Chapter 10: Temperature and Heat

Answers and Solutions

1. A cup of hot coffee that is placed on a table is not in thermal equilibrium with its surroundings. It would be in thermal equilibrium only if it had the same temperature as its surroundings.

2. The term *heat* refers to a transfer of energy between objects because of a temperature difference. For this reason, no, it is not correct to say that a hot object "contains" heat; it can only transfer heat. The question of whether a hot object contains more energy than a cold one is a complicated one because the thermal energy that an object contains depends upon the mass of the object, its specific heat capacity, and its temperature. However, if the two objects are otherwise identical, then yes, it is correct to say that a hot object contains more thermal energy than a cold object.

3. **Picture the Problem:** This is a follow-up question to Guided Example 10.1. The temperature of a system is known to be 110°F.

   Strategy: Use the conversion between degrees Fahrenheit and degrees Celsius to convert the Fahrenheit temperature to the Celsius temperature.

   Solution: Convert the temperature: $T_{\mathrm{C}} = \frac{5}{9}\left(T_{\mathrm{F}} - 32\right) = \frac{5}{9}\left(110 - 32\,°\mathrm{F}\right) = \boxed{43°\mathrm{C}}$

   Insight: This is an unpleasantly hot temperature for the environment, but a pleasant temperature for a cup of coffee.

4. **Picture the Problem:** The coldest temperature ever recorded on Earth is −89.2°C at Vostok, Antarctica.

   Strategy: Use the conversion between degrees Celsius and degrees Fahrenheit to convert the Celsius temperature to the Fahrenheit temperature.

   Solution: Convert the temperature: $T_{\mathrm{F}} = \frac{9}{5}\left(-89.2°\mathrm{C}\right) + 32°\mathrm{F} = \boxed{-128.6°\mathrm{F}}$

   Insight: This temperature is well below the −109°F freezing point of CO_2 (dry ice).

5. **Picture the Problem:** A temperature difference in degrees Fahrenheit is to be converted to degrees Celsius.

   Strategy: Write the temperature difference in the Fahrenheit scale as a final temperature minus the initial temperature. Use the conversion between degrees Fahrenheit and degrees Celsius to convert the Fahrenheit temperatures to Celsius temperatures.

   Solution: Find the temperature difference in Celsius. Note that the 32°F offset cancels out when the temperatures are subtracted:

$$\begin{aligned}\Delta T_{\mathrm{C}} &= T_{\mathrm{C2}} - T_{\mathrm{C1}} = \tfrac{5}{9}\left(T_{\mathrm{F2}} - \cancel{32°\mathrm{F}}\right) - \tfrac{5}{9}\left(T_{\mathrm{F1}} - \cancel{32°\mathrm{F}}\right)\\ &= \tfrac{5}{9}\left(T_{\mathrm{F2}} - T_{\mathrm{F1}}\right) = \tfrac{5}{9}\Delta T_{\mathrm{F}}\\ \Delta T_{\mathrm{C}} &= \tfrac{5}{9}\left(27\,°\mathrm{F}\right) = \boxed{15°\mathrm{C}}\end{aligned}$$

   Insight: Because the Celsius degree and the Kelvin degree have the same size, a change in Celsius temperature has the same magnitude as that change in Kelvin units.

6. **Picture the Problem:** A temperature has the same value on both the Fahrenheit and Celsius scales.

   Strategy: Set the value of the temperature in degrees Fahrenheit, T_F, equal to the same value in degrees Celsius, T_C, by substituting a single variable T for each. Solve the resulting expression for T.

   Solution: Set $T_F = T_C \overset{\text{set}}{=} T$ and solve for T:

$$T_F = \frac{9}{5}T_C + 32$$
$$T - \frac{9}{5}T = 32$$
$$T = \frac{32}{1-9/5} = \boxed{-40.0}$$

   Insight: Because the Celsius and the Kelvin scales have the same size degree and are offset from each other by 273.15, there is no temperature in Celsius that has the same numerical value in Kelvin. You can verify for yourself that 574.59 is the same temperature on both the Fahrenheit and Kelvin scales.

7. **Picture the Problem:** The temperature of the surface of the Sun is given in the Kelvin scale and is to be converted to the Celsius and Fahrenheit scales.

   Strategy: Use the conversion between kelvins and degrees Celsius to convert the Kelvin temperature to the Celsius temperature. Then use the conversion between degrees Celsius and degrees Fahrenheit to convert the Celsius temperature to the Fahrenheit temperature.

   Solution: 1. (a) Convert from Kelvin to Celsius: $T_C = T - 273.15\text{ K} = 6000 - 273.15\text{ K} = \boxed{5.7\times10^3\ ^\circ\text{C}}$

   2. (b) Convert from Celsius to Fahrenheit: $T_F = \frac{9}{5}(5727\,^\circ\text{C}) + 32\,^\circ\text{F} = 10{,}341^\circ\text{F} = \boxed{1.0\times10^4\ ^\circ\text{F}}$

   Insight: The surface of the Sun is hotter than 10,000°F! Remarkably, the surface is the coolest region of the Sun.

8. **Picture the Problem:** The temperature of the boiling point of water is to be converted from the Celsius scale to the Kelvin scale.

   Strategy: Use the conversion between kelvins and degrees Celsius to convert the Celsius temperature to the Kelvin temperature.

   Solution: Convert from Celsius to Kelvin: $T = T_C + 273.15 = 100.00 + 273.15\text{ K} = \boxed{373.15\text{ K}}$

   Insight: Similarly, the freezing point of water occurs at 273.15 K.

9. Temperature is a measure of the average kinetic energy of the particles in a system. Therefore, the average kinetic energy of the particles will increase when the temperature of the system is increased.

10. The term *heat* refers to a transfer of energy between objects because of a temperature difference. For this reason it is not correct to say that hot coffee “contains” heat; it can only transfer heat. However, it is correct to say that a cup of hot coffee contains more thermal energy than a cup of cold coffee.

11. The term *heat* refers to a transfer of energy between objects because of a temperature difference.

12. The thermal energy of a substance is the sum of all of its kinetic and potential energy. Thus, an object’s thermal energy refers to both the random motion of its particles (kinetic energy) and the separation and orientation of its particles relative to one another (potential energy).

13. The key characteristics of thermal equilibrium are that the two objects must be in contact with each other and they must be at the same temperature. There must be no net thermal energy transfer between the two objects.

14. Zero on the Kelvin temperature scale is called *absolute zero*. It is the temperature below which it is impossible to cool an object.

15. **Picture the Problem:** The temperature of the filament in an incandescent lightbulb is to be converted from degrees Fahrenheit to degrees Celsius.

    Strategy: Use the conversion between degrees Fahrenheit and degrees Celsius to convert the Fahrenheit temperature to the Celsius temperature.

    Solution: Convert the temperature:
    $$T_C = \frac{5}{9}(4500\,°F - 32\,°F) = 2482\,°C = \boxed{2.5\times10^3\ °C}$$

    Insight: For temperatures this large, the 32°F shift is insignificant. The temperature in Celsius is essentially 5/9th of the reading in Fahrenheit.

16. **Picture the Problem:** The outside temperature drops as a cold front moves through your area.

    Strategy: Use the conversion between degrees Fahrenheit and degrees Celsius to convert the Fahrenheit temperature change to the Celsius temperature change.

    Solution: 1. (a) Find the temperature difference in Celsius. Note that the 32°F offset cancels out when the temperatures are subtracted:
    $$\Delta T_C = T_{C2} - T_{C1} = \tfrac{5}{9}\left(T_{F2} - \cancel{32°F}\right) - \tfrac{5}{9}\left(T_{F1} - \cancel{32°F}\right)$$
    $$= \tfrac{5}{9}\left(T_{F2} - T_{F1}\right) = \tfrac{5}{9}\Delta T_F$$
    $$\Delta T_C = \tfrac{5}{9}(35\,°F) = \boxed{19\,°C}$$

    2. (b) The temperature difference in the Kelvin scale has the same magnitude as the temperature difference in the Celsius scale:
    $$\Delta T = \Delta T_C = \boxed{19\,K}$$

    Insight: Any temperature span in the Fahrenheit scale equals the span in the Celsius scale multiplied by 9/5, because in the Fahrenheit scale 180 degrees spans the freezing and boiling points of water, but there are only 100 Celsius degrees in that span.

17. **Picture the Problem:** The outside temperature increases as a high-pressure weather system moves into your area.

    Strategy: Use the conversion between degrees Fahrenheit and degrees Celsius to convert the Celsius temperature change to the Fahrenheit temperature change.

    Solution: 1. (a) Find the temperature difference in Fahrenheit. Note that the 32°F offset cancels out when the temperatures are subtracted:
    $$\Delta T_F = T_{F2} - T_{F1} = \left[\tfrac{9}{5}T_{C2} + \cancel{32}\right] - \left[\tfrac{9}{5}T_{C1} + \cancel{32}\right]$$
    $$= \tfrac{9}{5}\left(T_{C2} - T_{C1}\right) = \tfrac{9}{5}\Delta T_C$$
    $$\Delta T_F = \tfrac{9}{5}(29\,°C) = \boxed{52\,°F}$$

    2. (b) The temperature difference in the Kelvin scale has the same magnitude as the temperature difference in the Celsius scale:
    $$\Delta T = \Delta T_C = \boxed{29\,K}$$

    Insight: Any temperature span in the Fahrenheit scale equals the span in the Celsius multiplied by 9/5, because in the Fahrenheit scale 180 degrees spans the freezing and boiling points of water, but there are only 100 Celsius degrees in that span.

18. **Picture the Problem:** The Akashi Kaikyo Bridge in Japan is made of steel. When steel is heated it expands and when it is cooled it contracts.

    Strategy: In this problem we wish to find the change in length of the bridge between a cold winter day and a warm summer day. Use the thermal expansion equation to determine the change in length. The coefficient of thermal expansion for steel is given in Table 10.1.

Solution: Find the change in length:

$$\Delta L = \alpha L_{\text{i}} \Delta T$$

$$= \left[1.2\times10^{-5}\ \text{K}^{-1}\right](3910\ \text{m})\left[30.0\,°\text{C} - (-5.00\,°\text{C})\right] = \boxed{1.6\ \text{m}}$$

Insight: This change in length is about the height of a person. If there were no expansion joints in the bridge this increase in length would be sufficient to buckle the bridge.

19. **Picture the Problem:** An aluminum meterstick increases in length as it is heated.

Strategy: Solve the thermal expansion equation for the temperature difference required to change the length of 1.0000 m of aluminum by 1.0 mm. The coefficient of thermal expansion for aluminum is given in Table 10.1.

Solution: Solve for the temperature difference:

$$\Delta L = \alpha L_{\text{i}} \Delta T$$

$$\Delta T = \frac{\Delta L}{\alpha L_{\text{i}}} = \frac{1.0\ \text{mm}}{\left(2.4\times10^{-5}\ \text{K}^{-1}\right)(1000.0\ \text{mm})} = \boxed{42\ \text{K}}$$

Insight: This change in temperature is equivalent to an increase of 42°C or 75°F.

20. **Picture the Problem:** Two identical metal rods are at room temperature. One rod is heated by 10°C, and the other is cooled by 10°C, and their new lengths are compared.

Strategy: Use a ratio to compare the lengths of the two rods after the heating and cooling events.

Solution: 1. Make a ratio of the lengths:

$$\frac{L_{\text{new, heated}}}{L_{\text{new, cooled}}} = \frac{L_{\text{i}} + \Delta L_{\text{heated}}}{L_{\text{i}} + \Delta L_{\text{cooled}}} = \frac{L_{\text{i}} + \alpha L_{\text{i}} \Delta T_{\text{heated}}}{L_{\text{i}} + \alpha L_{\text{i}} \Delta T_{\text{cooled}}} = \frac{L_{\text{i}}\left(1+\alpha\left[+10\,°\text{C}\right]\right)}{L_{\text{i}}\left(1+\alpha\left[-10\,°\text{C}\right]\right)} = \boxed{\frac{1+10\alpha}{1-10\alpha}}$$

2. The rod that is heated is slightly longer than the rod that is cooled.

Insight: If the two rods were made of aluminum, so that $\alpha = 2.4\times10^{-5}\ \text{K}^{-1}$, then the heated rod would be 0.048% longer than the cooled rod.

21. Thermal conduction occurs when a hot object is in contact with a cool object. The rapidly moving molecules in the hot object collide with the slower molecules in the cool object, transferring some kinetic energy. Those molecules then collide with others in the cool object, and so the molecules in the cool object gradually move faster as energy is transferred by means of collisions. Thermal conduction describes how energy moves from the hot object to the cool object in this manner.

22. As boiling water is heated on a stove, several exchange processes carry the thermal energy through the water. The water (and the container) conduct heat from the hot burner to the cool atmosphere, convection currents in the boiling water circulate and transfer energy from the hot pan bottom to the cooler water surface, and thermal radiation from the hot water transfers energy into the cooler surroundings. There is a fourth exchange process (discussed later in this chapter) by which the bubbles of steam carry the latent heat of vaporization from the hot pan bottom to the cooler air above the water surface.

23. Thermal energy exchange by radiation is mediated by electromagnetic waves that can travel through the vacuum. No medium is required for the energy transfer. In fact, this is how the Sun transfers energy through the vacuum of space and to Earth.

24. A thermal conductor will transfer energy from a hot region to a cool region much more efficiently than a thermal insulator.

25. A bimetallic strip bends because of the different coefficients of thermal expansion between the two types of metal. Because aluminum has a larger coefficient of thermal expansion than does copper, it will change its length by a greater amount. This means the aluminum will be on the outside of the arc through which it curls, and we expect the strip to bend toward the copper side of the strip. See Figure 10.6 for an illustration.

26. **Picture the Problem:** Each of four systems consists of a metal rod of a given initial length that is subjected to a certain increase in temperature.

Strategy: Use the thermal expansion equation to rank the systems in order of increasing change in length.

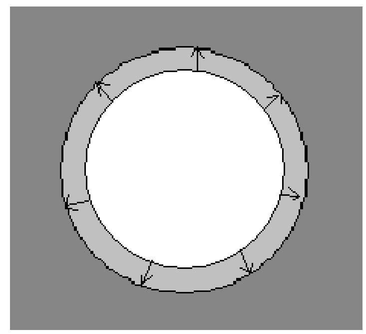
Solution: 1. Calculate the changes in length:

$$\Delta L_{\mathrm{A}} = \alpha_{\mathrm{A}} L_{\mathrm{i,\,A}} \Delta T_{\mathrm{A}} = \left(2.4\times10^{-5}\ \mathrm{K}^{-1}\right)(2\ \mathrm{m})(40\ \mathrm{K}) = 1.92\ \mathrm{mm}$$
$$\Delta L_{\mathrm{B}} = \alpha_{\mathrm{B}} L_{\mathrm{i,\,B}} \Delta T_{\mathrm{B}} = \left(1.2\times10^{-5}\ \mathrm{K}^{-1}\right)(2\ \mathrm{m})(20\ \mathrm{K}) = 0.48\ \mathrm{mm}$$
$$\Delta L_{\mathrm{C}} = \alpha_{\mathrm{C}} L_{\mathrm{i,\,C}} \Delta T_{\mathrm{C}} = \left(1.2\times10^{-5}\ \mathrm{K}^{-1}\right)(1\ \mathrm{m})(30\ \mathrm{K}) = 0.36\ \mathrm{mm}$$
$$\Delta L_{\mathrm{D}} = \alpha_{\mathrm{D}} L_{\mathrm{i,\,D}} \Delta T_{\mathrm{D}} = \left(2.4\times10^{-5}\ \mathrm{K}^{-1}\right)(1\ \mathrm{m})(10\ \mathrm{K}) = 0.24\ \mathrm{mm}$$

2. By comparing the length changes we arrive at the ranking $\boxed{\mathrm{D} < \mathrm{C} < \mathrm{B} < \mathrm{A}}$.

Insight: Aluminum expands twice as much as steel for the same initial length and change in temperature.

27. **Picture the Problem:** A copper plate has a hole cut in its center. The plate expands as it is heated.



Strategy: The hole will expand at the same rate as the copper. Because the diameter of the hole is the length that is expanding, use the thermal expansion equation to calculate the diameter as a function of the increase in temperature. The coefficient of thermal expansion is given in Table 10.1.

Solution: 1. Solve the thermal expansion equation for the final diameter:

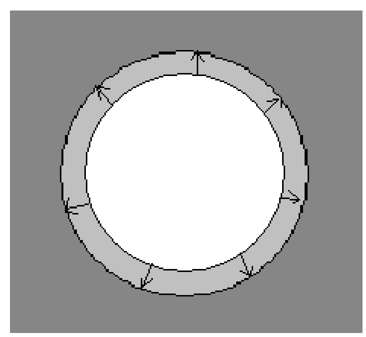
$$\Delta d = d - d_{\mathrm{i}} = \alpha d \Delta T$$
$$d = d_{\mathrm{i}} + \alpha d_{\mathrm{i}} \Delta T = d_{\mathrm{i}}\left(1 + \alpha \Delta T\right)$$

2. Substitute the numerical values:

$$d = 1.325\ \mathrm{cm}\left[1 + \left(1.7\times10^{-5}\ \mathrm{K}^{-1}\right)(224.0\ ^\circ\mathrm{C} - 21.00\ ^\circ\mathrm{C})\right] = \boxed{1.330\ \mathrm{cm}}$$

Insight: The diameter of the hole expanded by 0.0046 cm or 46 μm.

28. **Picture the Problem:** A steel plate has a hole cut in its center. The plate shrinks as it is cooled.



Strategy: The hole will shrink at the same rate as the steel. Because the diameter of the hole is the length that is shrinking, use the thermal expansion equation to calculate the diameter as a function of the change in temperature. Solve the resulting expression for the final temperature. The coefficient of thermal expansion is given in Table 10.1.

Solution: 1. Solve the thermal expansion equation for the final temperature:

$$\Delta d = d - d_{\mathrm{i}} = \alpha d_{\mathrm{i}} \Delta T$$
$$\Delta T = \frac{d - d_{\mathrm{i}}}{\alpha d_{\mathrm{i}}}$$

2. Substitute the numerical values:

$$\Delta T = \frac{1.164 - 1.166\ \mathrm{cm}}{\left(1.2\times10^{-5}\ \mathrm{K}^{-1}\right)(1.166\ \mathrm{cm})} = -143\ \mathrm{K}$$

3. Find the final temperature:

$$T_{\mathrm{f}} = T_{\mathrm{i}} + \Delta T = 23.00\ ^\circ\mathrm{C} + \left(-143\ ^\circ\mathrm{C}\right) = \boxed{-120\ ^\circ\mathrm{C}}$$

Insight: Steel has a small coefficient of thermal expansion, so that the plate must be cooled substantially in order to achieve the desired decrease in the hole's diameter.

29. **Picture the Problem:** An aluminum rod changes its length when its temperature is changed.

Strategy: Use the thermal expansion equation to calculate the length of the rod as a function of the change in temperature. Because the expansion is a linear function of the temperature change, it does not matter whether the rod is heated or cooled. We will assume it is heated. Solve the resulting expression for the initial length of the rod. The coefficient of thermal expansion is given in Table 10.1.

Solution: Solve the thermal expansion equation for the initial length:

$$\Delta L = \alpha L_{\mathrm{i}} \Delta T$$

$$L_{\mathrm{i}} = \frac{\Delta L}{\alpha \Delta T} = \frac{0.0032\ \mathrm{cm}}{\left(2.4\times 10^{-5}\ \mathrm{K}^{-1}\right)\left(120\ \mathrm{K}\right)} = \boxed{1.1\ \mathrm{cm}}$$

Insight: The rules of significant figures prevent us from saying that the initial length was 1.1111 cm. We would need to know all the values to five significant figures in order to determine the initial length with such precision.

30. **Picture the Problem:** A metal rod changes its length when its temperature is changed.

Strategy: Solve the thermal expansion equation for the coefficient of thermal expansion. Compare its value to those given in Table 10.1 to determine which metal it might be.

Solution: 1. Solve the thermal expansion equation for the coefficient:

$$\Delta L = \alpha L_{\mathrm{i}} \Delta T$$

$$\alpha = \frac{\Delta L}{L_{\mathrm{i}}\, \Delta T} = \frac{0.36\ \mathrm{cm}}{\left(250\ \mathrm{cm}\right)\left(85\ \mathrm{K}\right)} = \boxed{1.7\times 10^{-5}\ \mathrm{K}^{-1}}$$

2. By comparing the value of the coefficient of thermal expansion with those listed in Table 10.1, we conclude that the metal is most likely to be $\boxed{\text{copper}}$.

Insight: Sometimes the measurement of the coefficient of thermal expansion can help determine the identity of an unknown metal, but other chemical and optical methods are easier and more precise.

31. **Picture the Problem:** This is a follow-up question to Guided Example 10.7. A 74.0-kg person drinks a thick, rich, 305-C milkshake and then burns calories as he climbs a staircase.

Strategy: Use the energy conversion between Calories and joules (1 Cal = 4186 J) to convert the amount of work done against gravity, *mgH*, into an equivalent amount of Calories.

Solution: 1. Find the work done against gravity:

$$W = mgH = \left(74.0\ \mathrm{kg}\right)\left(9.81\ \mathrm{m/s^2}\right)\left(100\ \text{stairs} \times 0.200\ \mathrm{m/stair}\right)$$
$$= 14{,}518\ \mathrm{J}$$

2. Convert the mechanical energy in joules into thermal energy in Calories:

$$Q = 14{,}518\ \mathrm{J} \times \frac{1\ \mathrm{Cal}}{4186\ \mathrm{J}} = \boxed{3.47\ \mathrm{Cal}}$$

Insight: It might be disappointing to think that by climbing almost 7 stories (H = 20 m divided by about 3 m per story) you've burned less energy than that in a single saltine cracker (12 Cal). However, your body consumes much more food energy during the climbing process than the amount of gravitational potential energy that you gain. If your body were 20% efficient you would actually convert 3.47 Cal / 0.20 = 17.4 Cal of food energy into mechanical and thermal energies.

32. **Picture the Problem:** A person lifts a weight during a workout. The person does work against gravity each time the weight is lifted.

Strategy: Calculate the amount of work done each time the weight is lifted and convert the results to calories. Divide the total work done by the work per lift to calculate the number of lifts necessary to expend the specified amount of calories.

Solution: 1. Multiply force by distance to calculate work done in each repetition:

$$W = m\,g\Delta y = \left(6.2\ \mathrm{kg}\right)\left(9.81\ \mathrm{m/s^2}\right)\left(0.58\ \mathrm{m}\right) = 35.3\ \mathrm{J}$$

2. Convert from joules to Calories: $Q = 35.3\text{ J} \times \dfrac{1\text{ Cal}}{4186\text{ J}} = 0.00843\text{ Cal}$

3. Divide the total energy by the energy per repetition: $\text{repetitions} = \dfrac{150\text{ Cal}}{0.00843\text{ Cal/rep}} = \boxed{1.8 \times 10^4}$

Insight: Note that there are about 150 Calories in one-half of a standard size Snickers® candy bar. In order to do 17,800 repetitions to "work off" this half a candy bar, at the rate of 1 repetition every 2 seconds, it will take you almost 10 h! However, your body consumes much more food energy during the lifting process than the change of gravitational potential energy, and many fewer repetitions would actually be necessary.

33. **Picture the Problem:** Thermal energy is added to an aluminum bar, causing its temperature to increase.

Strategy: Solve the specific heat capacity equation for the change in temperature of the aluminum bar. The specific heat of aluminum is given in Table 10.2.

Solution: Solve the specific heat capacity for the final temperature:

$$c = \frac{Q}{m\Delta T} = \frac{Q}{m\left(T_\text{f} - T_\text{i}\right)}$$

$$T_\text{f} = T_\text{i} + \frac{Q}{mc} = 22.5\text{ °C} + \frac{79.3\text{ J}}{(0.111\text{ kg})[900\text{ J/(kg·°C)}]} = \boxed{23.3\text{ °C}}$$

Insight: The relatively large specific heat of aluminum results in a small change in temperature. If the bar were made of lead, with a specific heat of only 128 J/kg·°C, the final temperature would be 28.1°C.

34. **Picture the Problem:** Thermal energy is added to a glass ball, resulting in an increase in temperature.

Strategy: Use the specific heat capacity equation to find the thermal energy necessary to increase the temperature. The specific heat of glass is given in Table 10.2.

Solution: Calculate the required thermal energy: $Q = mc\Delta T = (0.055\text{ kg})[837\text{ J/(kg·°C)}](15\text{ °C}) = \boxed{0.69\text{ kJ}}$

Insight: The change in temperature is proportional to the heat added. Doubling the heat added would result in a temperature change of 30°C.

35. **Picture the Problem:** This is a follow-up question to Guided Example 10.9. A 0.50-kg block of metal with an initial temperature of 54.5 °C is dropped into a calorimeter holding 0.50 kg of water at 20.0 °C. Assume that the calorimeter can be ignored and that no thermal energy is exchanged with the surroundings.

Strategy: Thermal energy flows from the block to the water. Set the energy flow out of the block plus the energy flow into the water equal to zero (conservation of energy). The final temperature for both the block and the water is T. The initial temperature of the block is T_b, and the initial temperature of the water is T_w. Therefore, the change in temperature, $\Delta T = T_\text{f} - T_\text{i}$, for the block is $\Delta T = T - T_\text{b}$, and for the water it is $\Delta T = T - T_\text{w}$. Solve the resulting expression for T. The specific heat of water is 4186 J/(kg·°C) and the specific heat of the metal is 390 J/(kg·°C).

Solution: 1. Apply conservation of energy by setting the sum of the energies equal to zero:

$$Q_\text{block} + Q_\text{water} = 0$$

$$m_\text{b}c_\text{b}\left(T - T_\text{b}\right) + m_\text{w}c_\text{w}\left(T - T_\text{w}\right) = 0$$

2. Collect terms and rearrange to solve for T:

$$m_\text{b}c_\text{b}T + m_\text{w}c_\text{w}T = m_\text{b}c_\text{b}T_\text{b} + m_\text{w}c_\text{w}T_\text{w}$$

$$T = \frac{m_\text{b}c_\text{b}T_\text{b} + m_\text{w}c_\text{w}T_\text{w}}{m_\text{b}c_\text{b} + m_\text{w}c_\text{w}}$$

3. Cancel the masses because they are all 0.50 kg, then substitute the numerical values:

$$T = \frac{\cancel{m_\text{b}}c_\text{b}T_\text{b} + \cancel{m_\text{w}}c_\text{w}T_\text{w}}{\cancel{m_\text{b}}c_\text{b} + \cancel{m_\text{w}}c_\text{w}}$$

$$= \frac{[390\text{ J/(kg·°C)}](54.5\text{ °C}) + [4186\text{ J/(kg·°C)}](20.0\text{ °C})}{390 + 4186\text{ J/(kg·°C)}} = \boxed{22.9\text{ °C}}$$

Insight: With less cold water available to absorb the thermal energy from the warm metal, the final temperature of the system is higher than the 21.4°C that resulted when the metal was placed in 1.1 kg of water.

36. **Picture the Problem:** Thermal energy transfers from a hot lead ball to cool water, causing the lead to cool and the water to heat up. Eventually the water and lead will have the same equilibrium temperature.

    Strategy: Thermal energy flows from the ball to the water. Set the energy flow out of the ball plus the energy flow into the water equal to zero (conservation of energy). The final temperature for both the ball and the water is T. The initial temperature of the ball is T_b, and the initial temperature of the water is T_w. Therefore, the change in temperature, $\Delta T = T_f - T_i$, for the ball is $\Delta T = T - T_b$, and for the water it is $\Delta T = T - T_w$. Solve the resulting expression for T. The specific heats of water and lead are given in Table 10.2.

    Solution: 1. Apply conservation of energy by setting the sum of the energies equal to zero:

    $$Q_{\text{ball}} + Q_{\text{water}} = 0$$
    $$m_b c_b (T - T_b) + m_w c_w (T - T_w) = 0$$

    2. Collect terms and rearrange to solve for T:

    $$m_b c_b T + m_w c_w T = m_b c_b T_b + m_w c_w T_w$$
    $$T = \frac{m_b c_b T_b + m_w c_w T_w}{m_b c_b + m_w c_w}$$

    3. Substitute the numerical values:

    $$T = \frac{\begin{bmatrix}(0.235\text{ kg})[128\text{ J/(kg}\cdot{}^\circ\text{C)}](84.2\,{}^\circ\text{C}) \\ +\quad 0.177\text{ kg}[4186\text{ J/(kg}\cdot{}^\circ\text{C)}](21.5\,{}^\circ\text{C})\end{bmatrix}}{(0.235\text{ kg})[128\text{ J/(kg}\cdot{}^\circ\text{C)}] + (0.177\text{ kg})[4186\text{ J/(kg}\cdot{}^\circ\text{C)}]} = \boxed{23.9\,{}^\circ\text{C}}$$

    Insight: Because the specific heat of water is greater than the specific heat of lead, the final temperature is much closer to the initial temperature of the water.

37. Your friend is right. James Prescott Joule's experiment showed that stirring a liquid will increase its temperature because frictional forces in the fluid will convert mechanical energy into thermal energy.

38. A substance with a large specific heat capacity requires more heat for a given temperature change than does a substance with a low specific heat capacity.

39. A calorimeter is designed with substantial insulation to minimize thermal energy exchange with the surroundings. This ensures that any energy lost by the hot substances inside the calorimeter is gained by the cold substances, and no heat is exchanged with the environment outside the calorimeter.

40. A substance with a large specific heat capacity has a smaller temperature change for a given amount of thermal energy than does a substance with a low specific heat capacity. We conclude that the specific heat capacity of object A is less than the specific heat capacity of object B.

41. The specific heat capacity of a substance is the energy per kilogram required to change the temperature by 1°C. It is an intensive property; that is, its value does not depend on the mass of the substance. Therefore, the specific heat capacity of a large block of gold is equal to the specific heat capacity of a small gold coin.

42. **Picture the Problem:** Thermal energy is added to a piece of copper pipe, resulting in an increase in temperature.

    Strategy: Use the specific heat capacity equation to find the thermal energy necessary to increase the temperature. The specific heat of copper is given in Table 10.2.

    Solution: Calculate the required thermal energy: $Q = mc\Delta T = (0.75\text{ kg})[387\text{ J/(kg}\cdot{}^\circ\text{C)}](15\,{}^\circ\text{C}) = \boxed{4.4\text{ kJ}}$

    Insight: The change in temperature is proportional to the heat added. Doubling the heat added would result in a temperature change of 30°C.

43. **Picture the Problem:** As heat is added to an orange, its temperature increases.

Strategy: Use the specific heat capacity equation to find the heat necessary to increase the temperature. Because an orange is mostly water, use the specific heat of water, found in Table 10.2, to approximate that for an orange.

Solution: Calculate the required thermal energy: $Q = mc\Delta T = (0.20\text{ kg})[4186\text{ J/(kg}\cdot{}^\circ\text{C)}](22-15^\circ\text{C}) = \boxed{5.9\text{ kJ}}$

Insight: When you eat the orange, your body raises the orange's temperature from 22°C to body temperature (roughly 37°C). The heat required to do this is 12.6 kJ, or 3.0 Calories. The chemical (food) energy in the orange is approximately 65 Calories. Therefore, eating the 22-°C orange gives your body a net gain of 62 Calories.

44. **Picture the Problem:** Thermal energy is added to a block of ice, causing its temperature to increase.

Strategy: Solve the specific heat capacity equation for the change in temperature of the ice. The specific heat of ice is given in Table 10.2.

Solution: Solve the specific heat capacity for the final temperature:

$$c = \frac{Q}{m\Delta T} = \frac{Q}{m(T_\text{f} - T_\text{i})}$$

$$T_\text{f} = T_\text{i} + \frac{Q}{mc} = -10\,^\circ\text{C} + \frac{6200\text{ J}}{(1.4\text{ kg})[2090\text{ J/(kg}\cdot{}^\circ\text{C)}]} = \boxed{-7.9\,^\circ\text{C}}$$

Insight: The relatively large specific heat of ice results in a small change in temperature. If the block were made of lead, with a specific heat of only 128 J/kg·K, the final temperature would be 24.6°C.

45. **Picture the Problem:** A lead bullet traveling at 250 m/s has kinetic energy. As the bullet encounters a fence post it slows to a stop, converting its kinetic energy to thermal energy. Half of the energy heats the bullet and increases the bullet's temperature.

Strategy: Solve the specific heat capacity equation for the change in temperature. Set the heat equal to one-half of the initial kinetic energy of the bullet. The specific heat of lead is given in Table 10.2.

Solution: Set Q equal to half the initial kinetic energy and solve for ΔT:

$$\Delta T = \frac{Q}{mc} = \frac{\frac{1}{2}KE}{mc} = \frac{\frac{1}{2}\left(\frac{1}{2}mv^2\right)}{mc} = \frac{v^2}{4c} = \frac{(250\text{ m/s})^2}{4[128\text{ J/(kg}\cdot\text{K)}]} = \boxed{120\text{ K}}$$

Insight: The relatively small specific heat of lead leads to this large increase in temperature. A silver bullet traveling at the same speed would only heat up by 68 K.

46. **Picture the Problem:** Steam is made by adding heat to water that is initially at 100°C.

Strategy: Use the latent heat equation to calculate how much heat must be added to the water to convert it to steam.

Solution: Calculate the heat that must be added: $Q = mL_\text{v} = 1.26\text{ kg}(22.6\times10^5\text{J/kg}) = \boxed{2.8\times10^6\text{ J}}$

Insight: The same amount of heat removed from the steam at 100°C will convert it back to water.

47. Two phases are in equilibrium as long as the number of particles returning to one phase equals the number leaving the other phase. This can be verified in the lab by monitoring the mass of one of the two (or three) phases that are in contact with each other, ensuring that the mass of that phase remains constant.

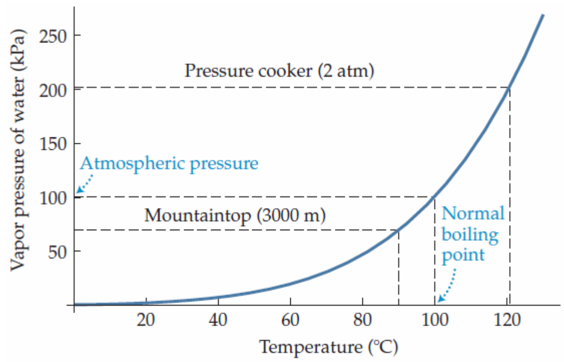
48. Energy must be added to a drop of sweat in order to provide the latent heat of vaporization necessary for converting the liquid water into vapor. This energy comes from your body, and as energy is extracted from your skin to evaporate the sweat, your body is cooled.

49. Latent heat is the thermal energy required to change 1 kilogram of a substance from one phase to another. During the conversion process from one phase to another, the temperature of the system remains constant.

50. Force per area is called *pressure*.

51. The pressure of a gas that is in equilibrium with its liquid phase is called *vapor pressure*.

52. **Picture the Problem:** Water is at equilibrium for a variety of temperatures and pressures.



Strategy: Use the equilibrium vapor pressure curve to decide whether water is a liquid or a gas at the specified temperatures and pressures. If the boiling point at the specified pressure is higher than the given temperature, the water exists as a liquid.

Solution: 1. (a) In the 2-atm pressure cooker and at 80°C water is a $\boxed{\text{liquid}}$ because the boiling point is 120°C.

2. (b) In the 2-atm pressure cooker and at 140°C water is a $\boxed{\text{vapor}}$ because the boiling point is 120°C.

3. (c) At the mountaintop and 100°C water is a $\boxed{\text{vapor}}$ because the boiling point is 90°C.

4. (d) At the mountaintop and 60°C water is a $\boxed{\text{liquid}}$ because the boiling point is 90°C.

Insight: The low boiling point at the mountaintop means that food cooking times and procedures must be modified at high altitude for best results.

53. **Picture the Problem:** Ice is made by extracting heat from water that is initially at 0°C.

Strategy: Use the latent heat equation to calculate how much heat must be extracted from the water to convert it to ice.

Solution: Calculate the heat that must be removed: $Q = mL_\text{f} = (0.96\text{ kg})(33.5\times10^4\text{ J/kg}) = \boxed{3.2\times10^5\text{ J}}$

Insight: The same amount of heat flowing into the ice at 0°C will convert it back to water.

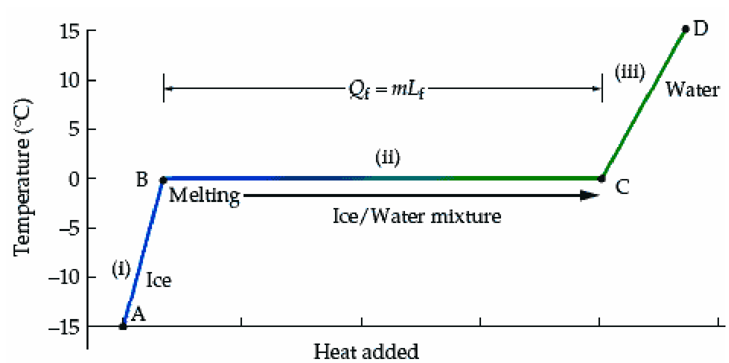
54. **Picture the Problem:** Steam is made by adding heat to water that is initially at 100°C.

Strategy: Use the latent heat equation to calculate how much heat must be added to the water to convert it to steam.

Solution: Calculate the heat that must be added: $Q = mL_\text{v} = (0.96\text{ kg})(22.6\times10^5\text{ J/kg}) = \boxed{2.2\times10^6\text{ J}}$

Insight: The same amount of heat removed from the steam at 100°C will convert it back to water.

55. **Picture the Problem:** As thermal energy is added to ice initially at −15°C, the heat first increases the temperature to the melting point, then melts the ice, and finally raises the temperature of the melted water to 15°C.



Strategy: Set the total heat equal to the sum of the heat needed to (i) raise the ice to the melting point, (ii) melt the ice, and (iii) increase the water to the final temperature. Solve the resulting equation for the mass.

Solution: 1. Sum the heats using the appropriate expressions:

$$Q = Q_\text{i} + Q_\text{ii} + Q_\text{iii}$$
$$= mc_\text{ice}(\Delta T)_1 + mL_\text{f} + mc_\text{water}(\Delta T)_2$$
$$Q = m\left[c_\text{ice}(\Delta T)_1 + L_\text{f} + c_\text{water}(\Delta T)_2\right]$$

2. Solve for the mass:

$$m = \frac{Q}{c_{\text{ice}}\left(\Delta T\right)_1 + L_{\text{f}} + c_{\text{water}}\left(\Delta T\right)_2}$$

$$= \frac{9.5\times10^5\ \text{J}}{\left[2090\ \text{J/(kg}\cdot{}^\circ\text{C)}\right]\left(15\,{}^\circ\text{C}\right) + 33.5\times10^4\,\text{J/kg} + \left[4186\ \text{J/(kg}\cdot{}^\circ\text{C)}\right]\left(15\,{}^\circ\text{C}\right)}$$

$$m = \boxed{2.2\ \text{kg}}$$

Insight: From the mass we can calculate the amount of thermal energy used in each of the three processes: $Q_{\text{i}} = 69.4$ kJ, $Q_{\text{ii}} = 742$ kJ, and $Q_{\text{iii}} = 139$ kJ. Most of the thermal energy is needed to melt the ice.

56. **Picture the Problem:** Thermal energy is added to copper at its melting point to convert it from solid to liquid.

Strategy: Calculate the thermal energy needed to melt copper from the latent heat equation.

Solution: Calculate the required heat: $Q = m\,L_{\text{f}} = \left(1.75\ \text{kg}\right)\left(20.7\times10^4\ \ \text{J/kg}\right) = 3.62\times10^5\ \text{J} = \boxed{362\ \text{kJ}}$

Insight: Extracting this same amount of heat from the liquid copper will convert it back to a solid.

57. Temperature is a measure of the average kinetic energy of the particles that comprise a system. Thermal energy is the total amount total amount of energy in the system, the sum of all of the kinetic and potential energy of the particles.

58. When an ice cube is thrown into a swimming pool the ice and the water are at different temperatures and are not in equilibrium. The temperature of the water will become slightly lower as the ice cube melts, but it will not become 0°C because the ice cube absorbs an insufficient amount of thermal energy to cool the water significantly.

59. A Kelvin has the same size as a Celsius degree, so a change in temperature of 20°C is equal to a change in temperature of 20 K.

60. A Celsius degree is larger than a Fahrenheit degree, so a change in temperature of 20°C is greater than a change in temperature of 20°F.

61. The Kelvin temperature scale has no negative values.

62. Boiling and freezing are not opposites; they are each an example of a phase change of water. The historical reasons for the numerical values of the Fahrenheit scale are complex, but they are not related to the 180° that separate opposite directions in geometry.

63. No. Heat is the energy that is transferred between objects of different temperatures; it is not a quantity that an object can "contain." However, a hot object does contain more thermal energy than an otherwise identical cold object.

64. **Picture the Problem:** The human body temperature in degrees Fahrenheit can be converted to degrees Celsius and kelvins.

Strategy: Use the conversion between degrees Fahrenheit and degrees Celsius to convert the Fahrenheit temperature to the Celsius temperature, and then convert the Celsius temperature to the Kelvin temperature.

Solution: 1. (a) Convert °F to °C: $T_{\text{C}} = \frac{5}{9}\left(98.6\,{}^\circ\text{F} - 32\,{}^\circ\text{F}\right) = \boxed{37.0\,{}^\circ\text{C}}$

2. (b) Convert °C into kelvins: $T = T_{\text{C}} + 273.15\ \text{K} = 37\ \text{K} + 273.15\ \text{K} = \boxed{310.2\ \text{K}}$

Insight: A person is said to have a fever if her temperature is above 100°F, which is 37.8°C.

65. **Picture the Problem:** A temperature is given in kelvins that can be converted to degrees Celsius.

Strategy: Subtract 273.15 from the Kelvin temperature to obtain the Celsius temperature.

Solution: Convert from Kelvin to Celsius: $T_C = T - 273.15\,°C = 1.0 - 273.15 = \boxed{-272.2\,°C}$

Insight: Note that our answer is close to absolute zero (−273.15 °C), as expected, because 1 K is close to absolute zero.

66. **Picture the Problem:** A freezer temperature in degrees Fahrenheit can be converted to degrees Celsius.

Strategy: Use the conversion between degrees Fahrenheit and degrees Celsius to convert the Fahrenheit temperature to the Celsius temperature.

Solution: Convert °F to °C: $T_C = \frac{5}{9}(30\,°F - 32\,°F) = \boxed{-1.1\,°C}$

Insight: A more typical freezer temperature is 0°F, which is −17.8°C.

67. **Picture the Problem:** The temperature of molten lava in degrees Celsius can be converted to kelvins and degrees Fahrenheit.

Strategy: Convert the Celsius temperature to the Kelvin temperature, and then use the conversion between degrees Celsius and degrees Fahrenheit to convert the Celsius temperature to the Fahrenheit temperature.

Solution: 1. (a) Convert °C into kelvins: $T = T_C + 273.15\text{ K} = 1200 + 273.15\text{ K} = \boxed{1473\text{ K}}$

2. (b) Convert °C to °F: $T_F = \frac{9}{5}T_C + 32 = \frac{9}{5}(1200) + 32 = \boxed{2192\,°F}$

Insight: An acetylene-oxygen flame used for welding burns at 3500°C, hot enough to melt rock!

68. **Picture the Problem:** A temperature has twice the value on the Fahrenheit scale as it reads on the Celsius scale.

Strategy: Set the value of the temperature in degrees Fahrenheit, T_F, equal to twice the value in degrees Celsius, T_C, by substituting a single variable T for T_C. Solve the resulting expression for T.

Solution: Set $T_C \overset{\text{set}}{=} T$, let $T_F = 2T$, and solve for T:

$$T_F = \frac{9}{5}T_C + 32$$

$$2T - \frac{9}{5}T = 32$$

$$T = \frac{32}{2 - 9/5} = 160°C \quad \Rightarrow T_F = 2T = \boxed{320°F}$$

Insight: A similar procedure shows that 58.18°F is four times greater than its corresponding temperature of 14.55°C.

69. **Picture the Problem:** An initial temperature of −4°F changes to 45°F in two minutes.

Strategy: We are asked to calculate the rate of change of the temperature in units of kelvins per second. Write the rate of change by dividing the temperature difference by the time. Then use unit conversions to convert the degrees Fahrenheit to kelvins and the minutes to seconds.

Solution: 1. Divide the change in temperature by the time: $\frac{\Delta T}{\Delta t} = \frac{45\,°F - (-4.0\,°F)}{2.0\text{ min}} = 24.5\ \frac{°F}{\text{min}}$

2. Convert the units: $\left(24.5\ \frac{°F}{\text{min}}\right)\left(\frac{1\text{ min}}{60\text{ s}}\right)\left(\frac{5\text{ K}}{9\,F°}\right) = \boxed{0.23\text{ K/s}}$

Insight: An alternative method of solving this problem would be to convert the temperatures to Kelvin and then divide by the time: $\frac{\Delta T}{\Delta t} = \frac{280.4\text{ K} - 253.2\text{ K}}{120\text{ s}} = 0.23\text{ K/s}.$

70. Heating the glass jar and its metal lid to the same higher temperature results in a greater expansion in the lid than in the glass, because the glass has a smaller coefficient of thermal expansion. As a result, the lid can become loose enough to turn.

71. As the temperature decreases, the wood and metal of which the house is constructed will contract at different rates. The house will often creak or groan as it adjusts to these changing lengths.

72. Updrafts are generally caused by different areas of the ground heating up at different rates on a sunny day. Air will rise faster over a warm patch of ground than it will over a relatively cool patch of ground, producing convective currents that circulate the air in the vertical direction.

73. A car will expand as it is heated, but the amount of expansion depends upon the initial length, the coefficient of thermal expansion, and the temperature change. Because the length of a car is longer than its height, the increase in the length of the car is greater than its increase in height for the same temperature change.

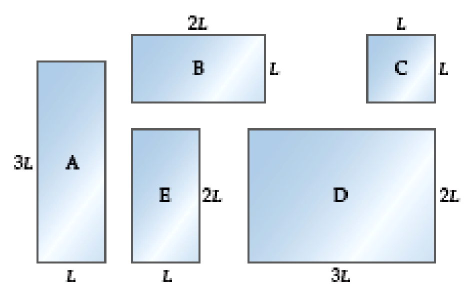
74. **Picture the Problem:** One bimetallic strip is made of copper and steel, and a second bimetallic strip is made of aluminum and steel.

Strategy: The bend in a bimetallic strip is due to the difference in the thermal expansion coefficients of the two metals. Compare the difference in thermal expansion coefficients for these two bimetallic strips.

Solution: The difference between thermal expansion coefficients for bimetallic strip A is $\alpha_{\text{Cu}} - \alpha_{\text{steel}} =$ $17 \times 10^{-6} - 12 \times 10^{-6}\ \text{K}^{-1} = 5{\times}10^{-6}\ \text{K}^{-1}$, whereas for bimetallic strip B it's $\alpha_{\text{Al}} - \alpha_{\text{steel}} = 24\times10^{-6} - 12\times10^{-6}\,\text{K}^{-1} =$ $12{\times}10^{-6}\ \text{K}^{-1}$. $\boxed{\text{Strip B}}$ has a larger coefficient difference and will therefore bend more than strip A for a given ΔT.

Insight: In other applications, such as reinforced concrete, the goal is to minimize the difference in coefficients of thermal expansion. Steel and concrete have nearly identical coefficients, so they expand and contract approximately the same amount for a given temperature difference.

75. **Picture the Problem:** The figure at right shows five metal plates, all at the same temperature and all made from the same material. They are all placed in an oven and heated by the same amount.



Strategy: Consider the expression for thermal expansion $\Delta L = \alpha L_i \Delta T$ to determine the rankings of the thermal expansions along the *x* and *y* directions.

Solution: 1. (a) The amount of expansion ΔL in any given direction is proportional to the initial length L_{i} in that direction. We conclude that along the vertical direction the ranking for ΔL is $\boxed{\text{B = C < D= E < A}}$.

2. (b) The amount of expansion ΔL in any given direction is proportional to the initial length L_{i} in that direction. We conclude that along the horizontal direction the ranking for ΔL is $\boxed{\text{A = C = E < B < D}}$.

Insight: If we were to rank the expansion along the diagonal direction $\ell = \sqrt{x^2 + y^2}$ we would arrive at the ranking C < B = E < A < D.

76. **Picture the Problem:** A brass plate has a circular hole whose diameter is slightly smaller than the diameter of an aluminum ball.

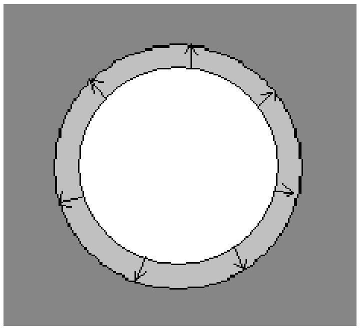
Strategy: The correct approach to get the ball through the hole depends upon the relative coefficients of thermal expansion. If the hole expands faster than the ball, the system should be heated. If the ball contracts faster than the hole, the system should be cooled.

Solution: 1. (a) The aluminum ball $(\alpha_{\text{Al}} = 24\times10^{-6}\,\text{K}^{-1})$ has a higher coefficient of thermal expansion than the brass ($\alpha_{\text{brass}} = 19\times10^{-6}\,\text{K}^{-1}$) hole. It will contract by a greater amount if it is cooled by the same amount as the brass. We conclude that the temperature of the system should be $\boxed{\text{decreased}}$ in order for the ball to fit through the hole.

2. (b) The best explanation is $\boxed{\text{A. The aluminum ball changes its diameter more with temperature than the brass plate changes its dimensions, and therefore the temperature should be decreased.}}$ Statement B is false, and statement C ignores the fact that the aluminum ball would expand at a faster rate than the brass if the system were heated.

Insight: It would also be possible to get the ball through the hole if the brass plate were heated but the aluminum ball was kept at the same temperature or cooled.

77. **Picture the Problem:** An aluminum plate has a hole cut in its center. The plate expands as it is heated.



Strategy: The hole will expand at the same rate as the aluminum. Because the diameter of the hole is the length that is expanding, use the thermal expansion equation to calculate the diameter as a function of the increase in temperature. The coefficient of thermal expansion is given in Table 10.1.

Solution: 1. Solve the thermal expansion equation for the final diameter:

$$\Delta d = d - d_\text{i} = \alpha d \Delta T$$
$$d = d_\text{i} + \alpha d_\text{i} \Delta T = d_\text{i}\left(1 + \alpha \Delta T\right)$$

2. Substitute the numerical values:

$$d = 1.178 \text{ cm}\left[1 + \left(2.4 \times 10^{-5} \text{ K}^{-1}\right)\left(199.0\,°\text{C} - 23.00\,°\text{C}\right)\right] = \boxed{1.183 \text{ cm}}$$

Insight: The diameter of the hole expanded by 0.0050 cm or 50 μm, about the width of a human hair.

78. **Picture the Problem:** A steel beam changes in length as its temperature is changed.

Strategy: Solve the thermal expansion equation for the temperature difference required to change the length of 5.5 m of steel by 0.0012 m. The coefficient of thermal expansion for steel is given in Table 10.1.

Solution: Solve for the temperature difference:

$$\Delta L = \alpha L_\text{i} \Delta T$$
$$\Delta T = \frac{\Delta L}{\alpha L_\text{i}} = \frac{0.0012 \text{ m}}{\left(1.2 \times 10^{-5} \text{ K}^{-1}\right)\left(5.5 \text{ m}\right)} = \boxed{18 \text{ K}}$$

Insight: The steel beam's length will either increase by 1.2 mm if its temperature increases by 18°C, or the length will decrease by 1.2 mm if its temperature decreases by 18°C.

79. **Picture the Problem:** The diameter of a metal ball changes when its temperature is changed.

Strategy: Solve the thermal expansion equation for the coefficient of thermal expansion. Compare its value to those given in Table 10.1 to determine which metal it might be.

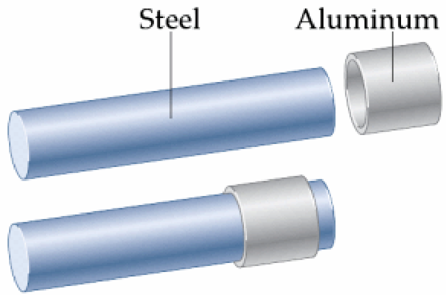
Solution: 1. Solve the thermal expansion equation for the coefficient:

$$\Delta L = \alpha L_\text{i} \Delta T$$
$$\alpha = \frac{\Delta L}{L_\text{i}\,\Delta T} = \frac{0.0022 \text{ m}}{\left(1.2 \text{ m}\right)\left(95 \text{ K}\right)} = \boxed{1.9 \times 10^{-5} \text{ K}^{-1}}$$

2. By comparing the value of the coefficient of thermal expansion with those listed in Table 10.1, we conclude that the metal is most likely to be $\boxed{\text{brass}}$.

Insight: A brass ball 1.20 m in diameter would have a volume of 0.905 m^3 and a mass of 7740 kg, almost 8 metric tons!

80. **Picture the Problem:** A steel bar has a larger diameter than an aluminum ring that must slip over the bar.



Strategy: Use the thermal expansion equation to calculate the temperature at which the ring's inner diameter will equal the diameter of the bar. The coefficient of thermal expansion is given in Table 10.1.

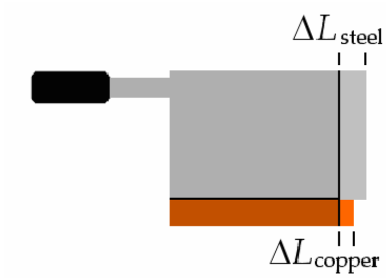
Solution: 1. (a) The ring should be $\boxed{\text{heated}}$. The reasoning in Conceptual Example 10.5 explains how both the inside and outside diameters of the aluminum ring will expand according to the thermal expansion equation.

2. (b) Solve the thermal expansion equation for the change in temperature: $\Delta d = \alpha d \Delta T \quad \Rightarrow \quad \Delta T = T - T_0 = \dfrac{\Delta d}{\alpha d}$

3. Solve for the final temperature: $T = T_{\text{i}} + \dfrac{\Delta d}{\alpha d_{\text{i}}} = 10.00\ ^\circ\text{C} + \dfrac{4.040\ \text{cm} - 4.000\ \text{cm}}{\left(2.4\times10^{-5}\ \text{K}^{-1}\right)\left(4.000\ \text{cm}\right)} = \boxed{430\ ^\circ\text{C}}$

Insight: When the aluminum is heated to 430℃ it will slip over the steel rod. As it cools back down it will shrink to form a tight bond with the steel. The melting point of aluminum is 660°C, so it will remain solid during the process.

81. **Picture the Problem:** When it is at room temperature, a stainless steel pot has the same diameter as the pot's copper bottom. When the pot is heated, the steel expands faster than the copper, causing a difference in diameters.



Strategy: Use the given coefficients of expansion and the thermal expansion equation to calculate the diameter changes of the steel and copper when the temperature is 610℃.

Solution: 1. Write the thermal expansion equations for copper and steel:

$$\Delta d_{\text{copper}} = \alpha_{\text{copper}} d_{\text{i}} \Delta T$$
$$\Delta d_{\text{steel}} = \alpha_{\text{steel}} d_{\text{i}} \Delta T$$

2. Subtract the two differences:

$$\Delta d_{\text{steel}} - \Delta d_{\text{copper}} = \left(\alpha_{\text{steel}} - \alpha_{\text{copper}}\right) d_{\text{i}}\ \Delta T$$
$$= \left(1.73\times10^{-5} - 1.70\times10^{-5}\ \text{K}^{-1}\right)\left(21\ \text{cm}\right)\left(610 - 22\ ^\circ\text{C}\right)$$
$$\Delta d_{\text{steel}} - \Delta d_{\text{copper}} = \boxed{0.0037\ \text{cm}} = 37\ \mu\text{m}$$

Insight: Because the coefficients of expansion between stainless steel and copper are similar (less than 2% difference) the difference in expansion is small. If normal steel ($\alpha = 1.2\times10^{-5}\ \text{K}^{-1}$) were used instead of stainless steel, the difference in diameters would be 0.062 cm, enough to break the pan apart.

82. The temperature change of an object is given by $\Delta T = Q/mc$. If two different objects receive the same amount of thermal energy Q, their temperature changes may still be different if their masses m or specific heat capacities c are different. Furthermore, any phase changes that occur for either substance will affect the temperature change.

83. One kilocalorie of energy is the same as 4186 joules. Because the specific heat of water is 4186 J/(kg·°C), we conclude that the temperature of one kilogram of water will increase by 1.0°C when one kilocalorie of energy is added.

84. Water has a very high specific heat, and the energy from the lighted match is insufficient to warm the water by very much. The water is also better than air at conducting the heat from the match flame away from the balloon's surface. The water thus keeps the latex balloon's temperature below its melting point, and the water-filled balloon does not burst.

85. **Picture the Problem:** A certain amount of thermal energy is transferred to 2 kg of aluminum, and the same amount of thermal energy is transferred to 1 kg of ice.

Strategy: The thermal energy exchanged will be the same for each object, but the temperature change $\Delta T = Q/mc$ of each object is inversely proportional to its heat capacity mc.

Solution: 1. (a) The heat capacity of the aluminum is $mc = (2\ \text{kg})(900\ \text{J/kg}\cdot\text{K}) = 1800\ \text{J/K}$, and the heat capacity of the ice is $mc = (1\ \text{kg})(2090\ \text{J/kg}\cdot\text{K}) = 2090\ \text{J/K}$. The aluminum, which has the smaller heat capacity mc, will have the greatest change in temperature. Thus, the increase in temperature of the aluminum is $\boxed{\text{greater than}}$ the increase in temperature of the ice.

2. (b) The best explanation is $\boxed{\text{A. Twice the specific heat capacity of aluminum is less than the specific heat capacity of ice, and hence the aluminum has the greater temperature change.}}$ Statement B is false because the mass of the aluminum is greater than that of the ice, and statement C is false because it ignores differences in heat capacities.

Insight: Statement B also ignores the fact that the heat capacity of an object depends upon both its mass and its specific heat capacity, so the mass alone is not enough information with which to predict the temperature change for a given heat input.

86. **Picture the Problem:** You have 0.5 kg of isopropyl alcohol at the temperature 20°C in one container, and 0.5 kg of water at the temperature 30°C in a second container. The two fluids are then poured into the same container and allowed to come to thermal equilibrium.

Strategy: Use the principles of specific heat and conservation of energy to answer the conceptual question.

Solution: 1. (a) The heat capacity of the isopropyl alcohol $m_a c_a$ is about half that of the water because the masses are the same but $c_a \cong \frac{1}{2} c_w$. The same amount of thermal energy that is removed from the warm water will enter the cool alcohol, but due to the smaller heat capacity the temperature of the alcohol increases more than the temperature of the water decreases ($\Delta T = Q/mc$). Therefore, the final temperature will be closer to the initial water temperature (30°C) than to the initial alcohol temperature (20°C); that is, the final temperature will be $\boxed{\text{greater than}}$ 25°C.

2. (b) The best explanation is $\boxed{\textbf{B.}\text{ More thermal energy is required to change the temperature of water than to change the temperature of isopropyl alcohol. Therefore, the final temperature will be greater than 25°C}}$. Statement A is false and statement C ignores the difference in the specific heat capacities of the water and the alcohol.

Insight: The final temperature would be 25°C only if the specific heat capacities of the two liquids were identical.

87. **Picture the Problem:** Thermal energy is removed from a piece of iron, causing its temperature to decrease.

Strategy: Solve the specific heat capacity equation for the final temperature of the iron. The specific heat of iron is given in Table 10.2. The value of Q is negative because thermal energy is removed from the iron.

Solution: Solve the specific heat capacity for the final temperature:

$$c = \frac{Q}{m\Delta T} = \frac{Q}{m\left(T_f - T_i\right)}$$

$$T_f = T_i + \frac{Q}{mc} = 26.5\ ^\circ\text{C} + \frac{-66.2\ \text{J}}{\left(0.141\ \text{kg}\right)\left[448\ \text{J/(kg}\cdot{}^\circ\text{C)}\right]} = \boxed{25.5\ ^\circ\text{C}}$$

Insight: The relatively large specific heat of iron results in a small change in temperature. If the metal piece had been made of lead, with a specific heat of only 128 J/kg·K, the final temperature would have been 22.8°C.

88. **Picture the Problem:** Thermal energy is removed from a chunk of ice, resulting in a decrease in temperature.

Strategy: Use the specific heat capacity equation to find the thermal energy that must be removed to decrease the temperature. The specific heat of ice is given in Table 10.2.

Solution: Calculate the required thermal energy:

$$Q = mc\Delta T = \left(0.21\ \text{kg}\right)\left[2090\ \text{J/(kg}\cdot{}^\circ\text{C)}\right]\left(-7.5\ ^\circ\text{C}\right) = \boxed{-3.3\ \text{kJ}}$$

Insight: The change in temperature is proportional to the heat removed. Doubling the heat removed would result in a temperature change of −15°C.

89. **Picture the Problem:** As thermal energy is added to an apple, its temperature increases.

Strategy: Use the specific heat equation to find the thermal energy necessary to increase the temperature. Because an apple is mostly water, use the specific heat of water, found in Table 10.1, to approximate that of an apple.

Solution: Calculate the thermal energy required:

$$Q = mc\Delta T = \left(0.15\ \text{kg}\right)\left[4186\ \text{J/}\left(\text{kg}\cdot\text{K}\right)\right]\left(36 - 12\ ^\circ\text{C}\right) = \boxed{15\ \text{kJ}}$$

Insight: When you eat an apple, your body raises the apple's temperature (roughly 20°C if it is at room temperature) to body temperature (roughly 37°C). The heat required to do this is 11 kJ, or 2.6 Calories.

90. **Picture the Problem:** The metabolic rate is the number of calories expended in bodily functions per second per kilogram.

Strategy: Multiply the metabolic rate by the person's mass to calculate the calories expended per second. Multiply this result by 8.0 hours to calculate the calories expended in a full night's sleep.

Solution: Multiply together the metabolic rate, mass, and time:

$$\left[2.6\times10^{-4}\,\text{Cal}/(\text{s}\cdot\text{kg})\right](75\text{ kg})(8.0\text{ h})\left(\frac{3600\text{ s}}{\text{h}}\right)=\boxed{560\text{ Cal}}$$

Insight: Extending this metabolic rate to a full day (24 hrs) shows that a person needs to consume a minimum of 1680 Calories, on average, per day, in order to support their metabolic rate.

91. **Picture the Problem:** An exercise machine records work in units of Calories and time in minutes. We wish to calculate the rate at which work is done (power) in units of watts and horsepower.

Strategy: Divide the work by the time elapsed to calculate the power. Convert calories to joules and convert watts to horsepower to obtain the desired units.

Solution: 1. Divide the work by the time to calculate power:

$$P=\frac{\Delta E}{\Delta t}=\left(\frac{2.5\text{ Cal}}{1.5\text{ min}}\right)\left(\frac{1\text{ min}}{60\text{ s}}\right)\left(\frac{4186\text{ J}}{\text{Cal}}\right)=116\text{ W}=\boxed{0.12\text{ kW}}$$

2. Convert to horsepower:

$$P=(116.3\text{ W})\left(\frac{1.0\text{ hp}}{746\text{ W}}\right)=\boxed{0.16\text{ hp}}$$

Insight: The power expended on the machine is more than sufficient to light a 100-W light bulb.

92. **Picture the Problem:** Thermal energy is transferred from a hot horseshoe to cold water. This decreases the temperature of the horseshoe and increases the temperature of the water until the water and horseshoe are at the same equilibrium temperature.

Strategy: Thermal energy flows from the horseshoe to the water. Set the energy flow out of the horseshoe plus the energy flow into the water equal to zero (conservation of energy). The final temperature for both the horseshoe and the water is T. The initial temperature of the horseshoe is T_h, and the initial temperature of the water is T_w. Therefore, the change in temperature, $\Delta T=T_f-T_i$, for the horseshoe is $\Delta T=T-T_h$, and for the water it is $\Delta T=T-T_w$. Solve the resulting expression for T. The specific heats of water and iron are given in Table 10.2.

Solution: 1. Apply conservation of energy by setting the sum of the energies equal to zero:

$$Q_{\text{horseshoe}}+Q_{\text{water}}=0$$
$$m_hc_h\left(T-T_h\right)+m_wc_w\left(T-T_w\right)=0$$

2. Collect terms and rearrange to solve for T:

$$m_hc_hT+m_wc_wT=m_hc_hT_h+m_wc_wT_w$$
$$T=\frac{m_hc_hT_h+m_wc_wT_w}{m_hc_h+m_wc_w}$$

3. Substitute the numerical values:

$$T=\frac{\left[\begin{array}{l}(0.50\text{ kg})\left[448\text{ J/(kg}\cdot{}^\circ\text{C)}\right](450\,{}^\circ\text{C})\\+\quad 25\text{ kg}\left[4186\text{ J/(kg}\cdot{}^\circ\text{C)}\right](23\,{}^\circ\text{C})\end{array}\right]}{(0.50\text{ kg})\left[448\text{ J/(kg}\cdot{}^\circ\text{C)}\right]+(25\text{ kg})\left[4186\text{ J/(kg}\cdot{}^\circ\text{C)}\right]}=\boxed{24\,{}^\circ\text{C}}$$

Insight: The temperature change of the water is only 1°C while the temperature change of the horseshoe is 426°C. This is due to the smaller mass and smaller specific heat capacity of the iron when compared with the water.

93. **Picture the Problem:** Thermal energy transfers from a hot lead ball to cool water, causing the lead to cool and the water to heat up. Eventually the water and lead will have the same equilibrium temperature.

Strategy: Thermal energy flows from the ball to the water. Set the energy flow out of the ball plus the energy flow into the water equal to zero (conservation of energy). The final temperature for both the ball and the water is T. The initial temperature of the ball is T_b, and the initial temperature of the water is T_w. Therefore, the change in temperature, $\Delta T=T_f-T_i$, for the ball is $\Delta T=T-T_b$, and for the water it is $\Delta T=T-T_w$. Solve the resulting expression for T. The specific heats of water and lead are given in Table 10.2.

Solution: 1. Apply conservation of energy by setting the sum of the energies equal to zero:

$$Q_{\text{ball}}+Q_{\text{water}}=0$$
$$m_bc_b\left(T-T_b\right)+m_wc_w\left(T-T_w\right)=0$$

2. Collect terms and rearrange to solve for T:

$$m_b c_b T + m_w c_w T = m_b c_b T_b + m_w c_w T_w$$

$$T = \frac{m_b c_b T_b + m_w c_w T_w}{m_b c_b + m_w c_w}$$

3. Substitute the numerical values:

$$T = \frac{\begin{bmatrix}(0.235\text{ kg})[128\text{ J/(kg}\cdot{}^\circ\text{C)}](84.2\,^\circ\text{C}) \\ +\quad 0.177\text{ kg}[4186\text{ J/(kg}\cdot{}^\circ\text{C)}](21.5\,^\circ\text{C})\end{bmatrix}}{(0.235\text{ kg})[128\text{ J/(kg}\cdot{}^\circ\text{C)}]+(0.177\text{ kg})[4186\text{ J/(kg}\cdot{}^\circ\text{C)}]} = \boxed{23.9\,^\circ\text{C}}$$

Insight: Because the specific heat of water is greater than the specific heat of lead, the final temperature is much closer to the initial temperature of the water.

94. **Picture the Problem:** As hot silver pellets are dropped into a container of cool water, heat transfers from the pellets to the water. This results in a decrease in the temperature of the pellets and an increase in the temperature of the water.

Strategy: Use conservation of energy to set the sum of the thermal energy lost by the silver and the thermal energy gained by the water equal to zero. Solve the resulting equation for the mass of the silver that gives a final temperature of 25°C. Divide the resulting mass by the mass of each silver pellet to calculate the number of pellets needed. For the copper pellets, repeat the same calculation, but substitute the specific heat of copper. The specific heats of water, silver, and copper are found in Table 10.2.

Solution: 1. (a) Set the net heat transfer to zero:

$$Q_{Ag} + Q_w = 0$$

$$m_{Ag} c_{Ag}\left(T - T_{Ag}\right) + m_w c_w\left(T - T_w\right) = 0$$

2. Solve for the mass of silver:

$$m_{Ag} = \frac{m_w c_w\left(T_w - T\right)}{c_{Ag}\left(T - T_{Ag}\right)}$$

$$= \frac{0.220\text{ kg}\left[4186\text{ J/}\left(\text{kg}\cdot\text{K}\right)\right](14-25)^\circ\text{C}}{\left[234\text{ J/}\left(\text{kg}\cdot\text{K}\right)\right](25-85)^\circ\text{C}} = \underline{\underline{0.722\text{ kg}}}$$

3. Divide by the mass of one pellet:

$$n = \frac{m_{Ag}}{m_{pellet}} = \frac{0.722\text{ kg}}{0.0010\text{ kg}} = 722\text{ pellets} = \boxed{7.2\times10^2\text{ pellets}}$$

4. (b) Copper has a higher specific heat capacity, which implies that the same mass of copper will transfer more thermal energy than is needed, so the required number of pellets would $\boxed{\text{decrease}}$.

5. (c) Solve the conservation of energy equation for the mass of copper:

$$m_{Cu} = \frac{m_w c_w\left(T_w - T\right)}{c_{Cu}\left(T - T_{Cu}\right)}$$

$$= \frac{(0.220\text{ kg})\left[4186\text{ J/}\left(\text{kg}\cdot\text{K}\right)\right](14-25)^\circ\text{C}}{\left[387\text{ J/}\left(\text{kg}\cdot\text{K}\right)\right](25-85)^\circ\text{C}} = \underline{\underline{0.436\text{ kg}}}$$

6. Divide by the mass of one pellet:

$$n = \frac{m_{Cu}}{m_{pellet}} = \frac{0.436\text{ kg}}{0.0010\text{ kg}} = 436\text{ pellets} = \boxed{4.4\times10^2\text{ pellets}}$$

Insight: The amount of thermal energy needed to increase the water's temperature does not depend on whether silver or copper pellets provide the energy. Because the copper has a higher specific heat, each pellet is able to transfer more heat to the water, so fewer copper pellets are needed.

95. **Picture the Problem:** A hot object is immersed in water in an aluminum calorimeter cup. Heat transfers from the hot object to the cold water and cup, causing the temperature of the object to decrease and the temperature of the water and aluminum cup to increase.

Strategy: Assume that thermal energy is only transferred between the water, cup, and object, and use conservation of energy to set the net heat transfer to zero. Solve the resulting expression for the specific heat capacity of the unknown object, and use Table 10.2 to identify its composition.

Solution: 1. Let $\sum Q = 0$ and solve for Q_{object}. Use the specific heat equation to expand the resulting expression:

$$0 = Q_{\text{object}} + Q_{\text{w}} + Q_{\text{Al}}$$
$$Q_{\text{object}} = -(Q_{\text{w}} + Q_{\text{Al}})$$
$$m_{\text{object}} c_{\text{object}} \Delta T_{\text{object}} = -(m_{\text{w}} c_{\text{w}} + m_{\text{Al}} c_{\text{Al}}) \Delta T_{\text{w}}$$

2. Solve for the specific heat of the object and substitute the numerical values:

$$c_{\text{object}} = \frac{-(m_{\text{w}} c_{\text{w}} + m_{\text{Al}} c_{\text{Al}})(T - T_{\text{w}})}{m_{\text{object}}(T - T_{\text{object}})}$$
$$= \frac{-(0.103\text{ kg}[4186\text{ J/(kg}\cdot{}^\circ\text{C)}] + 0.155\text{ kg}[900\text{ J/(kg}\cdot{}^\circ\text{C)}])(22 - 20\,{}^\circ\text{C})}{(0.0380\text{ kg})(22.0 - 100\,{}^\circ\text{C})}$$
$$c_{\text{object}} = \boxed{385\text{ J/(kg}\cdot{}^\circ\text{C)}}$$

3. Look up the specific heat in Table 10.2:

The object is made of $\boxed{\text{copper}}$.

Insight: It is important to include the effect of the aluminum cup in this calculation. If the contribution of the cup were excluded, the specific heat of the object would have been calculated as 291 J/(kg °C).

96. **Picture the Problem:** As coffee and cream are poured and mixed in a ceramic cup, thermal energy is transferred between the three objects until they have the same equilibrium temperature.

Strategy: Set the net heat transfer by the coffee, cream, and cup equal to zero because no heat leaves the system. Then use the specific heat equation to solve for the equilibrium temperature. The specific heat of ceramic is given in the problem. Use the specific heat of water (from Table 10.2) for the specific heat of the coffee and cream.

Solution: 1. Set the sum of the heats equal to zero:

$$0 = Q_{\text{cup}} + Q_{\text{cof}} + Q_{\text{crm}}$$
$$= m_{\text{cup}} c_{\text{cup}} (T - T_{\text{cup}}) + m_{\text{cof}} c_{\text{w}} (T - T_{\text{cof}}) + m_{\text{crm}} c_{\text{w}} (T - T_{\text{crm}})$$
$$0 = T\left[m_{\text{cup}} c_{\text{cup}} + (m_{\text{cof}} + m_{\text{crm}}) c_{\text{w}}\right] - \left[m_{\text{cup}} c_{\text{cup}} T_{\text{cup}} + (m_{\text{cof}} T_{\text{cof}} + m_{\text{crm}} T_{\text{crm}}) c_{\text{w}}\right]$$

2. Solve for the equilibrium temperature:

$$T = \frac{m_{\text{cup}} c_{\text{cup}} T_{\text{cup}} + (m_{\text{cof}} T_{\text{cof}} + m_{\text{crm}} T_{\text{crm}}) c_{\text{w}}}{m_{\text{cup}} c_{\text{cup}} + (m_{\text{cof}} + m_{\text{crm}}) c_{\text{w}}}$$
$$= \frac{\left\{\begin{array}{l}(0.116\text{ kg})[1090\text{ J/(kg}\cdot{}^\circ\text{C)}](24.0\,{}^\circ\text{C}) \\ \quad + [(0.225\text{ kg})(80.3\,{}^\circ\text{C}) + (0.0122\text{ kg})(5.00\,{}^\circ\text{C})][4186\text{ J/(kg}\cdot{}^\circ\text{C)}]\end{array}\right\}}{(0.116\text{ kg})[1090\text{ J/(kg}\cdot{}^\circ\text{C)}] + (0.225\text{ kg} + 0.0122\text{ kg})[4186\text{ J/(kg}\cdot{}^\circ\text{C)}]} = \boxed{70.5\,{}^\circ\text{C}}$$

Insight: The comparatively large heat capacity *mc* of the coffee, compared with the smaller heat capacities *mc* of the cream and cup, causes the equilibrium temperature to be much closer to the initial temperature of the coffee than to the initial temperature of the cream or cup.

97. A fan can make you feel cooler on a hot day for two reasons. First, the moving air carries thermal energy from your skin by a process similar to convection. (It is more precisely called *advection*.) More importantly, the moving air accelerates the evaporation of moisture from your skin, carrying away the latent heat of vaporization and cooling your body.

98. The isopropyl alcohol evaporates readily, carrying away the latent heat of vaporization from the body.

99. **Picture the Problem:** Water, initially at the freezing point, freezes to ice.

Strategy: Examine the properties of an equilibrium mixture of water and ice at the freezing point. During a phase change the temperature remains constant. Adding thermal energy during the phase change converts ice to water, but extracting thermal energy converts water to ice.

Solution: The answer is (d) a removal of thermal energy from the water. Removing the latent heat of fusion from the water will cause it to freeze if it is at the freezing point temperature.

Insight: Water is unusual because the freezing process is also accompanied by an increase in volume. This makes ice less dense than water, and causes ice to float at the surface.

100. An equilibrium mixture of ice and water maintains a constant temperature of 0°C. Therefore, as long as some ice remains in equilibrium with the water, the resulting temperature of the system is equal to 0°C.

101. **Picture the Problem:** Heat is removed from four liquids that are at their freezing temperature, and they each solidify completely. The amount of heat that must be removed, Q, and the mass, m, of each of the liquids is given.

Strategy: Use $L_f = Q/m$ (the latent heat equation) to determine the ranking of the latent heats of fusion.

Solution: 1. Find $L_{f,A}$ and $L_{f,B}$: $L_{f,A} = \dfrac{Q_A}{m_A} = \dfrac{16,600 \text{ J}}{0.050 \text{ kg}} = 3.3\times10^5 \text{ J/kg}$, and $L_{f,B} = \dfrac{Q_B}{m_B} = \dfrac{3,150 \text{ J}}{0.025 \text{ kg}} = 1.3\times10^5 \text{ J/kg}$

2. Find $L_{f,C}$ and $L_{f,D}$: $L_{f,C} = \dfrac{Q_C}{m_C} = \dfrac{3,350 \text{ J}}{0.010 \text{ kg}} = 3.4\times10^5 \text{ J/kg}$, and $L_{f,D} = \dfrac{Q_D}{m_D} = \dfrac{5,400 \text{ J}}{0.050 \text{ kg}} = 1.1\times10^5 \text{ J/kg}$

3. By comparing the values of the latent heats we arrive at the ranking $\boxed{D < B < A < C}$.

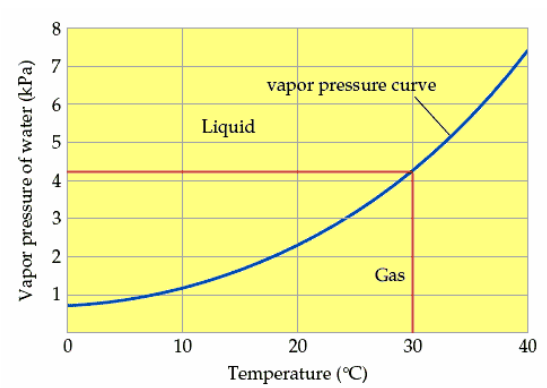
Insight: A large latent heat of fusion corresponds to a material that is difficult to melt, requiring a large amount of heat Q to melt a small amount of mass m. Such a material typically has very strong attractive forces between its molecules.

102. **Picture the Problem:** The liquid vapor curve shows the relationship between the vapor pressure and boiling point temperature of water.

Strategy: Examine the graph to find at what pressure the boiling point is 30°C.

Solution: The pressure is about 4.2 kPa.

Insight: Note from the graph that the vapor pressure increases as the temperature increases. This is why the boiling point is low on a mountaintop, where the pressure is low.

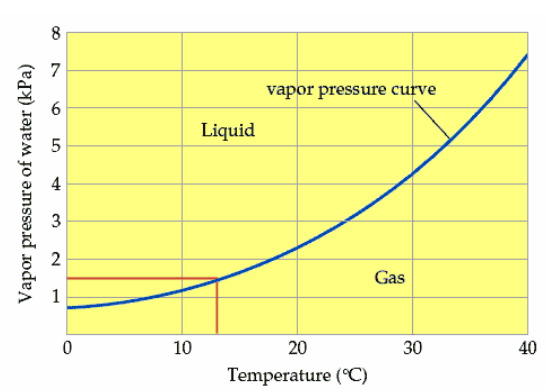


103. **Picture the Problem:** The liquid vapor curve shows the relationship between the vapor pressure and boiling point temperature of water.

Strategy: Examine the graph to find at what temperature water boils when the vapor pressure is 1.5 kPa:

Solution: The temperature is about 13°C.

Insight: Note from the graph that the boiling temperature increases as the vapor pressure increases. This is why the boiling point is low on a mountaintop, where the pressure is low.



104. **Picture the Problem:** Ice is made by extracting heat from water that is initially at 0℃.

Strategy: Use the latent heat equation to find the thermal energy that must be extracted from the water to freeze it.

Solution: Calculate the thermal energy to extract: $Q = mL_{\text{f}} = (1.7\text{ kg})(33.5\times10^4\text{ J/kg}) = \boxed{5.7\times10^5\text{ J}}$

Insight: The same amount of heat flowing into the ice at 0℃ will convert it back to water.

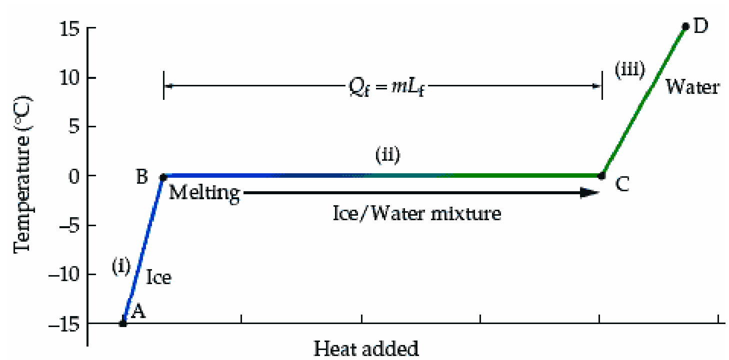
105. **Picture the Problem:** Thermal energy is added to lead at its melting point to convert it from solid to liquid.

Strategy: Use the latent heat equation to calculate the thermal energy needed to melt the piece of lead.

Solution: Calculate the required heat: $Q = m\,L_{\text{f}} = (0.95\text{ kg})(2.32\times10^4\text{ J/kg}) = 2.2\times10^4\text{ J} = \boxed{22\text{ kJ}}$

Insight: Extracting this same amount of heat from the liquid lead will convert it back to a solid.

106. **Picture the Problem:** As thermal energy is added to ice initially at −12℃, the heat first increases the temperature to the melting point, then melts the ice, and finally raises the temperature of the melted water to 24℃.



Strategy: Set the total heat equal to the sum of the heat needed to (i) raise the ice to the melting point, (ii) melt the ice, and (iii) increase the water to the final temperature. Solve the resulting equation for the mass.

Solution: 1. Sum the heats using the appropriate expressions:

$$Q = Q_{\text{i}} + Q_{\text{ii}} + Q_{\text{iii}}$$
$$= mc_{\text{ice}}(\Delta T)_1 + mL_{\text{f}} + mc_{\text{water}}(\Delta T)_2$$
$$Q = m\left[c_{\text{ice}}(\Delta T)_1 + L_{\text{f}} + c_{\text{water}}(\Delta T)_2\right]$$

2. Solve for the mass:

$$m = \frac{Q}{c_{\text{ice}}(\Delta T)_1 + L_{\text{f}} + c_{\text{water}}(\Delta T)_2}$$
$$= \frac{8.8\times10^5\text{ J}}{[2090\text{ J/(kg}\cdot{}^\circ\text{C)}](12\,^\circ\text{C}) + 33.5\times10^4\text{J/kg} + [4186\text{ J/(kg}\cdot{}^\circ\text{C)}](24\,^\circ\text{C})}$$
$$m = \boxed{1.9\text{ kg}}$$

Insight: From the mass we can calculate the amount of thermal energy used in each of the three processes: $Q_{\text{i}} = 47.9\text{ kJ}$, $Q_{\text{ii}} = 640\text{ kJ}$, and $Q_{\text{iii}} = 192\text{ kJ}$. Most of the thermal energy is needed to melt the ice.

107. **Picture the Problem:** As a specified amount of heat is added to ice initially at −5.0℃, the heat first increases the temperature to the melting point, then melts the ice, and finally raises the water to its final temperature.

Strategy: Use the specific heat equation to calculate the amount of thermal energy necessary to raise the temperature to the melting point. Use the latent heat equation to calculate the amount of thermal energy necessary to melt the ice. Subtract these two amounts of energy from the total thermal energy available. Insert the remainder of the thermal energy into the specific heat equation to calculate the final temperature of the water.

Solution: 1. Calculate the thermal energy necessary to raise the ice to the melting point: $Q_1 = mc_{\text{ice}}\Delta T = (1.1\text{ kg})[2090\text{ J/(kg}\cdot{}^\circ\text{C)}](5.0\,^\circ\text{C}) = \underline{\underline{1.15\times10^4\text{ J}}}$

2. Calculate the heat necessary to melt the ice: $Q_2 = m\,L_{\text{f}} = (1.1\text{ kg})(33.5\times10^4\text{ J/kg}) = \underline{\underline{3.685\times10^5\text{ J}}}$

3. Subtract the thermal energies from the total thermal energy that is added to the system:

$$Q_3 = Q_{\text{total}} - Q_1 - Q_2$$
$$= 5.2\times10^5 \text{ J} - 1.15\times10^4 \text{ J} - 3.685\times10^5 \text{ J} = \underline{\underline{1.40\times10^5 \text{ J}}}$$

4. Solve the specific heat equation for T_f:

$$Q_3 = mc_{\text{water}}(T_\text{f} - 0\,°\text{C})$$
$$T_\text{f} = \frac{Q_3}{mc_{\text{water}}} = \frac{1.40\times10^5 \text{ J}}{(1.1 \text{ kg})[4186 \text{ J/(kg}\cdot°\text{C)}]} = \boxed{30\,°\text{C}}$$

5. $\boxed{\text{No ice remains}}$ because $T_\text{f} > 0\,°\text{C}$.

Insight: If the heat added to the system had been only 3.0×10^5 J, the result of step 3 above would have been a negative number (not possible). This would mean that only part of the ice melted. The final temperature would be 0°C, with 0.86 kg of water and 0.24 kg of ice remaining in the system.

108. **Picture the Problem:** A large barrel of warm water gives off heat as it cools and freezes to ice. This thermal energy is compared to the thermal energy from an electric heater.

Strategy: Use the specific heat and latent heat equations to calculate the amount of thermal energy lost by the water as it cools and freezes. Use the definition of power to find the time it would take an electric heater with a power output of 2.00 kW to produce the same amount of energy.

Solution: 1. Calculate the thermal energy lost by the water:

$$Q = mc_{\text{water}}\Delta T_{\text{water}} + mL_\text{f} = m\left[c_{\text{water}}(20.0\,°\text{C} - 0\,°\text{C}) + L_\text{f}\right]$$
$$= (865 \text{ kg})\left[(4186 \text{ J/kg}\cdot\text{K})(20.0\,°\text{C}) + 33.5\times10^4 \text{ J/kg}\right] = \underline{\underline{3.62\times10^8 \text{ J}}}$$

2. Solve the power equation for time:

$$P = \frac{Q}{t} \Rightarrow t = \frac{Q}{P} = \frac{3.62\times10^8 \text{ J}}{2000 \text{ J/s}} = 1.81\times10^5 \text{ s}\left(\frac{1 \text{ hr}}{3600 \text{ s}}\right) = \boxed{50.3 \text{ hrs}}$$

Insight: Storing water in a pantry helps to keep the produce from freezing during the winter. It also helps to keep the pantry cool during the summer.

109. **Picture the Problem:** Thermal energy is added at a constant rate to ice initially at 0°C. Over time the heat melts the ice and raises the water temperature to 15°C.

Strategy: Calculate the time required for each step of the heating process by dividing the thermal energy added in that process by the rate at which the thermal energy is added.

Solution: 1. Solve for the time to melt the ice:

$$t_{\text{melt}} = \frac{Q_{\text{melt}}}{\Delta Q/\Delta t} = \frac{m\,L_\text{f}}{\Delta Q/\Delta t} = \frac{1.000 \text{ kg}(33.5\times10^4 \text{ J/kg})}{12{,}250 \text{ J/s}} = \underline{\underline{27.3 \text{ s}}}$$

2. Solve for the time to heat the water to 15°C:

$$t_{\text{warm}} = \frac{mc\Delta T}{\Delta Q/\Delta t} = \frac{(1.000 \text{ kg})[4186 \text{ J/(kg}\cdot°\text{C)}](15 - 0\,°\text{C})}{12{,}250 \text{ J/s}} = \underline{\underline{5.1 \text{ s}}}$$

3. Add the time to melt the ice to the time to heat the water:

$$t_{\text{AC}} = t_{\text{AB}} + t_{\text{BC}} = 27.3 \text{ s} + 5.1 \text{ s} = \boxed{32.4 \text{ s}}$$

Insight: The thermal energy required to boil the water is significantly greater than the heat needed to melt the same amount of ice or to increase the temperature of the water from freezing to boiling.

110. **Picture the Problem:** Ice cubes are placed in a bowl of lemonade. Thermal energy transfers from the lemonade to the ice, causing the ice to melt, until the ice and lemonade arrive at the same temperature.

Strategy: Assume that all of the ice melts and that the lemonade and melted ice arrive at an equilibrium temperature between 0° and 20.5°C. The thermal energy absorbed by the ice will raise its temperature to 0°C, melt it, and then raise the temperature of the melted water to the equilibrium temperature. Set the amount of thermal energy absorbed by the ice equal to the amount of thermal energy given off by the lemonade as it cools to the same final temperature. Solve the resulting equation for the final temperature.

Solution: 1. Use the specific heat and latent heat equations to calculate the thermal energy gained by the ice:

$$Q_i = m_{ice}c_{ice}\Delta T_{ice} + m_{ice}L_f + m_{ice}c_w\left(T_f - 0\,°C\right)$$
$$= (0.0550\text{ kg})\left(\left[2090\text{ J}/(\text{kg}\cdot\text{K})\right](10.2\,°C) + 33.5\times10^4\text{ J/kg}\right) + m_{ice}c_wT_f$$
$$Q_i = 19.6\text{ kJ} + m_{ice}c_wT_f$$

2. Calculate thermal energy lost by the lemonade:

$$Q_w = m_{lem}c_w\left(20.5\,°C - T_f\right)$$

3. Set the two energies equal:

$$Q_i = Q_w \quad\Rightarrow\quad 19.6\text{ kJ} + m_{ice}c_wT_f = m_{lem}c_w\left(20.5\text{ °C } - T_f\right)$$

4. Solve for the final temperature:

$$T_f = \frac{m_{lem}c_w\,(20.5\,°C) - 1.960\times10^4\text{ J}}{\left(m_{ice}+m_{lem}\right)c_w}$$
$$= \frac{(3.99\text{ kg})\left[4186\text{ J/(kg}\cdot°C)\right](20.5\,°C) - 1.960\times10^4\text{ J}}{(0.0550\text{ kg} + 3.99\text{ kg})\left[4186\text{ J/(kg}\cdot°C)\right]} = \boxed{19.1\,°C}$$

5. Because the temperature is greater than 0°C, we conclude that $\boxed{\text{no ice remains}}$ in the lemonade.

Insight: The final temperature falls within our assumed range. If the temperature calculated by this method had been less than 0℃, then our assumption that the ice had completely melted would have been incorrect. We would then need to reevaluate our strategy to solve for the amount of ice that had melted.

111. **Picture the Problem:** A cube of very cold aluminum is placed into a container of water. Heat transfers from the warm water to the cold aluminum until the two are in equilibrium.

Strategy: Assume that the final temperature is $T_f = 0\,°C$, with part of the water frozen into ice. Use the specific heat equation to calculate the amount of thermal energy the aluminum absorbs as it heated up to 0℃. Subtract from that thermal energy the amount of heat the water gives off as it cools to 0℃. Finally, use the latent heat equation to calculate the mass of ice that freezes as the aluminum absorbs the remaining thermal energy.

Solution: 1. Calculate the thermal energy gained by the aluminum as it warms up:

$$Q_{Al} = m_{Al}c_{Al}\left(T_f - T_{Al,i}\right)$$
$$= (0.155\text{ kg})\left[653\text{ J/(kg}\cdot°C)\right]\left[0\,°C - (-196\,°C)\right] = \underline{\underline{19{,}838\text{ J}}}$$

2. Calculate the thermal energy removed from water as it cools to freezing:

$$Q_w = m_wc_w\Delta T$$
$$= (0.0800\text{ kg})\left[4186\text{ J/(kg}\cdot°C)\right](0 - 15.0\,°C) = \underline{\underline{-5023\text{ J}}}$$

3. Apply energy conservation to find the thermal energy removed from the water as it freezes:

$$Q_{Al} + Q_w + Q_f = 0$$
$$Q_f = -Q_{Al} - Q_w = -19{,}838\text{ J} - (-5023\text{ J}) = -14{,}815\text{ J}$$

4. Divide the thermal energy by the latent heat of fusion to calculate the mass of the water that freezes to ice:

$$m_f = \frac{Q_f}{L_f} = \frac{14{,}815\text{ J}}{33.5\times10^4\text{ J/kg}} = \boxed{44.2\text{ g}}$$

Insight: Because the mass of water that is frozen is greater than zero but less than the total mass of the water ($0 < 44.2\text{ g} < 80.0\text{ g}$), our assumption was correct that the final temperature would be zero and some, but not all, of the water would be frozen to ice. If the calculations gave a mass less than zero, we would have to reevaluate our strategy to calculate a final temperature greater than zero. If the calculation gave us a mass greater than the total mass of the water, we would reevaluate the strategy to find a temperature less than zero and all of the water frozen to ice.

112. Thermal energy exchange between the Sun and the Earth is mediated by electromagnetic waves that travel through the vacuum of space. This kind of thermal energy transfer is called *radiation*.

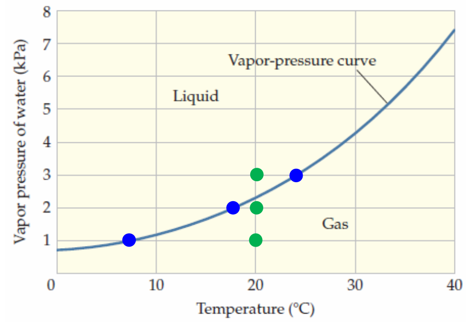
113. **Picture the Problem:** A steel tape measure is marked in such a way that it gives accurate length measurements at a normal room temperature of 20°C. This tape measure is used outdoors on a cold day when the temperature is 0°C.

Strategy: Use the principle of thermal expansion to answer the conceptual question.

Solution: The measurements of the tape measure are $\boxed{\text{too long}}$ because the distance between tick marks on the measure has decreased. Therefore, the cool tape measure shows more tick marks between two points than should be the case.

Insight: The thermal expansion coefficient for steel is only $12\times10^{-6}\ \text{K}^{-1}$. This means that an object that is 25.000 cm long will measure 25.006 cm on the cold 0°C day. The difference is barely noticeable.

114. **Picture the Problem:** Consider the vapor pressure curve of water depicted in Figure 10.28 and shown at the right.



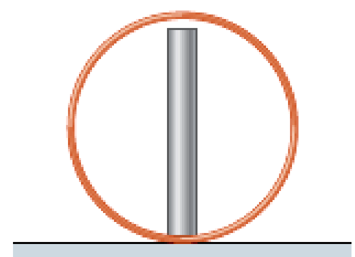
Strategy: Locate the mentioned points on the vapor pressure curve in order to answer the conceptual questions. The points mentioned in part (a) are shown in green, and the points mentioned in part (b) are shown in blue.

Solution: 1. (a) At 20°C the points corresponding to 1 kPa and 2 kPa are below the vapor pressure curve, in the gas region, so water is a $\boxed{\text{gas}}$ at those temperatures and pressures. At 20°C and 3 kPa the point is above the vapor pressure curve, and water is a $\boxed{\text{liquid}}$ at that temperature and pressure.

2. (b) The boiling point of water is the temperature that corresponds to the point along the vapor pressure curve that is at the specified pressure (see the blue dots on the figure above). At a pressure of 1 kPa the boiling point of water is about $\boxed{7°\text{C}}$. At 2 kPa the boiling point is about $\boxed{18°\text{C}}$, and at 3 kPa it is $\boxed{24°\text{C}}$.

Insight: These extremely low pressures correspond to very high altitudes, near the edge of outer space. The atmospheric pressure at the top of Mt. Everest is 33.6 kPa and the boiling point of water there is 71°C (160°F).

115. **Picture the Problem:** A copper ring stands on edge with a metal rod placed inside it, as shown in the figure at right. The system is then heated.



Strategy: Use the principle of thermal expansion to answer the conceptual question.

Solution: 1. (a) The length of the metal rod and the diameter of the copper ring will each increase as the system is heated. If the coefficient of thermal expansion for the metal is larger than that of copper, the rod will expand faster than the ring and the two will touch. For a copper rod and a copper ring the coefficients of thermal expansion are identical and $\boxed{\text{no}}$, the rod will never touch the top of the ring.

2. (b) For an aluminum rod the coefficients of thermal expansion are $\alpha_{\text{Al}} = 24\times10^{-6}\,\text{K}^{-1}$ and $\alpha_{\text{Cu}} = 17\times10^{-6}\,\text{K}^{-1}$. The rod will expand faster than the ring and $\boxed{\text{yes}}$, it will eventually touch the top of the ring (provided neither melts first!).

3. (c) For a steel rod the coefficients of thermal expansion are $\alpha_{\text{steel}} = 12\times10^{-6}\,\text{K}^{-1}$ and $\alpha_{\text{Cu}} = 17\times10^{-6}\,\text{K}^{-1}$. The ring will expand faster than the rod and $\boxed{\text{no}}$, the rod will never touch the top of the ring.

Insight: If you could somehow heat the steel rod without heating the copper ring, it would eventually expand enough to touch the top of the ring.

116. **Picture the Problem:** This is a units conversion problem.

Strategy: Convert the Celsius temperature to the Fahrenheit temperature.

Solution: Convert the temperature to Fahrenheit:

$$T_{\text{F}} = \frac{9}{5}T_{\text{C}} + 32 = \frac{9\,°\text{F}}{5\,°\text{C}}(121\,°\text{C}) + 32\,°\text{F} = \boxed{250\,°\text{F}}$$

Insight: As expected, this temperature is slightly above the boiling point of water (212°F) at atmospheric pressure.

117. **Picture the Problem:** Heat is removed from two liquids that are at their freezing temperature, and they each solidify completely. The amount of heat that must be removed, Q, and the mass, m, of each of the liquids is given.

Strategy: Use $L_{\text{f}} = Q/m$ (the latent heat equation) to determine the ranking of the latent heats of fusion.

Solution: 1. Use the latent heat equation to find $L_{f,A}$: $L_{f,A} = \dfrac{Q_A}{m_A} = \dfrac{33{,}500\ \text{J}}{0.100\ \text{kg}} = 3.35\times10^5\ \text{J/kg}$

2. Use the latent heat equation to find $L_{f,B}$: $L_{f,B} = \dfrac{Q_B}{m_B} = \dfrac{166{,}000\ \text{J}}{0.500\ \text{kg}} = 3.32\times10^5\ \text{J/kg}$

3. By comparing the values of the latent heats we conclude that the latent heat of fusion of liquid A is $\boxed{\text{greater than}}$ the latent heat of fusion of liquid B.

Insight: A large latent heat of fusion corresponds to a material that is difficult to melt, requiring a large amount of heat Q to melt a small amount of mass m. Such a material typically has very strong attractive forces between its molecules.

118. **Picture the Problem:** A new laptop design removes heat by vaporizing methanol.

Strategy: Use the latent heat equation to calculate the latent heat of vaporization for methanol.

Solution: Calculate the latent heat of vaporization: $L_v = \dfrac{Q}{m} = \dfrac{5100\ \text{J}}{0.0046\ \text{kg}} = \boxed{1.1\times10^6\ \text{J/kg}}$

Insight: The latent heat of vaporization for water (2.26×10^6 J/kg) is about twice that of methanol. However, the boiling point of methanol is only 65°C, making it a better choice to keep the laptop components cool.

119. **Picture the Problem:** Various heats will change the temperatures of different materials by differing amounts.

Strategy: Use the specific heat equation $c = Q/m\,\Delta T$ to determine the ranking of the specific heats.

Solution: 1. Find c_A: $c_A = \dfrac{Q}{m\,\Delta T}$

2. Find c_B: $c_B = \dfrac{2Q}{(3m)(3\Delta T)} = \dfrac{2}{9}\dfrac{Q}{m\,\Delta T}$

3. Find c_C: $c_C = \dfrac{3Q}{(3m)\Delta T} = \dfrac{Q}{m\,\Delta T}$

4. Find c_D: $c_D = \dfrac{4Q}{(4m)(2\Delta T)} = \dfrac{1}{2}\dfrac{Q}{m\,\Delta T}$

5. By comparing the specific heats we arrive at the ranking $\boxed{B < D < A = C}$.

Insight: A large specific heat corresponds to a material that does not easily change its temperature, requiring a large amount of heat Q to change its temperature by a small amount.

120. **Picture the Problem:** Thermal energy is added to a container of water at a known rate, causing the temperature of the water to increase.

Strategy: Find out how much thermal energy is added to the water by multiplying the rate at which the energy is added by the amount of time. Then use the specific heat equation to calculate the temperature change that results from the addition of the thermal energy.

Solution: 1. Calculate the thermal energy gained by the water: $P = \dfrac{Q}{t} \Rightarrow Q = Pt = (55\ \text{J/s})(2.5\ \text{min}\times 60\ \text{s/min}) = 8250\ \text{J}$

2. Use the specific heat equation to find the temperature change:

$$Q = mc_{\text{water}}\Delta T_{\text{water}}$$

$$\Delta T_{\text{water}} = \frac{Q}{mc_{\text{water}}} = \frac{8250\ \text{J}}{(0.150\ \text{kg})[4186\ \text{J/(kg}\cdot{}^\circ\text{C)}]} = \boxed{13\,^\circ\text{C}}$$

Insight: 150 g of water is about 2/3 of a cup. A microwave oven would be a much more efficient way to heat this small amount of water, because many microwave ovens can deliver over 1000 J/s of heating power.

121. **Picture the Problem:** Thermal energy is added to a container of water, causing the temperature of the water to increase.

Strategy: Find out how much thermal energy is added to the water by using the specific heat equation. Then divide by the time elapsed to find the heating rate.

Solution: 1. Use the specific heat equation to find the thermal energy that is added:

$$Q = mc_{\text{water}}\Delta T_{\text{water}} = (0.180\ \text{kg})[4186\ \text{J/(kg}\cdot{}^\circ\text{C)}](12\,^\circ\text{C}) = 9042\ \text{J}$$

2. Divide by the time elapsed to find the heating rate:

$$P = \frac{Q}{t} = \frac{9042\ \text{J}}{(3.5\ \text{min} \times 60\ \text{s/min})} = \boxed{43\ \text{J/s}}$$

Insight: 180 g of water is about 3/4 of a cup. A microwave oven would be a much more efficient way to heat this small amount of water, because many microwave ovens can deliver over 1000 J/s of heating power.

122. **Picture the Problem:** Heat is extracted from 1.5 kg of steam at 110°C to completely convert it to ice at 0.0°C.

Strategy: Use the specific heat and latent heat equations to calculate the thermal energy extracted from the steam as it cools and condenses to water and then to ice.

Solution: Sum the heat lost by the steam as it:
i) cools to the boiling point,
ii) condenses to water,
iii) cools to the freezing point, and
iv) solidifies to ice.

$$Q = mc_{\text{steam}}(110\,°\text{C} - 100\,°\text{C}) + mL_{\text{v}} + mc_{\text{w}}(100\,°\text{C} - 0\,°\text{C}) + mL_{\text{f}}$$

$$= m\left[c_{\text{steam}}(10\,°\text{C}) + L_{\text{v}} + c_{\text{w}}(100\,°\text{C}) + L_{\text{f}}\right]$$

$$Q = 1.5\ \text{kg}\left\{\begin{aligned}&[2010\ \text{J/(kg}\cdot°\text{C)}](10\,°\text{C}) + 22.6\times10^{5}\ \text{J/kg}\\ &+[4186\ \text{J/(kg}\cdot°\text{C)}](100\,°\text{C}) + 33.5\times10^{4}\ \text{J/kg}\end{aligned}\right\} = \boxed{4.6\ \text{MJ}}$$

Insight: An energy of 4.6 MJ is equivalent to 1100 nutritional Calories.

123. **Picture the Problem:** A solar-powered water heater delivers thermal energy at a known rate to some water, raising the temperature of the water.

Strategy: Multiply the area of the solar collector by the intensity of the sunlight to find the total rate at which thermal energy is added to the water. Use the specific heat equation to find the thermal energy required to warm up the water, then divide the thermal energy by the rate at which it is added in order to find the required time to heat the water.

Solution: 1. Find the rate at which thermal energy is added to the water:

$$I = \frac{\Delta Q/\Delta t}{A} \quad \Rightarrow \Delta Q/\Delta t = I\,A = (520\ \text{W/m}^2)(5.5\ \text{m}^2) = 2860\ \text{W}$$

2. Calculate the required amount of thermal energy:

$$Q = m\,c_{\text{w}}\Delta T = (45\ \text{kg})[4186\ \text{J/(kg}\cdot°\text{C)}](12\,°\text{C}) = 2.26\times10^{6}\ \text{J}$$

3. Find the required time:

$$\Delta t = \frac{Q}{\Delta Q/\Delta t} = \frac{2.26\times10^{6}\ \text{J}}{2860\ \text{W}} = 790\ \text{s} = \boxed{13.2\ \text{min}}$$

Insight: While you cannot rely entirely on solar energy for water heating, a solar water heating system can significantly reduce your heating bill and pay for itself within a few years.

124. **Picture the Problem:** Thermal energy is added to a mixture of ice and water at 0°C until all of the ice melts and the temperature of the water increases to 15.0°C.

Strategy: Use the latent heat equation to calculate the amount of thermal energy necessary to melt the ice. Then use the specific heat equation to calculate the amount of thermal energy necessary to raise the temperature of the water (both the original water and the melted ice) to 15.0°C. Add the two energies together to find the total amount of thermal energy that must be added to the system.

Solution: 1. Calculate the thermal energy necessary to melt the ice:

$$Q_1 = m\,L_{\text{f}} = (0.130\ \text{kg})(33.5\times10^{4}\ \text{J/kg}) = \underline{\underline{4.36\times10^{4}\ \text{J}}}$$

2. Calculate the thermal energy necessary to warm the entire 1.25 kg of water:

$$Q_2 = mc_{\text{water}}\Delta T = (1.25\ \text{kg})[4186\ \text{J/(kg}\cdot°\text{C)}](15.0\,°\text{C})$$

$$= \underline{\underline{7.85\times10^{4}\ \text{J}}}$$

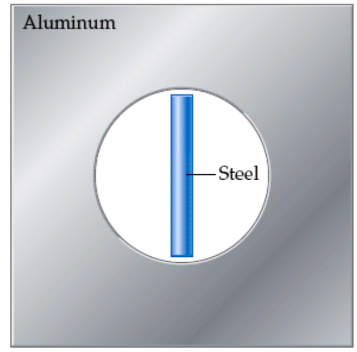
3. Add the thermal energies:

$$Q = Q_1 + Q_2 = 4.36\times10^{4}\ \text{J} + 7.85\times10^{4}\ \text{J}$$

$$= \boxed{1.22\times10^{5}\ \text{J}}$$

Insight: If the heat added to the system had been less than 4.36×10^{4} J, some (but not all) of the ice would have melted and the final temperature of the system would have remained 0°C.

125. **Picture the Problem:** A steel rod is slightly smaller than the diameter of a hole in an aluminum plate. We must either heat or cool the rod and plate until the length of the rod is equal to the diameter of the hole.



Strategy: If the steel has a larger coefficient of thermal expansion than the aluminum, it will expand faster than the aluminum as the system is heated and touch both sides of the circle. If aluminum has the larger coefficient, the system should be cooled. Solve the thermal expansion equation for the length of the rod and the diameter of the hole as a function of temperature. Set the two lengths equal and solve for the temperature.

Solution: 1. (a) Because aluminum has a larger coefficient of thermal expansion than steel, the temperature of the system should be $\boxed{\text{decreased}}$.

2. (b) Write the lengths as a function of temperature:

$$L = L_\text{i} + \alpha_\text{steel} L_\text{i} \Delta T$$
$$D = D_\text{i} + \alpha_\text{Al} D_\text{i} \Delta T$$

3. Set the length of the rod equal to the diameter of the hole:

$$L = D$$
$$L_\text{i} + \alpha_\text{steel} L_\text{i} \Delta T = D_\text{i} + \alpha_\text{Al} D_\text{i} \Delta T$$

4. Solve for the change in temperature:

$$\Delta T = \frac{D_\text{i} - L_\text{i}}{\alpha_\text{steel} L_\text{i} - \alpha_\text{Al} D_\text{i}}$$
$$= \frac{0.100\ \text{m} - 0.0999\ \text{m}}{\left(1.2\times10^{-5}\ \text{K}^{-1}\right)(0.0999\ \text{m}) - \left(2.4\times10^{-5}\ \text{K}^{-1}\right)(0.100\ \text{m})}$$
$$\Delta T = \boxed{-83\,^\circ\text{C}}$$

Insight: If the rod were aluminum and the plate were steel, they would have to be heated by 84°C for the rod to be the same size as the hole.

126. **Picture the Problem:** Both a warm piece of steel and a chunk of lead are added to an isolated container of water, but the temperature of the water remains the same.

Strategy: Because the water temperature remains the same, we conclude that any thermal energy added by the warm steel is absorbed by the chunk of lead. Both the steel and the lead have final temperatures equal to 22°C, the same as the water. Set the thermal energy change of the system equal to zero and solve for the initial temperature of the lead.

Solution: 1. (a) Because the water temperature remains the same, we conclude that any thermal energy added by the warm steel is absorbed by the chunk of lead. That implies that the initial temperature of the lead was $\boxed{\text{less than}}$ 22°C.

2. (b) Apply conservation of energy by setting the sum of the thermal energies to zero:

$$Q_\text{steel} + Q_\text{lead} = 0$$
$$m_\text{steel} c_\text{steel} \Delta T_\text{steel} = -m_\text{lead} c_\text{lead} \Delta T_\text{lead}$$
$$m_\text{steel} c_\text{steel} \left(22\,^\circ\text{C} - T_\text{i, steel}\right) = -m_\text{lead} c_\text{lead} \left(22\,^\circ\text{C} - T_\text{i, lead}\right)$$

3. Rearrange and solve for $T_\text{i, lead}$:

$$m_\text{steel} c_\text{steel} \left(22\,^\circ\text{C} - T_\text{i, steel}\right) + m_\text{lead} c_\text{lead} \left(22\,^\circ\text{C}\right) = m_\text{lead} c_\text{lead} T_\text{i, lead}$$
$$T_\text{i, lead} = \frac{m_\text{steel} c_\text{steel} \left(22\,^\circ\text{C} - T_\text{i, steel}\right) + m_\text{lead} c_\text{lead} \left(22\,^\circ\text{C}\right)}{m_\text{lead} c_\text{lead}}$$
$$= \frac{\begin{bmatrix}(0.33\ \text{kg})[448\ \text{J/(kg}\cdot{}^\circ\text{C)}](22 - 42\,^\circ\text{C}) \\ +\ \ (0.51\ \text{kg})[128\ \text{J/(kg}\cdot{}^\circ\text{C)}](22\,^\circ\text{C})\end{bmatrix}}{(0.51\ \text{kg})[128\ \text{J/(kg}\cdot{}^\circ\text{C)}]} = \boxed{-23\,^\circ\text{C}}$$

Insight: In this situation the hot steel loses 2960 J of thermal energy and the cold lead gains 2960 J, while the thermal energy of the water does not change at all.

127. **Picture the Problem:** The rate at which a cricket chirps is related to the temperature of the cricket. Using the provided equation, we wish to calculate the temperature of the cricket from the number of chirps in one minute.

Strategy: Solve the given equation for the temperature in kelvins, and then convert the temperature to Celsius.

Solution: 1. Find the number of chirps N in 13.0 seconds: $N = \dfrac{185 \text{ chirps}}{60.0 \text{ s}} \times 13.0 \text{ s} = \underline{\underline{40.1 \text{ chirps}}}$

2. Isolate the exponential and take the natural logarithm of both sides of the equation: $\ln\left(\dfrac{N}{5.63\times10^{10}}\right) = -\dfrac{6290 \text{ K}}{T}$

3. Solve for the temperature: $T = \dfrac{-6290 \text{ K}}{\ln\left(40.1/5.63\times10^{10}\right)} = 298.6 \text{ K}$

4. Convert the temperature to Celsius: $T_C = T - 273.15 = 298.63 - 273.15 = \boxed{25.5\,°\text{C}}$

Insight: This corresponds to a Fahrenheit temperature of 77.9°F. If the temperature were 90°F, the cricket would chirp 290 times in 60.0 s.

128. Answers will vary. The milk, cream, sugar mixture condenses into solid ice cream at about -3 °C. About 4 tablespoons of salt and 4 cups of crushed ice will produce temperatures cold enough to make ice cream in 5 – 10 minutes. Try it yourself in the laboratory and enjoy the results of your efforts!

129. When two sticks are rubbed together, friction converts the mechanical energy into thermal energy. By pressing the sticks tightly together, you can increase the normal force, which increases the force of friction and more rapidly converts the mechanical energy into thermal energy. If the rate that thermal energy is added to the sticks is sufficiently high, they will reach their combustion temperature and catch fire. This will not work with steel rods because steel will quickly conduct the thermal energy away from the rubbing point, making it impossible to reach the combustion temperature for the fuel you are trying to burn.

130. **Picture the Problem:** When the SR-71 Blackbird is in flight, its surface heats up significantly. This increase in temperature causes the plane to expand in length.

Strategy: Solve the thermal expansion equation for the final temperature of the plane.

Solution: Solve $\Delta L = \alpha L_i \left(T - T_i\right)$ for T. The calculated answer is choice C.

$$T = T_i + \frac{\Delta L}{\alpha L_i} = 23\,°\text{C} + \frac{0.20 \text{ m}}{\left(22\times10^{-6} \text{ K}^{-1}\right)(32.74 \text{ m})} = \boxed{300\,°\text{C}}$$

Insight: The final temperature is equivalent to 572°F, hotter than a household oven set to its self-cleaning temperature!

131. **Picture the Problem:** When the SR-71 Blackbird is in flight, its surface heats up significantly. This increase in temperature causes the plane to expand in length.

Strategy: Use the thermal expansion equation to find the length of the plane as a result of its change in temperature.

Solution: 1. Use the thermal expansion equation: $\Delta L = \alpha L_i \Delta T = \left(22\times10^{-6} \text{ K}^{-1}\right)(32.74 \text{ m})(120 - 23\,°\text{C}) = 0.070 \text{ m}$

2. Find the final length: $L = L_i + \Delta L = 32.74 + 0.070 \text{ m} = 32.81 \text{ m}$

3. Convert to feet and inches:

$$32.81 \text{ m} \times \frac{3.281 \text{ ft}}{1.000 \text{ m}} = 107.65 \text{ ft}$$

$$0.65 \text{ ft} \times \frac{12 \text{ in}}{\text{ft}} = 7.8 \text{ in} \quad \Rightarrow \boxed{107 \text{ ft } 7.8 \text{ in}}$$

The calculated answer is choice C.

Insight: Although 120°C is nowhere near the 300°C of problem 130, it's still plenty hot enough to boil water!