1. (e) On each scale there are 100 degrees between the ice and steam points, so the size of the degree is the same on each scale.

2. (b) According to Equation 12.2, the change in length \( \Delta L \) of each rod is given by \( \Delta L = \alpha L_0 \Delta T \), where \( \alpha \) is the coefficient of linear expansion, \( L_0 \) is the initial length, and \( \Delta T \) is the change in temperature. Since the initial length and the change in temperature are the same for each rod, the rod with the larger coefficient of linear expansion has the greater increase in length as the temperature rises. Thus, the aluminum rod lengthens more than the steel rod, so the rods will meet to the right of the midpoint.

3. \( 1.2 \times 10^{-3} \text{ cm} \)

4. (d) In Arrangement I cooling allows the ball to pass through the hole. Therefore, the ball must shrink more than the hole, and the coefficient of linear thermal expansion of metal A must be greater than that of metal B. In Arrangement II heating allows the ball to pass through the hole. Therefore, the coefficient of linear thermal expansion of metal C must be greater than that of metal A.

5. (c) The gap expands as the temperature is increased, in a way similar to that of a hole when it expands according to the coefficient of linear thermal expansion of the surrounding material. In this case the surrounding material is copper.

6. (b) The change in volume \( \Delta V \) is given by Equation 12.3 as \( \Delta V = \beta V_0 \Delta T \), where \( \beta \) is the coefficient of volume thermal expansion, \( V_0 \) is the initial volume, and \( \Delta T \) is the change in temperature. Since the sphere and the cube are made from the same material, the coefficient of volume expansion is the same for each. Moreover, the temperature change is the same for each. Therefore, the change in volume is proportional to the initial volume. The initial volume of the cube is greater, since the sphere would fit within the cube. Thus, the change in volume of the cube is greater.

7. (a) To keep the overflow to a minimum, the container should be made from a material that has the greatest coefficient of volume thermal expansion and filled with a liquid that has the smallest coefficient of volume thermal expansion. That way, when the full container is heated, the cavity holding the liquid will expand more and the liquid will expand less, both effects leading to a reduced amount of overflow.

8. \( 77 \text{ C°} \)
9. (e) The heat $Q$ required to raise the temperature of a mass $m$ of material by an amount $\Delta T$ is given by Equation 12.4 as $Q = cm\Delta T$, where $c$ is the specific heat capacity of the material. Since the material is the same in all cases, the specific heat capacity is the same. What matters is the product of $m$ and $\Delta T$. Since this product is the same in all cases, the amount of heat needed is also the same.

10. (c) The samples cool as heat is removed from each one. However, the temperature change that results as heat is removed is different. The heat $Q$ that must be removed to lower the temperature of a mass $m$ of material by an amount $\Delta T$ is given by Equation 12.4 as $Q = cm\Delta T$, where $c$ is the specific heat capacity of the material. Solving for $\Delta T$ gives $\Delta T = Q/(cm)$. For a given amount of heat removed, the fall in temperature is inversely proportional to the product $cm$. The sample (sample A) with the largest value of $cm$ will experience the smallest drop in temperature. The sample (sample B) with the smallest value of $cm$ will experience the largest drop in temperature.

11. 49 °C

12. 21.6 °C

13. 6.75 kg

14. 0.38 kg

15. (d) Technique A is the way water normally freezes at normal atmospheric pressure. Technique B applies at pressures that are above normal, since the freezing point is then lower. Technique C works also, because the heat of vaporization is carried away by each kilogram of vapor that is removed. This heat comes from the remaining liquid, and since no heat can flow in from the surroundings to replenish this loss of heat, the remaining liquid will freeze.

16. $5.54 \times 10^{-4}$ kg/s

17. (a) Relative humidity is defined by Equation 12.6 as the ratio (expressed as a percentage) of the partial pressure of water vapor in the air to the equilibrium vapor pressure of water at the existing temperature. The greater the temperature, the greater is the equilibrium vapor pressure of water. It is the equilibrium vapor pressure of water at the existing temperature, then, that determines the maximum amount of water that the air can contain. Warmer air can contain a greater maximum amount of water vapor than cooler air. Statement A is certainly true if both humidity values are quoted at the same temperature. Statement B could be true if the 30% humidity referred to a higher temperature than the 40% value. Likewise, statement C could be true if the 30% humidity referred to a higher temperature than the 40% value.

18. (b) The dew point is the temperature at which the existing partial pressure of water vapor in the air would be the equilibrium vapor pressure of water. The equilibrium vapor pressure of water always increases with increasing temperature, and only this answer is consistent with such a relationship.
3. **REASONING**
   a. The relationship between the Kelvin temperature \( T \) and the Celsius temperature \( T_C \) is given by \( T = T_C + 273.15 \) (Equation 12.1).

   b. The relationship between the Kelvin temperature \( T \) and the Fahrenheit temperature \( T_F \) can be obtained by following the procedure outlined in Examples 1 and 2 in the text. On the Kelvin scale the ice point is 273.15 K. Therefore, a Kelvin temperature \( T \) is \( T - 273.15 \) kelvins above the ice point. The size of the kelvin is larger than the size of a Fahrenheit degree by a factor of \( \frac{9}{5} \). As a result a temperature that is \( T - 273.15 \) kelvins above the ice point on the Kelvin scale is \( \frac{9}{5} (T - 273.15) \) °F above the ice point on the Fahrenheit scale. This amount must be added to the ice point of 32.0 °F. The relationship between the Kelvin and Fahrenheit temperatures, then, is given by

   \[
   T_F = \frac{9}{5} (T - 273.15) + 32.0
   \]

**SOLUTION**

a. Solving Equation 12.1 for \( T_C \), we find that

   - **Day** \( T_C = T - 273.15 = 375 - 273.15 = 102 ^\circ C \)
   - **Night** \( T_C = T - 273.15 = 1.00 \times 10^2 - 273.15 = -173 ^\circ C \)

b. Using the equation developed in the **REASONING**, we find

   - **Day** \( T_F = \frac{9}{5} (T - 273.15) + 32.0 = \frac{9}{5} (375 - 273.15) + 32.0 = 215 ^\circ F \)
   - **Night** \( T_F = \frac{9}{5} (T - 273.15) + 32.0 = \frac{9}{5} (1.00 \times 10^2 - 273.15) + 32.0 = -2.80 \times 10^2 ^\circ F \)

5. **SSM REASONING AND SOLUTION**
   a. The Kelvin temperature and the temperature on the Celsius scale are related by Equation 12.1: \( T = T_c + 273.15 \), where \( T \) is the Kelvin temperature and \( T_c \) is the Celsius temperature. Therefore, a temperature of 77 K on the Celsius scale is

   \[
   T_c = T - 273.15 = 77 \text{ K} - 273.15 \text{ K} = -196 ^\circ C
   \]
b. The temperature of \(-196 \, ^\circ C\) is 196 Celsius degrees below the ice point of 0 \, ^\circ C. Since 
1 \, ^\circ C = \frac{9}{5} \, ^\circ F, this number of Celsius degrees corresponds to

\[
196 \left( \frac{\frac{9}{5} \, ^\circ F}{1 \, ^\circ C} \right) = 353 \, ^\circ F
\]

Subtracting 353 Fahrenheit degrees from the ice point of 32.0 \, ^\circ F on the Fahrenheit scale gives a Fahrenheit temperature of \(-321\, ^\circ F\).

11. **REASONING AND SOLUTION** Using Equation 12.2 and the value for the coefficient of thermal expansion of steel given in Table 12.1, we find that the linear expansion of the aircraft carrier is

\[
\Delta L = \alpha L_0 \Delta T = (12 \times 10^{-6} \, ^\circ C^{-1})(370 \, m)(21 \, ^\circ C - 2.0 \, ^\circ C) = 0.084 \, m
\]

19. **REASONING AND SOLUTION** \(\Delta L = \alpha L_0 \Delta T\) gives for the expansion of the aluminum

\[
\Delta L_A = \alpha_A L_A \Delta T
\]

and for the expansion of the brass

\[
\Delta L_B = \alpha_B L_B \Delta T
\]

The air gap will be closed when \(\Delta L_A + \Delta L_B = 1.3 \times 10^{-3} \, m\). Thus, taking the coefficients of thermal expansion for aluminum and brass from Table 12.1, adding Equations (1) and (2), and solving for \(\Delta T\), we find that

\[
\Delta T = \frac{\Delta L_A + \Delta L_B}{\alpha_A L_A + \alpha_B L_B} = \frac{1.3 \times 10^{-3} \, m}{23 \times 10^{-6} \, (^\circ C)^{-1}(1.0 \, m) + 19 \times 10^{-6} \, (^\circ C)^{-1}(2.0 \, m)} = 21 \, ^\circ C
\]

The desired temperature is then

\[
T = 28 \, ^\circ C + 21 \, ^\circ C = 49 \, ^\circ C
\]

31. **REASONING AND SOLUTION** The volume \(V_0\) of an object changes by an amount \(\Delta V\) when its temperature changes by an amount \(\Delta T\); the mathematical relationship is given by Equation 12.3:  \(\Delta V = \beta V_0 \Delta T\). Thus, the volume of the kettle at 24 \, ^\circ C can be found by solving Equation 12.3 for \(V_0\). According to Table 12.1, the coefficient of volumetric expansion for copper is \(51 \times 10^{-6} \, (^\circ C)^{-1}\). Solving Equation 12.3 for \(V_0\), we have
\[ V_0 = \frac{\Delta V}{\beta \Delta T} = \frac{1.2 \times 10^{-5} \text{ m}^3}{[51 \times 10^{-6} \text{ (C}^\circ\text{)}^{-1}] (100 \text{ }^\circ\text{C} - 24 \text{ }^\circ\text{C})} = 3.1 \times 10^{-3} \text{ m}^3 \]

35. **SSM REASONING** When the temperature increases, both the gasoline and the tank cavity expand. If they were to expand by the same amount, there would be no overflow. However, the gasoline expands more than the tank cavity, and the overflow volume is the amount of gasoline expansion minus the amount of the tank cavity expansion. The tank cavity expands as if it were solid steel.

**SOLUTION** The coefficients of volumetric expansion \( \beta_g \) and \( \beta_s \) for gasoline and steel are available in Table 12.1. According to Equation 12.3, the volume expansion of the gasoline is

\[ \Delta V_g = \beta_g V_0 \Delta T = \left[ 950 \times 10^{-6} \text{ (C}^\circ\text{)}^{-1} \right] (20.0 \text{ gal}) \left[ (35 \text{ C}^\circ) - (17 \text{ C}^\circ) \right] = 0.34 \text{ gal} \]

while the volume of the steel tank expands by an amount

\[ \Delta V_s = \beta_s V_0 \Delta T = \left[ 36 \times 10^{-6} \text{ (C}^\circ\text{)}^{-1} \right] (20.0 \text{ gal}) \left[ (35 \text{ C}^\circ) - (17 \text{ C}^\circ) \right] = 0.013 \text{ gal} \]

The amount of gasoline that spills out is

\[ \Delta V_g - \Delta V_s = 0.33 \text{ gal} \]

38. **REASONING** When the mercury is heated, it expands a distance \( \Delta L \) into the capillary, creating a small cylinder of mercury in the capillary with a volume \( \Delta V = \pi r^2 \Delta L \). The radius \( r \) of the capillary is assumed constant, because we are ignoring the thermal expansion of the glass. Because the increase \( \Delta V \) in the volume of the mercury is due to thermal expansion, we can also express it as \( \Delta V = \beta V_0 \Delta T \) (Equation 12.3), where \( \beta = 182 \times 10^{-6} \text{ (C}^\circ\text{)}^{-1} \) is the coefficient of volume expansion for mercury (see Table 12.1), \( V_0 \) is the volume of the mercury before heating, and \( \Delta T = 1.0 \text{ C}^\circ \) is the increase in the temperature of the mercury.

**SOLUTION** Solving \( \Delta V = \pi r^2 \Delta L \) for \( \Delta L \) yields

\[ \Delta L = \frac{\Delta V}{\pi r^2} \]  

Substituting \( \Delta V = \beta V_0 \Delta T \) (Equation 12.3) into Equation (1), we obtain

\[ \Delta L = \frac{\Delta V}{\pi r^2} = \frac{\beta V_0 \Delta T}{\pi r^2} = \frac{\left[ 182 \times 10^{-6} \text{ (C}^\circ\text{)}^{-1} \right] (45 \text{ mm}^3) (1.0 \text{ C}^\circ)}{\pi (1.7 \times 10^{-2} \text{ mm})^2} = 9.0 \text{ mm} \]
51. **REASONING** According to Equation 6.10b, the average power is the change in energy divided by the time. The change in energy in this problem is the heat supplied to the water and the coffee mug to raise their temperature from 15 to 100 °C, which is the boiling point of water. The time is given as three minutes (180 s). The heat $Q$ that must be added to raise the temperature of a substance of mass $m$ by an amount $\Delta T$ is given by Equation 12.4 as $Q = cm\Delta T$, where $c$ is the specific heat capacity. This equation will be used for the water and the material of which the mug is made.

**SOLUTION** Using Equation 6.10b, we write the average power $\bar{P}$ as

$$\bar{P} = \frac{\text{Change in energy}}{\text{Time}} = \frac{Q_{\text{Water}} + Q_{\text{Mug}}}{\text{Time}}$$

The heats $Q_{\text{Water}}$ and $Q_{\text{Mug}}$ each can be expressed with the aid of Equation 12.4, so that we obtain

$$\bar{P} = \frac{Q_{\text{Water}} + Q_{\text{Mug}}}{\text{Time}} = \frac{c_{\text{Water}} m_{\text{Water}} \Delta T + c_{\text{Mug}} m_{\text{Mug}} \Delta T}{\text{Time}}$$

$$= \frac{[4186 \text{ J/(kg} \cdot \text{°C)})(0.25 \text{ kg})(100.0 \text{ °C} - 15 \text{ °C})}{180 \text{ s}} + \frac{[920 \text{ J/(kg} \cdot \text{°C)})(0.35 \text{ kg})(100.0 \text{ °C} - 15 \text{ °C})}{180 \text{ s}} = 650 \text{ W}$$

The specific heat of water has been taken from Table 12.2.

57. **SSM REASONING** Heat $Q_1$ must be added to raise the temperature of the aluminum in its solid phase from 130 °C to its melting point at 660 °C. According to Equation 12.4, $Q_1 = cm\Delta T$. The specific heat $c$ of aluminum is given in Table 12.2. Once the solid aluminum is at its melting point, additional heat $Q_2$ must be supplied to change its phase from solid to liquid. The additional heat required to melt or liquefy the aluminum is $Q_2 = mL_1$, where $L_1$ is the latent heat of fusion of aluminum. Therefore, the total amount of heat which must be added to the aluminum in its solid phase to liquefy it is

$$Q_{\text{total}} = Q_1 + Q_2 = m(c\Delta T + L_1)$$

**SOLUTION** Substituting values, we obtain

$$Q_{\text{total}} = (0.45 \text{ kg}) \left\{[9.00 \times 10^2 \text{ J/(kg} \cdot \text{°C)})(660 \text{ °C} - 130 \text{ °C}) + 4.0 \times 10^5 \text{ J/kg}\right\} = 3.9 \times 10^5 \text{ J}$$
63. **REASONING AND SOLUTION** The heat required to evaporate the water is \( Q = mL_v \), and to lower the temperature of the jogger we have \( Q = m_j c \Delta T \). Equating these two expressions and solving for the mass \( m \) of the water, we have

\[
m = \frac{m_j c \Delta T}{L_v}
\]

\[
m = \frac{(75 \text{ kg})[3500 \text{ J/(kg \cdot } ^\circ \text{C})][1.5 \text{ } ^\circ \text{C}]}{2.42 \times 10^6 \text{ J/kg}} = 0.16 \text{ kg}
\]

92. **REASONING** According to Equation 12.4, the heat required to warm the pool can be calculated from \( Q = cm\Delta T \). The specific heat capacity \( c \) of water is given in Table 12.2. In order to use Equation 12.4, we must first determine the mass of the water in the pool. Equation 11.1 indicates that the mass can be calculated from \( m = \rho V \), where \( \rho \) is the density of water and \( V \) is the volume of water in the pool.

**SOLUTION** Combining these two expressions, we have \( Q = cpV\Delta T \), or

\[
Q = \left[4186 \text{ J/(kg \cdot } ^\circ \text{C})\right](1.00 \times 10^3 \text{ kg/m}^3)(12.0 \text{ m} \times 9.00 \text{ m} \times 1.5 \text{ m})(27 \text{ } ^\circ \text{C} - 15 \text{ } ^\circ \text{C}) = 8.14 \times 10^9 \text{ J}
\]

Using the fact that 1 kWh = \(3.6 \times 10^6\) J, the cost of using electrical energy to heat the water in the pool at a cost of \$0.10 per kWh is

\[
(8.14 \times 10^9 \text{ J}) \left(\frac{$0.10}{3.6 \times 10^6 \text{ J}}\right) = $230.
\]

101. **REASONING** Because the container is insulated, no heat is transferred to the surroundings. Therefore, in order to reach equilibrium at temperature \( T_{eq} \), the oil must absorb an amount of heat \( Q_{oil} \) equal to the heat \( Q_{water} \) given up by the water. Neither the water nor the oil undergoes a phase change, so we will use \( Q = cm \Delta T \) (Equation 12.4) to determine the amount of heat exchanged between the liquids. In Equation 12.4, \( c \) is the specific heat, \( m \) is the mass and \( \Delta T \) is the temperature difference that each liquid undergoes. Thus, we have

\[
Q_{oil} = c_{oil} m_{oil} \Delta T_{oil} \quad \text{and} \quad Q_{water} = c_{water} m_{water} \Delta T_{water}
\]

(1)

For the water, the difference between the higher and lower temperatures is \( \Delta T_{water} = 90.0 \text{ } ^\circ \text{C} - T_{eq} \). With this substitution, the expression for \( Q_{water} \) becomes

\[
Q_{water} = c_{water} m_{water} (90.0 \text{ } ^\circ \text{C} - T_{eq})
\]

(2)
For the oil, the temperature change $\Delta T_{\text{oil}}$ is related to the increase $\Delta V$ in its volume by $\Delta V = \beta V_0 \Delta T_{\text{oil}}$ (Equation 12.3), where $\beta$ is the coefficient of volume expansion of the oil, and $V_0$ is the volume of the oil before the water is added. Solving Equation 12.3 for $\Delta T_{\text{oil}}$, we obtain

$$\Delta T_{\text{oil}} = \frac{\Delta V}{\beta V_0}$$  \hspace{1cm} (3)

Substituting Equation (3) into the first of Equations (1) yields

$$Q_{\text{oil}} = \frac{c_{\text{oil}} m_{\text{oil}} \Delta V}{\beta V_0}$$  \hspace{1cm} (4)

The mass $m_{\text{oil}}$ of the oil in the container is related to its density $\rho$ and volume $V_0$ according to $\rho = m_{\text{oil}}/V_0$ (Equation 11.1). Solving Equation 11.1 for the mass of the oil yields $m_{\text{oil}} = \rho V_0$, which we substitute into Equation (4):

$$Q_{\text{oil}} = \frac{c_{\text{oil}} \rho V_0 \Delta V}{\beta V_0} = \frac{c_{\text{oil}} \rho \Delta V}{\beta}$$  \hspace{1cm} (5)

**SOLUTION** Equation (5) gives the amount of heat absorbed by the oil, so it must be equal to Equation (2), which gives the amount of heat lost by the water. Therefore, we have

$$\frac{c_{\text{oil}} \rho \Delta V}{\beta} = c_{\text{water}} m_{\text{water}} (90.0 \, ^\circ \! \mathrm{C} - T_{\text{eq}}) \quad \text{or} \quad 90.0 \, ^\circ \! \mathrm{C} - T_{\text{eq}} = \frac{c_{\text{oil}} \rho \Delta V}{\beta c_{\text{water}} m_{\text{water}}}$$  \hspace{1cm} (6)

Solving Equation (6) for the equilibrium temperature, we obtain

$$T_{\text{eq}} = 90.0 \, ^\circ \! \mathrm{C} - \frac{c_{\text{oil}} \rho \Delta V}{\beta c_{\text{water}} m_{\text{water}}}$$

$$= 90.0 \, ^\circ \! \mathrm{C} - \frac{1970 \, J/(\text{kg} \cdot ^\circ \! \mathrm{C}) \cdot (924 \, \text{kg/m}^3) \cdot (1.20 \times 10^{-5} \, \text{m}^3)}{721 \times 10^{-6} \, (\text{C}^{-1}) \cdot 4186 \, J/(\text{kg} \cdot ^\circ \! \mathrm{C}) \cdot (0.125 \, \text{kg})} = 32.1 \, ^\circ \! \mathrm{C}$$