Chapter 16

Temperature and Heat

Answers to Even-numbered Conceptual Questions

2. No. The Kelvin temperature is always 273.15 degrees greater than the Celsius temperature.

4. No. Heat is not a quantity that one object has more of than another. Heat is the energy that is *transferred* between objects of different temperatures.

6. In this case, the volume within the glass would increase more than the volume of the mercury would increase. As a result, the mercury level would drop with increasing temperature.

8. The mercury level drops at the beginning because the glass is the first to increase its temperature when it comes into contact with the hot liquid. Therefore, the glass expands before the mercury, leading to a drop in level. As the mercury rises to the same temperature a few moments later, its level will increase.

10. 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. As a result, the lid can become loose enough to turn.

12. (a) The measurements of the tape measure are 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.

14. As the temperature of the house decreases, the length of the various pieces of wood from which it is constructed will decrease as well. As the house adjusts to these changing lengths, it will often creak or groan.

16. The rod will be firmly wedged in the ring. Recall that the cool rod starts out fitting snugly inside the hot ring. As the ring and the rod come to room temperature, the ring shrinks and the rod expands. The result is a very tight fit.

18. The final temperature will be considerably closer to the initial water temperature, T_w, than to the initial alcohol temperature, T_a. The reason is that as heat flows from the water to the alcohol, the temperature of the alcohol increases more rapidly than the temperature of the water decreases. It follows that when the alcohol and water have the same temperature, it will be a temperature closer to the initial temperature of the water.

20. This could happen if the objects have the same mass but different specific heats. Similarly, it could happen if the objects have the same specific heat but different masses. Bottom line: The objects must have different heat capacities.

22. Both the metal and the wood are at a lower temperature than your skin. Therefore, heat will flow from your skin to both the metal and the wood. The metal feels cooler, however, because it has a greater thermal conductivity. This allows the heat from your skin to flow to a larger effective volume than is the case with the wood.

24. As the ground warms up during the day, the ground of the surrounding suburbs warms up faster, since it has a smaller specific heat. This would lead to a wind blowing from the city to the suburbs. Of course, if the city is warmer than the suburbs – due to factories and cars – then the winds would blow into the city instead.

26. The paper is burned on the wooden half of the rod. The reason is that as we hold the rod over the flame, the heat it gives to the rod is conducted over a large volume on the metal side – because of its high thermal conductivity – but is concentrated in a small volume on the wood side. This concentration of heat in the wood results in a greater increase in temperature, and the paper being burned.

28. (e) The only factor in this list that does not affect the rate of heat flow is the specific heat of the slab.

30. Updrafts are generally caused by different areas of the ground heating up at different rates on a sunny day. When skydiving, for example, it is common to experience more of an updraft when you are descending over a plowed field than when you are over a field of grass.

32. The soup with the metal spoon in it has the lower temperature. This is due to the fact that heat conducts readily from the soup into the metal spoon, and then from the spoon into the cool surrounding air.

34. When people huddle together, their rate of heat production is the same, but the surface area over which this heat is radiated to the surroundings is decreased. This results in the people being warmer.

36. The hollow fibers of hair are effective insulators because the gas within the fibers has a low thermal conductivity. This is analogous to double-pane windows, which trap a layer of gas between the panes for a greatly enhanced insulating effect.

Solutions to Problems

1. $T_\text{F} = \dfrac{9°\text{F}}{5°\text{C}}(-89.2°\text{C}) + 32°\text{F} = \boxed{-128.6°\text{F}}$

2. $T_\text{C} = \dfrac{5°\text{C}}{9°\text{F}}(4500°\text{F} - 32°\text{F}) = \boxed{2500°\text{C}}$

3. **(a)** $T_\text{C} = \left(\dfrac{5\ °\text{C}}{9\ °\text{F}}\right)(T_\text{F} - 32\ °\text{F}) = \left(\dfrac{5\ °\text{C}}{9\ °\text{F}}\right)(98.6\ °\text{F} - 32\ °\text{F}) = \boxed{37.0\ °\text{C}}$

(b) $T = T_\text{C} + 273.15\ \text{K} = 37\ \text{K} + 273.15\ \text{K} = \boxed{310.2\ \text{K}}$

4. $T_\text{F} = \left(\dfrac{9\ °\text{F}}{5\ °\text{C}}\right)(T - 273.15)°\text{C} + 32\ °\text{F} = \left(\dfrac{9\ °\text{F}}{5\ °\text{C}}\right)(1.0 - 273.15)°\text{C} + 32\ °\text{F} = \boxed{-458\ °\text{F}}$

5. **(a)** $T_\text{C} = T - 273.15\ \text{K} = 6000\ \text{K} - 273.15\ \text{K} = \boxed{5727\ °\text{C}}$

(b) $T_\text{F} = \left(\dfrac{9\ °\text{F}}{5\ °\text{C}}\right)(5727\ °\text{C}) + 32\ °\text{F} = \boxed{10{,}340\ °\text{F}}$

6. (a) $\Delta T_C = \frac{\Delta T_F}{1.8\ \frac{°F}{°C}} = \frac{35\ °F}{1.8\ \frac{°F}{°C}} = \boxed{19\ °C}$

(b) $\Delta T_C = \Delta T_K = \boxed{19\ °C}$

7. (a) $\text{rate} = \frac{95.0\ \text{kPa}}{376.15\ \text{C°}} = 0.25256\ \frac{\text{kPa}}{\text{C°}}$

$P = 95.0\ \text{kPa} + \left(0.25256\ \frac{\text{kPa}}{\text{C°}}\right)(50.0\ °C - 103\ °C) = \boxed{81.6\ \text{kPa}}$

(b) $P = P_0 + (\text{rate})(T - T_0)$

$T = T_0 + \frac{P - P_0}{\text{rate}} = 103\ °C + \frac{115\ \text{kPa} - 95.0\ \text{kPa}}{0.25256\ \frac{\text{kPa}}{\text{C°}}} = \boxed{182\ °C}$

8. (a) $\text{rate} = \frac{86.4\ \text{kPa} - 80.3\ \text{kPa}}{10.0\ °C - (-10.0\ °C)} = 0.305\ \frac{\text{kPa}}{\text{C°}}$

$T = T_0 + \frac{P - P_0}{\text{rate}} = 10.0\ °C + \frac{0 - 86.4\ \text{kPa}}{0.305\ \frac{\text{kPa}}{\text{C°}}} = \boxed{-273\ °C}$

(b) $P_F = P_0 + (\text{rate})(T - T_0) = 86.4\ \text{kPa} + \left(0.305\ \frac{\text{kPa}}{\text{C°}}\right)(0 - 10.0\ °C) = \boxed{83.4\ \text{kPa}}$

$P_B = 86.4\ \text{kPa} + \left(0.305\ \frac{\text{kPa}}{\text{C°}}\right)(100\ °C - 10.0\ °C) = \boxed{114\ \text{kPa}}$

(c) Different gases have different pressures at any given temperature, so the values for part (b) could be different. However, all gases extend down to zero pressure at the same temperature, so the answer to part (a) should be the same.

9. $\frac{\Delta T}{\Delta t} = \frac{45\ °F - (-4.0\ °F)}{2.0\ \text{min}} = 24.5\ \frac{\text{F°}}{\text{min}}$

$\left(24.5\ \frac{\text{F°}}{\text{min}}\right)\left(\frac{1\ \text{min}}{60\ \text{s}}\right)\left(\frac{1\ \text{K}}{1.8\ \text{F°}}\right) = \boxed{0.23\ \text{K/s}}$

10. $T_F = \left(\frac{9}{5}\frac{°F}{°C}\right)(T - 273.15)°C + 32\ °F$

$= \left(\frac{9}{5}\frac{°F}{°C}\right)T - 459.67\ °F$

$T = \left(\frac{5}{9}\frac{°C}{°F}\right)(T_F - 32\ °F) + 273.15\ \text{K}$

$= \left(\frac{5}{9}\frac{°C}{°F}\right)T_F + 255.37\ \text{K}$

Set $T_F = T$ and drop the units.

$$\frac{9}{5}T - 459.67 = \frac{5}{9}T + 255.37$$
$$\frac{56}{45}T = 715.04$$
$$T = \boxed{574.6}$$

11. $\text{rate} = \frac{227\text{ mmHg}}{373.15\text{ C°}} = 0.60833\ \frac{\text{mmHg}}{\text{C°}}$

$$T = T_0 + \frac{P - P_0}{\text{rate}} = 100\text{ °C} + \frac{162\text{ mmHg} - 227\text{ mmHg}}{0.60833\ \frac{\text{mmHg}}{\text{C°}}} = \boxed{-6.85\text{ °C}}$$

12. $\Delta L = \alpha L_0 \Delta T$

$$\begin{aligned} T &= T_0 + \frac{\Delta L}{\alpha L_0} \\ &= 23\text{°C} + \frac{0.50\text{ ft}}{(24\times10^{-6}\text{K}^{-1})(107\tfrac{5}{12}\text{ ft})} \\ &= \boxed{220\text{°C}} \end{aligned}$$

13. $\Delta L = \alpha L_0 \Delta T = (1.2\times10^{-5}\ (\text{C°})^{-1})(3910\text{ m})[30.0\text{ °C} - (-5.00\text{ °C})] = \boxed{1.6\text{ m}}$

14. (a) $d' = d + \alpha d\Delta T = d(1+\alpha\Delta T) = (1.178\text{ cm})\left[1+(24\times10^{-6}\text{K}^{-1})(199.0\text{°C} - 23.00\text{°C})\right] = \boxed{1.183\text{ cm}}$

(b)
$$d' = d + \alpha d\Delta T$$
$$\Delta T = \frac{d' - d}{\alpha d}$$
$$T = T_0 + \frac{d' - d}{\alpha d} = 23.00\text{°C} + \frac{1.176\text{ cm} - 1.178\text{ cm}}{(24\times10^{-6}\text{K}^{-1})(1.178\text{ cm})} = \boxed{-48\text{°C}}$$

15. (a) The ring should be heated. Imagine that the ring is cut and "unrolled". It would be a rectangle. If the rectangle is heated, it would expand along its length and width. Its length is the circumference of the ring. Since the length of the rectangle increases, the circumference of the circle increases, and therefore, so does its diameter.

(b)
$$L = C = \pi d$$
$$\Delta L = \Delta C = \pi\Delta d$$
$$\pi\Delta d = \alpha(\pi d_0)\Delta T$$

$$T = T_0 + \frac{\Delta d}{\alpha d_0} = 10.00\text{ °C} + \frac{4.040\text{ cm} - 4.000\text{ cm}}{(2.4\times10^{-5}\ (\text{C°})^{-1})(4.000\text{ cm})} = \boxed{430\text{°C}}$$

16. (a)
$$L = C = \pi d$$
$$\Delta L = \Delta C = \pi\Delta d$$
$$\pi\Delta d = \alpha(\pi d_0)\Delta T$$
$$T = T_0 + \frac{\Delta d}{\alpha d_0} = 12.25\text{ °C} + \frac{2.199\text{ cm} - 2.196\text{ cm}}{(1.9\times10^{-5}\text{ K}^{-1})(2.196\text{ cm})} = \boxed{80\text{°C}}$$

(b) $T = T_0 + \dfrac{\Delta d}{\alpha d_0} = 12.25\text{°C} + \dfrac{(2.196\text{ cm} - 2.199\text{ cm})}{(12\times 10^{-6}\text{K}^{-1})(2.199\text{ cm})} = \boxed{-100\text{°C}}$

17. The volume of spilled gasoline $= \Delta V_{\text{gas}} - \Delta V_{\text{tank}}$.

$$\begin{aligned}\Delta V_{\text{gas}} - \Delta V_{\text{tank}} &= (\beta_{\text{gas}} V_0 - \beta_{\text{tank}} V_0)\Delta T \\ &= (\beta_{\text{gas}} - \beta_{\text{tank}})V_0 \Delta T \\ &= (9.5\times 10^{-4}(\text{C°})^{-1} - 3.6\times 10^{-5}(\text{C°})^{-1})(51\text{ L})(25\text{ °C} - 5.0\text{ °C}) \\ &= \boxed{0.93\text{ L}}\end{aligned}$$

18. $$\begin{aligned}\Delta d_{\text{Cu}} &= \alpha_{\text{Cu}} d_0 \Delta T \\ \Delta d_{\text{st}} &= \alpha_{\text{st}} d_0 \Delta T \\ \Delta d_{\text{st}} - \Delta d_{\text{Cu}} &= (\alpha_{\text{st}} - \alpha_{\text{Cu}}) d_0 \Delta T \\ &= (1.73\times 10^{-5}(\text{C°})^{-1} - 1.70\times 10^{-5}(\text{C°})^{-1})(8.0\text{ in.})(610\text{ °C} - 22\text{ °C}) \\ &= \boxed{0.0014\text{ in.}}\end{aligned}$$

19. (a) $\boxed{\text{Aluminum}}$ has the larger coefficient of volumetric expansion, therefore, the aluminum cube will enclose a greater volume.

(b) $$\begin{aligned}\Delta V_{\text{Al}} &= \beta_{\text{Al}} V_0 \Delta T \\ \Delta V_{\text{Cu}} &= \beta_{\text{Cu}} V_0 \Delta T \\ \Delta V_{\text{Al}} = \Delta V_{\text{Cu}} &= (\beta_{\text{Al}} - \beta_{\text{Cu}})V_0 \Delta T \\ &= (7.2\times 10^{-5}(\text{C°})^{-1} - 5.1\times 10^{-5}(\text{C°})^{-1})V_0(95\text{ °C} - 23\text{ °C}) \\ &= \boxed{0.0015 V_0}\end{aligned}$$

20. $$\begin{aligned}\Delta V &= \beta V_0 \Delta T \\ T &= T_0 + \frac{\Delta V}{\beta V_0} \\ &= T_0 + \frac{\frac{4}{3}\pi(r+\Delta r)^3 - \frac{4}{3}\pi r^3}{\beta\left(\frac{4}{3}\pi r^3\right)} \\ &= 22\text{°C} + \frac{(1.3\text{ cm} + 0.010\text{ cm})^3 - (1.3\text{ cm})^3}{(5.1\times 10^{-5}\ (\text{C°})^{-1})(1.3\text{ cm})^3} \\ &= \boxed{480\text{°C}}\end{aligned}$$

21. (a) Because water has a larger coefficient of volumetric expansion, its volume will increase more than the volume of the aluminum sauce pan. Therefore, $\boxed{\text{water will overflow}}$ from the pan.

(b) $$\begin{aligned}\Delta V_{\text{w}} - \Delta V_{\text{Al}} &= (\beta_{\text{w}} - \beta_{\text{Al}})V_0 \Delta T \\ &= (2.1\times 10^{-4}(\text{C°})^{-1} - 7.2\times 10^{-5}(\text{C°})^{-1})\left[\pi\left(\frac{23\text{ cm}}{2}\right)^2(6.0\text{ cm})\right](88\text{ °C} - 19\text{ °C}) \\ &= \boxed{24\text{ cm}^3}\end{aligned}$$

22. $\left(2.6\times 10^{-4}\dfrac{\text{C}}{\text{s}\cdot\text{kg}}\right)(75\text{ kg})(8.0\text{ h})\left(\dfrac{3600\text{ s}}{\text{h}}\right) = \boxed{560\text{ C}}$

23. $P = \frac{\Delta E}{\Delta t} = \left(\frac{2.5\text{ kcal}}{1.5\text{ min}}\right)\left(\frac{1\text{ min}}{60\text{ s}}\right)\left(\frac{4186\text{ J}}{\text{kcal}}\right) = (116.3\text{ W})\left(\frac{1.341\times 10^{-3}\text{ hp}}{\text{W}}\right) = 0.16\text{ hp}$

Your power output is $\boxed{120\text{ W}}$ or $\boxed{0.16\text{ hp}}$.

24.
$$\begin{aligned} W &= F\Delta y \\ &= mgh \\ &= (12\text{ lb})(1.5\text{ ft}) \\ &= (18\text{ lb}\cdot\text{ft})\left(\frac{1\text{ m}}{3.281\text{ ft}}\right)\left(\frac{4.448\text{ N}}{\text{lb}}\right)\left(\frac{1\text{ C}}{4186\text{ N}\cdot\text{m}}\right) \\ &= 5.83\times 10^{-3}\text{ C} \end{aligned}$$

$$\text{reps} = \frac{120\text{ C}}{5.83\times 10^{-3}\text{ C}} = \boxed{2.1\times 10^4}$$

25. (a) $W = mgh = 2(0.95\text{ kg})\left(9.81\ \frac{\text{m}}{\text{s}^2}\right)(0.48\text{ m}) = 8.95\text{ J}$

$$\left(\frac{1.0\text{ C}°}{6200\text{ J}}\right)(8.95\text{ J}) = \boxed{1.4\times 10^{-3}\text{ C}°}$$

(b) Fahrenheit degrees are smaller, so the answer in Fahrenheit degrees would be $\boxed{\text{greater}}$.

(c) $\Delta T_\text{F} = \frac{9\text{ F}°}{5\text{ C}°}(1.44\times 10^{-3}\text{ C}°) = \boxed{2.6\times 10^{-3}\text{ F}°}$

26. $\left(62\ \frac{\text{J}}{\text{s}}\right)\left(\frac{1\text{ C}}{4186\text{ J}}\right) = 1.481\times 10^{-2}\ \frac{\text{C}}{\text{s}}$

$$\left(\frac{230\text{ C}}{1.481\times 10^{-2}\ \frac{\text{C}}{\text{s}}}\right)\left(\frac{1\text{ h}}{3600\text{ s}}\right) = \boxed{4.3\text{ h}}$$

27.
$$\begin{aligned} Q &= mc\Delta T \\ T &= T_0 + \frac{Q}{mc} \\ &= 25.0\ °\text{C} + \frac{63.0\text{ J}}{(0.128\text{ kg})\left(900\ \frac{\text{J}}{\text{kg}\cdot\text{K}}\right)} \\ &= \boxed{25.5\ °\text{C}} \end{aligned}$$

28. $Q = mc\Delta T = (0.055\text{ kg})\left(837\ \frac{\text{J}}{\text{kg}\cdot\text{K}}\right)(15\ °\text{C}) = \boxed{0.69\text{ kJ}}$

29. Because an apple is mostly water, use the specific heat of water to approximate that for an apple.

$$Q = mc\Delta T = (0.13\text{ kg})\left(4186\frac{\text{J}}{\text{kg}\cdot\text{K}}\right)(35\ °\text{C} - 15\ °\text{C}) = \boxed{11\text{ kJ}}$$

30. $\Delta T = \dfrac{Q}{mc} = \dfrac{\frac{1}{2}K}{mc} = \dfrac{\frac{1}{2}\left(\frac{1}{2}mv^2\right)}{mc} = \dfrac{v^2}{4c} = \dfrac{\left(250\ \frac{\text{m}}{\text{s}}\right)^2}{4\left(128\ \frac{\text{J}}{\text{kg}\cdot\text{K}}\right)} = \boxed{120\ °\text{C}}$

31. (a) $Q_{\text{Ag}} + Q_{\text{w}} = 0$

$$= m_{\text{Ag}}c_{\text{Ag}}(T - T_{\text{Ag}}) + m_{\text{w}}c_{\text{w}}(T - T_{\text{w}})$$

$$m_{\text{Ag}} = \frac{m_{\text{w}}c_{\text{w}}(T_{\text{w}} - T)}{c_{\text{Ag}}(T - T_{\text{Ag}})} = \frac{(0.220\ \text{kg})\left(4186\ \frac{\text{J}}{\text{kg}\cdot\text{K}}\right)(18°\text{C} - 25°\text{C})}{\left(234\ \frac{\text{J}}{\text{kg}\cdot\text{K}}\right)(25°\text{C} - 85°\text{C})} = 0.459\ \text{kg}$$

$\boxed{\text{460 pellets}}$ are needed.

(b) Copper has a higher specific heat, so the required number of pellets $\boxed{\text{decreases}}$.

(c) $m_{\text{Cu}} = \dfrac{m_{\text{w}}c_{\text{w}}(T_{\text{w}} - T)}{c_{\text{Cu}}(T - T_{\text{Cu}})} = \dfrac{(0.220\ \text{kg})\left(4186\ \frac{\text{J}}{\text{kg}\cdot\text{K}}\right)(18°\text{C} - 25°\text{C})}{\left(387\ \frac{\text{J}}{\text{kg}\cdot\text{K}}\right)(25°\text{C} - 85°\text{C})} = 0.278\ \text{kg}$

$\boxed{\text{280 pellets}}$ are needed.

32. $Q_{\text{Pb}} + Q_{\text{w}} = 0$

$$= m_{\text{Pb}}c_{\text{Pb}}(T - T_{\text{Pb}}) + m_{\text{w}}c_{\text{w}}(T - T_{\text{w}})$$

$$= T(m_{\text{Pb}}c_{\text{Pb}} + m_{\text{w}}c_{\text{w}}) - (m_{\text{Pb}}c_{\text{Pb}}T_{\text{Pb}} + m_{\text{w}}c_{\text{w}}T_{\text{w}})$$

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

$$= \frac{(0.223\ \text{kg})\left(128\ \frac{\text{J}}{\text{kg}\cdot\text{K}}\right)(83.2\ °\text{C}) + (0.178\ \text{kg})\left(4186\ \frac{\text{J}}{\text{kg}\cdot\text{K}}\right)(24.5\ °\text{C})}{(0.223\ \text{kg})\left(128\ \frac{\text{J}}{\text{kg}\cdot\text{K}}\right) + (0.178\ \text{kg})\left(4186\ \frac{\text{J}}{\text{kg}\cdot\text{K}}\right)}$$

$$= \boxed{26.7\ °\text{C}}$$

33. (a) $C = \dfrac{Q}{\Delta T} = \dfrac{2200\ \text{J}}{12\ °\text{C}} = \boxed{0.18\ \text{kJ/°C}}$

(b) $c = \dfrac{Q}{m\Delta T} = \dfrac{2200\ \text{J}}{(0.190\ \text{kg})(12\ °\text{C})} = \boxed{0.96\ \text{kJ/(kg}\cdot\text{K)}}$

34. $\Delta T = \dfrac{Q}{mc} = \dfrac{K}{mc} = \dfrac{U}{mc} = \dfrac{mgh}{mc} = \dfrac{gh}{c} = \dfrac{\left(9.81\ \frac{\text{m}}{\text{s}^2}\right)(5.43\ \text{m})}{128\ \frac{\text{J}}{\text{kg}\cdot\text{K}}} = \boxed{0.416\ °\text{C}}$

35. $Q_{\text{Ob}} + Q_{\text{w}} + Q_{\text{Al}} = 0$

$$0 = m_{\text{Ob}}c_{\text{Ob}}\Delta T_{\text{Ob}} + m_{\text{w}}c_{\text{w}}\Delta T_{\text{w}} + m_{\text{Al}}c_{\text{Al}}\Delta T_{\text{Al}}$$

$$c_{\text{Ob}} = \frac{m_{\text{w}}c_{\text{w}}(T_{\text{w}} - T) + m_{\text{Al}}c_{\text{A1}}(T_{\text{Al}} - T)}{m_{\text{Ob}}(T - T_{\text{Ob}})}$$

$$= \frac{(0.103\ \text{kg})\left(4186\ \frac{\text{J}}{\text{kg}\cdot\text{K}}\right)(20.0\ °\text{C} - 22.0\ °\text{C}) + (0.155\ \text{kg})\left(900\ \frac{\text{J}}{\text{kg}\cdot\text{K}}\right)(20.0\ °\text{C} - 22.0\ °\text{C})}{(0.0380\ \text{kg})(22.0\ °\text{C} - 100\ °\text{C})}$$

$$= \boxed{385\ \text{J/(kg}\cdot\text{K)}}$$

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

36. (a)
$$\begin{aligned}Q_h + Q_w &= 0\\ &= m_h c_h (T - T_h) + m_w c_w (T - T_w)\\ &= T(m_h c_h + m_w c_w) - (m_h c_h T_h + m_w c_w T_w)\end{aligned}$$

$$\begin{aligned}T &= \frac{m_h c_h T_h + m_w c_w T_w}{m_h c_h + m_w c_w}\\ &= \frac{(0.50\text{ kg})\left(448\ \frac{\text{J}}{\text{kg}\cdot\text{K}}\right)(450\ ^\circ\text{C}) + (25\text{ kg})\left(4186\ \frac{\text{J}}{\text{kg}\cdot\text{K}}\right)(23\ ^\circ\text{C})}{(0.50\text{ kg})\left(448\ \frac{\text{J}}{\text{kg}\cdot\text{K}}\right) + (25\text{ kg})\left(4186\ \frac{\text{J}}{\text{kg}\cdot\text{K}}\right)}\\ &= \boxed{24\ ^\circ\text{C}}\end{aligned}$$

(b) $\boxed{\text{less than}}$ 1 kg of lead has less heat capacity $\left(1\text{ kg}\times 128\ \frac{\text{J}}{\text{kg}\cdot\text{K}}\right)$ than 0.50 kg of iron $\left(0.50\text{ kg}\times 448\ \frac{\text{J}}{\text{kg}\cdot\text{K}}\right)$.

37. $Q_{cup} + Q_{cof} + Q_{crm} = 0$

$$\begin{aligned}0 &= m_{cup} c_{cup} (T - T_{cup}) + m_{cof} c_w (T - T_{cof}) + m_{crm} c_w (T - T_{crm})\\ &= T[m_{cup} c_{cup} + (m_{cof} + m_{crm}) c_w] - [m_{cup} c_{cup} T_{cup} + (m_{cof} T_{cof} + m_{crm} T_{crm}) c_w]\end{aligned}$$

$$\begin{aligned}T &= \frac{m_{cup} c_{cup} T_{cup} + (m_{cof} T_{cof} + m_{crm} T_{crm}) c_w}{m_{cup} c_{cup} + (m_{cof} + m_{crm}) c_w}\\ &= \frac{(0.116\text{ kg})\left(1090\ \frac{\text{J}}{\text{kg}\cdot\text{K}}\right)(24.0\ ^\circ\text{C}) + [(0.225\text{ kg})(80.3\ ^\circ\text{C}) + (0.0122\text{ kg})(5.00\ ^\circ\text{C})]\left(4186\ \frac{\text{J}}{\text{kg}\cdot\text{K}}\right)}{(0.116\text{ kg})\left(1090\ \frac{\text{J}}{\text{kg}\cdot\text{K}}\right) + (0.225\text{ kg} + 0.0122\text{ kg})\left(4186\ \frac{\text{J}}{\text{kg}\cdot\text{K}}\right)}\\ &= \boxed{70.5\ ^\circ\text{C}}\end{aligned}$$

38. $\frac{Q}{t} = kA\left(\frac{\Delta T}{L}\right) = \left(0.84\ \frac{\text{W}}{\text{m}\cdot\text{K}}\right)(0.85\text{ m})(0.38\text{ m})\left(\frac{18\text{C}^\circ}{0.0050\text{ m}}\right)\left(\frac{60\text{ s}}{\text{min}}\right) = \boxed{59\ \text{kJ/min}}$

39. $\frac{Q}{t} = kA\left(\frac{\Delta T}{L}\right) = \left(0.0234\ \frac{\text{W}}{\text{m}\cdot\text{K}}\right)(0.85\text{ m})(0.38\text{ m})\left(\frac{18^\circ\text{C}}{0.0050\text{ m}}\right)\left(\frac{60\text{ s}}{\text{min}}\right) = \boxed{1.6\ \frac{\text{kJ}}{\text{min}}}$

40. $P_{net} = e\sigma A(T^4 - T_s^4) = \frac{\Delta Q}{\Delta t}$

$$\Delta t = \frac{\Delta Q}{e\sigma A(T^4 - T_s^4)} = \frac{(306\text{ C})\left(4186\ \frac{\text{J}}{\text{C}}\right)}{0.915\left(5.67\times10^{-8}\ \frac{\text{W}}{\text{m}^2\cdot\text{K}^4}\right)(1.22\,\text{m}^2)\left[(310.35\,\text{K})^4 - (294.95\,\text{K})^4\right]} = \boxed{3.29\text{ h}}$$

41. $Q = kA\left(\frac{\Delta T}{L}\right)t = \left(34.3\ \frac{\text{W}}{\text{m}\cdot\text{K}}\right)(1.2\times10^{-3}\,\text{m}^2)\left(\frac{8.5\ ^\circ\text{C}}{0.15\text{ m}}\right)(1.0\text{ s}) = \boxed{2.3\text{ J}}$

42. (a) $\frac{Q}{t} = kA\left(\frac{\Delta T}{L}\right) = \left(0.0234\ \frac{\text{W}}{\text{m}\cdot\text{K}}\right)(0.725\text{ m}^2)\left(\frac{20.0\text{ C}^\circ}{0.0175\text{ m}}\right) = \boxed{19.4\text{ J/s}}$

(b) $\Delta T=\left(\frac{Q}{t}\right)\left(\frac{L}{kA}\right)=\left(19.4\ \frac{\text{J}}{\text{s}}\right)\left[\frac{0.0050\ \text{m}}{\left(0.84\ \frac{\text{W}}{\text{m}\cdot\text{K}}\right)(0.725\ \text{m}^2)}\right]=\boxed{0.16\ \text{C}°}$

43. (a)

$$\begin{aligned}\frac{Q_{\text{total}}}{t}&=\frac{Q_{\text{Al}}}{t}+\frac{Q_{\text{st}}}{t}\\&=k_{\text{Al}}A\left(\frac{\Delta T}{L}\right)+k_{\text{st}}A\left(\frac{\Delta T}{L}\right)\\&=A\left(\frac{\Delta T}{L}\right)(k_{\text{Al}}+k_{\text{st}})\\&=\frac{\pi}{4}d^2\left(\frac{\Delta T}{L}\right)(k_{\text{Al}}+k_{\text{st}})\\L&=\frac{\pi d^2\Delta T(k_{\text{Al}}+k_{\text{st}})}{4\left(\frac{Q_{\text{total}}}{t}\right)}\\&=\frac{\pi(0.0350\ \text{m})^2(118°\text{C}-20.0°\text{C})\left(217\ \frac{\text{W}}{\text{m}\cdot\text{K}}+16.3\ \frac{\text{W}}{\text{m}\cdot\text{K}}\right)}{4\left(27.5\ \frac{\text{J}}{\text{s}}\right)}\\&=\boxed{0.800\ \text{m}}\end{aligned}$$

(b) decreases by a factor of 2

44.

$$\begin{aligned}\frac{Q_{\text{total}}}{t}&=\frac{Q_{\text{Cu}}}{t}+\frac{Q_{\text{Pb}}}{t}\\&=k_{\text{Cu}}A_{\text{Cu}}\left(\frac{\Delta T}{L}\right)+k_{\text{Pb}}A_{\text{Pb}}\left(\frac{\Delta T}{L}\right)\\&=\left[k_{\text{Cu}}\left(\frac{\pi}{4}d_{\text{Cu}}^{\ 2}\right)+k_{\text{Pb}}\left(\frac{\pi}{4}d_{\text{Pb}}^{\ 2}\right)\right]\left(\frac{\Delta T}{L}\right)\\\left(\frac{Q_{\text{total}}}{t}\right)\left(\frac{4L}{\pi\Delta T}\right)&=k_{\text{Cu}}d_{\text{Cu}}^{\ 2}+k_{\text{Pb}}d_{\text{Pb}}^{\ 2}\\d_{\text{Cu}}&=\sqrt{\frac{1}{k_{\text{Cu}}}\left[\left(\frac{Q_{\text{total}}}{t}\right)\left(\frac{4L}{\pi\Delta T}\right)-k_{\text{Pb}}d_{\text{Pb}}^{\ 2}\right]}\\&=\sqrt{\left(\frac{1}{395\ \frac{\text{W}}{\text{m}\cdot\text{K}}}\right)\left[\left(33.2\ \frac{\text{J}}{\text{s}}\right)\frac{4(0.750\ \text{m})}{\pi(112\ °\text{C}-21.0\ °\text{C})}\right]-\left(34.3\ \frac{W}{\text{m}\cdot°\text{C}}\right)(0.0260\ \text{m})^2}\\&=\boxed{2.87\ \text{cm}}\end{aligned}$$

45. (a) The temperature of the junction is greater than 54 °C. Since lead has a smaller thermal conductivity than copper, it must have a greater temperature difference across it to have the same heat flow.

(b) $\frac{Q}{t}=1.41\ \frac{\text{J}}{\text{s}}=k_{\text{Cu}}A_{\text{Cu}}\frac{\Delta T_{\text{Cu}}}{L_{\text{Cu}}}=\left(395\ \frac{\text{W}}{\text{m}\cdot\text{K}}\right)\frac{(0.015\ \text{m})^2}{(0.525\ \text{m})}\Delta T_{\text{Cu}}$

$$\begin{aligned}\Delta T_{\text{Cu}}&=8.3\ \text{C}°=106°\text{C}-T\\T&=\boxed{98°\text{C}}\end{aligned}$$

46. (a) $\boxed{\text{The rate of flow of heat through both rods is the same.}}$

(b) $k_{\text{Al}} \cdot A\dfrac{\Delta T_{\text{Al}}}{L_{\text{Al}}} = k_{\text{Pb}} A\dfrac{\Delta T_{\text{Pb}}}{L_{\text{Pb}}}$

$$L_{\text{Al}} = \left(\frac{k_{\text{Al}}}{k_{\text{Pb}}}\right)\left(\frac{\Delta T_{\text{Al}}}{\Delta T_{\text{Pb}}}\right)L_{\text{Pb}} = \left(\frac{217\ \frac{\text{W}}{\text{m}\cdot\text{K}}}{34.3\ \frac{\text{W}}{\text{m}\cdot\text{K}}}\right)\left(\frac{80.0°\text{C} - 50.0°\text{C}}{50.0°\text{C} - 20.0°\text{C}}\right)(14\text{ cm}) = \boxed{89\text{ cm}}$$

47.

$$\frac{Q}{t} = \frac{Q_{23}}{t}$$

$$kA\left(\frac{87\ °\text{C} - 24\ °\text{C}}{95\text{ cm}}\right) = kA\left(\frac{T_{23} - 24\ °\text{C}}{23\text{ cm}}\right)$$

$$T_{23} - 24\ °\text{C} = \left(\frac{23\text{ cm}}{95\text{ cm}}\right)(63\ °\text{C})$$

$$T_{23} = 24\ °\text{C} + 15\ °\text{C}$$

$$= \boxed{39\ °\text{C}}$$

48. $$\frac{P_1}{P_2} = \frac{e\sigma A(T_1^4 - T_s^4)}{e\sigma A(T_2^4 - T_s^4)} = \frac{[(273.15+95)\text{ K}]^4 - [(273.15+23)\text{ K}]^4}{[(273.15+25)\text{ K}]^4 - [(273.15+23)\text{ K}]^4} = \boxed{51}$$

49. $$P = kA\left(\frac{\Delta T}{L'}\right) = k(2L^2)\left(\frac{\Delta T}{3L}\right) = \frac{2}{3}kL\Delta T$$

(a) $$P_a = k(3L^2)\left(\frac{\Delta T}{2L}\right) = \frac{3}{2}kL\Delta T = \boxed{\frac{9}{4}P}$$

(b) $$P_b = k(6L^2)\left(\frac{\Delta T}{L}\right) = 6kL\Delta T = \boxed{9P}$$

50. <u>length</u>

$\Delta L = \alpha L_0 \Delta T = (1.2\times10^{-5}\ (\text{C}°)^{-1})(10.0\text{ m})(20.0\ °\text{C} - 872\ °\text{C}) = -0.10\text{ m}$

$L' = L_0 + \Delta L = 10.0\text{ m} - 0.10\text{ m} = \boxed{9.9\text{ m}}$

<u>width</u>

$L' = 2.03\text{ m} + (1.2\times10^{-5}(\text{C}°)^{-1})(2.03\text{ m})(20.0\ °\text{C} - 872\ °\text{C}) = \boxed{2.01\text{ m}}$

<u>height</u>

$L' = 0.254\text{ m} + (1.2\times10^{-5}\ (\text{C}°)^{-1})(0.254\text{ m})(20.0\ °\text{C} - 872\ °\text{C}) = \boxed{25.1\text{ m}}$

The dimensions of the cooled steel sheet are $25.1\text{ cm}\times2.01\text{ m}\times9.9\text{ m}$.

51. The differing final temperatures may be due to differences in $\boxed{\text{mass and/or specific heat}}$. To explain, we look at the specific heat equation, $Q = mc\Delta T$. For the same Q and different ΔTs, m and/or c must be different. If the objects have the same mass, then their specific heats must differ. If they have the same specific heats, then their masses must differ. The following must be satisfied:

$$Q = m_1c_1\Delta T_1 = m_2c_2\Delta T_2$$

$$\frac{\Delta T_1}{\Delta T_2} = \frac{m_2c_2}{m_1c_1}$$

52. **(a)** $T_{\text{F}}=\left(\frac{9\text{ F}°}{5\text{ C}°}\right)(1500°\text{C})+32=\boxed{2700°\text{F}}$

(b) $T=1500°\text{C}+273.15=\boxed{1800\text{ K}}$

53. **(a)** $Q=mc\Delta T=\rho Vc\Delta T$

$$=\left(1.29\ \frac{\text{kg}}{\text{m}^3}\right)(1.00\text{ m}^3)\left(1004\ \frac{\text{J}}{\text{kg}\cdot\text{K}}\right)(1.00\text{ C}°)=\boxed{1.30\times10^3\text{ J}}$$

(b) $Q=\left(1000\ \frac{\text{kg}}{\text{m}^3}\right)(1.00\text{ m}^3)\left(4186\ \frac{\text{J}}{\text{kg}\cdot\text{K}}\right)(1.00\text{ C}°)=\boxed{4.19\times10^6\text{ J}}$

This is $\boxed{\text{bigger by a factor of 3000}}$.

54. **(a)** $E=Pt=\left(22\ \frac{\text{J}}{\text{s}}\right)(3600\text{ s})=79.2\text{ kJ}$

$E=mgh=(65\text{ kg})(9.81\text{ m/s}^2)(0.21\text{ m})=134\text{ J/step}$

$\text{number of steps}=\frac{79,200\text{ J}}{134\text{ J/step}}=\boxed{590\text{ steps}}$

(b) $\Delta T=\frac{Q}{mc}=\frac{79,200\text{ J}}{[(1.4\text{ kg})]\left(4186\ \frac{\text{J}}{\text{kg}\cdot\text{K}}\right)}=\boxed{14°\text{C}}$

55. $\ln\left(\frac{N}{5.63\times10^{10}}\right)=-\frac{6290\text{ K}}{T}$

$$T=\frac{-6290\text{ K}}{\ln\left(\frac{185\times\frac{13.0}{60.0}}{5.63\times10^{10}}\right)}=299\text{ K}$$

$$T_{\text{F}}=\frac{9°\text{F}}{5°\text{C}}(298.6\text{ K}-273.2\text{ K})+32=\boxed{78°\text{F}}$$

56. **(a)** Since heat is transferred at the same rate for the same amount of time to the water and the mystery material, each material has absorbed the same amount of heat.

$$Q=mc_{\text{w}}\Delta T_{\text{w}}=mc\Delta T$$

$$c=\left(\frac{\Delta T_{\text{w}}}{\Delta T}\right)c_{\text{w}}=\left(\frac{13\text{ C}°}{61\text{ C}°}\right)\left(4186\ \frac{\text{J}}{\text{kg}\cdot\text{K}}\right)=8.9\times10^2\ \frac{\text{J}}{\text{kg}\cdot\text{K}}$$

$c_{\text{Al}}=900\text{ J/kg}\cdot°\text{C}$, so the mystery material is likely $\boxed{\text{aluminum}}$.

(b) $\frac{Q}{\Delta t}=\frac{mc_{\text{w}}\Delta T_{\text{w}}}{\Delta t}=\frac{(0.150\text{ kg})\left(4186\ \frac{\text{J}}{\text{kg}\cdot\text{K}}\right)(13\text{ °C})}{(2.5\text{ min})\left(\frac{60\text{ s}}{\text{min}}\right)}=\boxed{54\text{ J/s}}$

57. (a) For small oscillations, the period of a pendulum is $T = 2\pi\sqrt{L/g}$. If the temperature increases, L will increase by $\Delta L = \alpha L_0 \Delta T$, therefore, the period will $\boxed{\text{increase}}$.

(b) $\Delta L = \alpha L_0 \Delta T = (1.200\times10^{-5}\ (\text{C°})^{-1})(0.9500\ \text{m})(150.0\ \text{C°}) = \boxed{0.1710\ \text{cm}}$

(c) $T_{\text{before}} = 2\pi\sqrt{\frac{L}{g}} = 2\pi\sqrt{\frac{0.9500\ \text{m}}{9.810\ \frac{\text{m}}{\text{s}^2}}} = \boxed{1.955\ \text{s}}$

$T_{\text{after}} = 2\pi\sqrt{\frac{0.95171\ \text{m}}{9.810\ \frac{\text{m}}{\text{s}^2}}} = \boxed{1.957\ \text{s}}$

* $g = 9.810\ \text{m/s}^2$ at the city of Winnipeg.

58. (a) Because aluminum expands and contracts at a greater rate than steel, the system should be $\boxed{\text{heated}}$.

(b) ring

$$A' = A_0 + 2\alpha_{\text{Al}} A_0 \Delta T$$

$$\frac{\pi}{4} d_{\text{Al}}'^2 = \frac{\pi}{4} d_{\text{Al}}^2 + 2\alpha_{\text{Al}}\left(\frac{\pi}{4} d_{\text{Al}}^2\right)\Delta T$$

$$d_{\text{Al}}'^2 = d_{\text{Al}}^2 + 2\alpha_{\text{Al}} d_{\text{Al}}^2 \Delta T$$

bar

$$d'_{\text{St}}{}^2 = d_{\text{St}}^2 + 2\alpha_{\text{St}} d_{\text{St}}^2 \Delta T$$

Set the results for the ring and the bar equal to each other.

$$d_{\text{Al}}^2 + 2\alpha_{\text{Al}} d_{\text{Al}}^2 \Delta T = d_{\text{St}}^2 + 2\alpha_{\text{St}} d_{\text{St}}^2 \Delta T$$

$$\begin{aligned} T &= \frac{d_{\text{St}}^2 - d_{\text{Al}}^2}{2(\alpha_{\text{Al}} d_{\text{Al}}^2 - \alpha_{\text{St}} d_{\text{St}}^2)} + T_0 \\ &= \frac{(4.040\ \text{cm})^2 - (4.000\ \text{cm})^2}{2[(2.4\times10^{-5}\ (\text{C°})^{-1})(4.000\ \text{cm})^2 - (1.2\times10^{-5}\ (\text{C°})^{-1})(4.040\ \text{cm})^2]} + 10\ \text{°C} \\ &= \boxed{860\ \text{°C}} \end{aligned}$$

59. plate

$$d'_{\text{st}} = d_{\text{st}} + \alpha_{\text{st}} d_{\text{st}} \Delta T$$

glass marble

$$d'_{\text{g}} = d_{\text{g}} + \alpha_{\text{g}} d_{\text{g}} \Delta T$$

Set the results for the plate and the marble equal to each other.

$$d_{\text{St}} + \alpha_{\text{St}} d_{\text{St}} \Delta T = d_{\text{g}} + \alpha_{\text{g}} d_{\text{g}} \Delta T$$

$$\Delta T = \frac{d_{\text{St}} - d_{\text{g}}}{\alpha_{\text{g}} d_{\text{g}} - \alpha_{\text{St}} d_{\text{St}}} = \frac{1.000\ \text{cm} - 1.003\ \text{cm}}{(3.3\times10^{-6}\ (\text{C°})^{-1})(1.003\ \text{cm}) - (1.2\times10^{-5}\ (\text{C°})^{-1})(1.000\ \text{cm})} = \boxed{350\ \text{°C}}$$

60. $Q_\text{r} = mghs$

$$Q_\text{f} + Q_\text{r} + Q_\text{w} = 0 = -mgh + m_\text{r}c_\text{r}(T - T_\text{r}) + m_\text{w}c_\text{w}(T - T_\text{w})$$

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

$$= \frac{(206\text{ kg})\left(9.81\ \frac{\text{m}}{\text{s}^2}\right)(5.00\text{ m}) + (206\text{ kg})\left(1010\ \frac{\text{J}}{\text{kg}\cdot\text{K}}\right)(30.2\text{ °C}) + (6.00\text{ m}^3)\left(1.00\times10^3\ \frac{\text{kg}}{\text{m}^3}\right)\left(4186\ \frac{\text{J}}{\text{kg}\cdot\text{K}}\right)(15.5\text{ °C})}{(206\text{ kg})\left(1010\ \frac{\text{J}}{\text{kg}\cdot\text{K}}\right) + (6.00\text{ m}^3)\left(1.00\times10^3\ \frac{\text{kg}}{\text{m}^3}\right)\left(4186\ \frac{\text{J}}{\text{kg}\cdot\text{K}}\right)}$$

$$= \boxed{15.6\text{ °C}}$$

61. $Q = mc\Delta T = mgh$

$$\Delta T = \frac{gh}{c} = \frac{\left(9.81\ \frac{\text{m}}{\text{s}^2}\right)(72\text{ m})}{4186\ \frac{\text{J}}{\text{kg}\cdot\text{K}}} = \boxed{0.17\text{ C°}}$$

62. **(a)** $\dfrac{Q}{t} = \dfrac{m_\text{w}c_\text{w}\Delta T}{t} + \dfrac{m_\text{s}c_\text{s}\Delta T}{t}$

$$= (m_\text{w}c_\text{w} + m_\text{s}c_\text{s})\frac{\Delta T}{t}$$

$$= \frac{\left[(2.1\text{ L})\left(1\ \frac{\text{kg}}{\text{L}}\right)\left(4186\ \frac{\text{J}}{\text{kg}\cdot\text{K}}\right) + (0.22\text{ kg})\left(448\ \frac{\text{J}}{\text{kg}\cdot\text{K}}\right)\right](100\text{ °C} - 22\text{ °C})}{(8.5\text{ min})\left(\frac{60\text{ s}}{\text{min}}\right)}$$

$$= \boxed{1.4\text{ kJ/s}}$$

(b) less time

63. **(a)** $mgh = Q$

$$h = \frac{Q}{mg}$$

$$= \frac{(525\text{ kcal})\left(4186\ \frac{\text{J}}{\text{kcal}}\right)}{(0.145\text{ kg})\left(9.81\ \frac{\text{m}}{\text{s}^2}\right)}$$

$$= \boxed{1.54\times10^6\text{ m}}$$

(b) $\dfrac{1}{2}mv^2 = Q$

$$v = \sqrt{\frac{2Q}{m}}$$

$$= \sqrt{\frac{2(525\text{ kcal})\left(4186\ \frac{\text{J}}{\text{kcal}}\right)}{0.145\text{ kg}}}$$

$$= \boxed{5.51\text{ km/s}}$$

64. $Pt = mc\Delta T$

$$t = \frac{mc\Delta T}{P} = \frac{(0.65\text{ kg})\left(4186\ \frac{\text{J}}{\text{kg}\cdot\text{K}}\right)(5.0\text{ C}°)}{(0.12\text{ hp})\left(\frac{745.7\ \frac{\text{J}}{\text{s}}}{\text{hp}}\right)} = (152\text{ s})\left(\frac{1\text{ min}}{60\text{ s}}\right) = \boxed{2.5\text{ min}}$$

65. **(a)** $$\frac{Q}{t} = kA\left(\frac{\Delta T}{L}\right) = \left(0.60\ \frac{\text{W}}{\text{m}\cdot\text{K}}\right)(1.40\text{ m}^2)\left(\frac{3.0\text{ C}°}{0.012\text{ m}}\right) = \boxed{210\text{ W}}$$

(b) $2(210\text{ W}) = \boxed{420\text{ W}}$

The rate of heat transfer is proportional to the temperature difference.

66. **(a)** $$P_{\text{net}} = e\sigma A(T^4 - T_{\text{s}}^4) = (1.0)\left(5.67\times10^{-8}\ \frac{\text{W}}{\text{m}^2\cdot\text{K}^4}\right)(4\pi)(7.0\times10^8\text{ m})^2[(5500°\text{C} + 273\text{ K})^4 - (3\text{ K})^4] = \boxed{3.9\times10^{26}\text{ W}}$$

(b) $$\textit{solar constant} = \frac{P}{A} = \frac{3.9\times10^{26}\text{ W}}{4\pi(1.5\times10^{11}\text{ m})^2} = \boxed{1.4\ \frac{\text{kW}}{\text{m}^2}}$$

67. $\Delta L_{\text{A}} = \alpha_{\text{A}} L_{\text{A}} \Delta T$

$\Delta L_{\text{B}} = \alpha_{\text{B}} L_{\text{B}} \Delta T$

If $\Delta L_{\text{A}} - \Delta L_{\text{B}} = 0$, D will not change.

$$\Delta L_{\text{A}} - \Delta L_{\text{B}} = 0 = \alpha_{\text{A}} L_{\text{A}} \Delta T - \alpha_{\text{B}} L_{\text{B}} \Delta T$$

Assuming $\Delta T \neq 0$, we have

$$0 = \alpha_{\text{A}} L_{\text{A}} - \alpha_{\text{B}} L_{\text{B}}$$

$$\alpha_{\text{A}} L_{\text{A}} = \alpha_{\text{B}} L_{\text{B}}$$

$$\frac{L_{\text{A}}}{L_{\text{B}}} = \frac{\alpha_{\text{B}}}{\alpha_{\text{A}}}$$

68. For small oscillations, the period of a pendulum is $T_{\text{p}} = 2\pi\sqrt{L/g}$.

$$T_{\text{p}} = 2\pi\sqrt{\frac{L}{g}}$$

$$T_{\text{p}}^2 = 4\pi^2\frac{L}{g}$$

$$L = \frac{gT_{\text{p}}^2}{4\pi^2}$$

$$\Delta L = \alpha L \Delta T = \alpha \left(\frac{g T_\text{p}{}^2}{4\pi^2} \right) \Delta T$$

$$T'_\text{p} = 2\pi \sqrt{\frac{L + \Delta L}{g}} = 2\pi \sqrt{\frac{\frac{g T_\text{p}{}^2}{4\pi^2} + \frac{\alpha g T_\text{p}{}^2 \Delta T}{4\pi^2}}{g}} = \sqrt{T_\text{p}{}^2 + \alpha T_\text{p}{}^2 \Delta T} = T_\text{p} \sqrt{1 + \alpha \Delta T}$$

There are (3600 s/h)(12 h) = 43,200 s between 10 P.M. and 10 A.M. So, the time difference is

$$\begin{aligned}\Delta t &= (43,200 \text{ s})(1 - T_\text{p} \sqrt{1 + \alpha \Delta T}) \\ &= (43,200 \text{ s})\left[1 - (1.00 \text{ s})\sqrt{1 + (1.9 \times 10^{-5} (\text{C}°)^{-1})(19.1\ °\text{C} - 23.0\ °\text{C})}\right] \\ &= 1.6 \text{ s}\end{aligned}$$

The actual time is 9:59:58.4 A.M.

69. (a) Since aluminum has a larger coefficient of thermal expansion than steel, the temperature of the system should be decreased.

(b) aluminum sheet

$d' = d + \alpha_\text{Al} d \Delta T$

steel rod

$L' = L + \alpha_\text{St} L \Delta T$

Set $d' = L'$.

$$\begin{aligned}d + \alpha_\text{Al} d \Delta T &= L + \alpha_\text{st} L \Delta T \\ \Delta T &= \frac{L - d}{\alpha_\text{Al} d - \alpha_\text{st} L} \\ &= \frac{9.99 \text{ cm} - 10.0 \text{ cm}}{\left(2.4 \times 10^{-5} \text{K}^{-1}\right)(10.0 \text{ cm}) - \left(1.2 \times 10^{-5} \text{K}^{-1}\right)(9.99 \text{ cm})} \\ &= \boxed{-83 \text{ K}}\end{aligned}$$

70. $L = 1.4\text{ m}$
ℓ = thickness of the ice
1 = solid water
2 = liquid water
T = temperature at the solid-liquid interface = 0 °C

$$Q_1 = k_1 A\left(\frac{T - T_1}{\ell}\right)t$$
$$Q_2 = k_2 A\left(\frac{T_2 - T}{L - \ell}\right)t$$
$$Q_1 = Q_2$$
$$k_1 A\left(\frac{T - T_1}{\ell}\right)t = k_2 A\left(\frac{T_2 - T}{L - \ell}\right)t$$
$$\frac{k_1}{\ell}(T - T_1) = \frac{k_2}{L - \ell}(T_2 - T)$$
$$\frac{L - \ell}{\ell} = \frac{k_2(T_2 - T)}{k_1(T - T_1)}$$
$$\frac{L}{\ell} - 1 = \frac{k_2(T_2 - T)}{k_1(T - T_1)}$$
$$\ell = \frac{L}{1 + \frac{k_2(T_2 - T)}{k_1(T - T_1)}}$$
$$= \frac{1.4\text{ m}}{1 + \frac{\left(0.60\ \frac{\text{W}}{\text{m}\cdot\text{K}}\right)(4.0\text{ °C} - 0.0\text{ °C})}{\left(1.6\ \frac{\text{W}}{\text{m}\cdot\text{K}}\right)[0.0\text{ °C} - (-5.4\text{ °C})]}}$$
$$= \boxed{1.1\text{ m}}$$

71. T_3 = the temperature at the left glass-air interface
T_4 = the temperature at the right glass-air interface

$$\frac{Q}{At} = \frac{k_1}{L_1}(T_3 - T_1) = \frac{k_2}{L_2}(T_4 - T_3) = \frac{k_1}{L_1}(T_2 - T_4)$$

From the rate of heat flow per unit area across the glass panes, we have

$$T_3 - T_1 = T_2 - T_4$$
$$T_3 = T_2 - T_4 + T_1$$

Substitute this result into the equation for air, equate it to that for the right glass pane, and solve for T_4.

$$\frac{k_2}{L_2}(T_4 - T_2 + T_4 - T_1) = \frac{k_1}{L_1}(T_2 - T_4)$$
$$T_4\left(\frac{2k_2}{L_2} + \frac{k_1}{L_1}\right) = \left(\frac{k_1}{L_1} + \frac{k_2}{L_2}\right)T_2 + \frac{k_2}{L_2}T_1$$
$$T_4 = \frac{\left(\frac{k_1}{L_1} + \frac{k_2}{L_2}\right)T_2 + \frac{k_2}{L_2}T_1}{\frac{2k_2}{L_2} + \frac{k_1}{L_1}}$$

Substitute this result into the equation for the right glass pane.

$$\frac{Q}{At} = \frac{k_1}{L_1}T_2 - \frac{k_1}{L_1}\left[\frac{\left(\frac{k_1}{L_1}+\frac{k_2}{L_2}\right)T_2 + \frac{k_2}{L_2}T_1}{\frac{2k_2}{L_2}+\frac{k_1}{L_1}}\right]$$

$$= \frac{k_1}{L_1}T_2\left(1 - \frac{\frac{k_1}{L_1}+\frac{k_2}{L_2}}{\frac{2k_2}{L_2}+\frac{k_1}{L_1}}\right) - \frac{k_1}{L_1}\left(\frac{\frac{k_2}{L_2}T_1}{\frac{2k_2}{L_2}+\frac{k_1}{L_1}}\right)$$

$$= \frac{k_1}{L_1}T_2\left(\frac{\frac{2k_2}{L_2}+\frac{k_1}{L_1}-\frac{k_1}{L_1}-\frac{k_2}{L_2}}{\frac{2k_2}{L_2}+\frac{k_1}{L_1}}\right) - \frac{k_1}{L_1}T_1\left(\frac{k_2}{2k_2+\frac{k_1 L_2}{L_1}}\right)$$

$$= \frac{k_1}{L_1}T_2\left(\frac{\frac{k_2}{L_2}}{\frac{2k_2}{L_2}+\frac{k_1}{L_1}}\right) - T_1\left(\frac{k_1 k_2}{2k_2 L_1 + k_1 L_2}\right)$$

$$= T_2\left(\frac{k_1 k_2}{2k_2 L_1 + k_1 L_2}\right) - T_1\left(\frac{1}{\frac{2L_1}{k_1}+\frac{L_2}{k_2}}\right)$$

$$= \frac{T_2 - T_1}{\frac{2L_1}{k_1}+\frac{L_2}{k_2}}$$