW, how many times in 1 h can he roll the rock up the hill?

SOLUTION:

The amount of work needed to roll the rock up once is

$W = mgh$ = (215 kg)(9.8 N/kg)(33 m)
= 7.0×10^{4} J

In one hour Sisyphus does an amount of work
W = (0.2×10^{3} W)(3600 s) = 700,000 J

He pushes the rock up the hill
(700,000 J) / (7.0×10^{4} J) = 10 times in one hour