5. (a) Let the reading on the Celsius scale be x and the reading on the Fahrenheit scale be y. Then $y = \frac{9}{5}x + 32$. If we require $y = 2x$, then we have

$$2x = \frac{9}{5}x + 32 \quad \Rightarrow \quad x = (5)(32) = 160°\text{C}$$

which yields $y = 2x = 320°$F.

(b) In this case, we require $y = \frac{1}{2}x$ and find

$$\frac{1}{2}x = \frac{9}{5}x + 32 \quad \Rightarrow \quad x = -\frac{(10)(32)}{13} \approx -24.6°\text{C}$$

which yields $y = x/2 = -12.3°$F.

6. We assume scales X and Y are linearly related in the sense that reading x is related to reading y by a linear relationship $y = mx + b$. We determine the constants m and b by solving the simultaneous equations:

$$-70.00 = m(-125.0) + b$$

$$-30.00 = m(375.0) + b$$

which yield the solutions $m = 40.00/500.0 = 8.000 \times 10^{-2}$ and $b = -60.00$. With these values, we find x for $y = 50.00$:

$$x = \frac{y - b}{m} = \frac{50.00 + 60.00}{0.08000} = 1375°\text{X}.$$

8. The increase in the surface area of the brass cube (which has six faces), which had side length L at 20°, is

$$\Delta A = 6(L+\Delta L)^2 - 6L^2 \approx 12 L\Delta L = 12\alpha_b L^2 \Delta T = 12\ (19\times 10^{-6}/\text{C}°)\ (30\,\text{cm})^2 (75°\text{C} - 20°\text{C})$$
$$= 11\,\text{cm}^2.$$

11. The volume at 30°C is given by

$$V' = V(1+\beta\Delta T) = V(1+3\alpha\Delta T) = (50.00\,\text{cm}^3)[1+3(29.00\times 10^{-6}/\text{C}°)\,(30.00°\text{C} - 60.00°\text{C})]$$
$$= 49.87\,\text{cm}^3$$

where we have used $\beta = 3\alpha$.

16. (a) We use $\rho = m/V$ and

$$\Delta\rho = \Delta(m/V) = m\Delta(1/V) \simeq -m\Delta V/V^2 = -\rho(\Delta V/V) = -3\rho(\Delta L/L).$$

The percent change in density is

$$\frac{\Delta\rho}{\rho} = -3\frac{\Delta L}{L} = -3(0.23\%) = -0.69\%.$$

(b) Since $\alpha = \Delta L/(L\Delta T) = (0.23 \times 10^{-2}) / (100°C - 0.0°C) = 23 \times 10^{-6}$ /C°, the metal is aluminum (using Table 18-2).

18. The change in length for the section of the steel ruler between its 20.05 cm mark and 20.11 cm mark is

$$\Delta L_s = L_s \alpha_s \Delta T = (20.11\text{cm})(11\times10^{-6}/\text{C}^\circ)(270^\circ\text{C} - 20^\circ\text{C}) = 0.055\text{cm}.$$

Thus, the actual change in length for the rod is

$$\Delta L = (20.11 \text{ cm} - 20.05 \text{ cm}) + 0.055 \text{ cm} = 0.115 \text{ cm}.$$

The coefficient of thermal expansion for the material of which the rod is made is then

$$\alpha = \frac{\Delta L}{\Delta T} = \frac{0.115 \text{ cm}}{270^\circ\text{C} - 20^\circ\text{C}} = 23\times10^{-6}/\text{C}^\circ.$$

23. **THINK** Electrical energy is supplied and converted into thermal energy to raise the water temperature.

EXPRESS The water has a mass m = 0.100 kg and a specific heat c = 4190 J/kg·K. When raised from an initial temperature T_i = 23°C to its boiling point T_f = 100°C, the heat input is given by $Q = cm(T_f - T_i)$. This must be the power output of the heater P multiplied by the time t: $Q = Pt$.

ANALYZE The time it takes to heat up the water is

$$t = \frac{Q}{P} = \frac{cm(T_f - T_i)}{P} = \frac{(4190\,\text{J/kg}\cdot\text{K})(0.100\,\text{kg})(100°\text{C} - 23°\text{C})}{200\,\text{J/s}} = 160\,\text{s}.$$

LEARN With a fixed power output, the time required is proportional to Q, which is proportional to $\Delta T = T_f - T_i$. In real life, it would take longer because of heat loss.

25. We use $Q = cm\Delta T$. The textbook notes that a nutritionist's "Calorie" is equivalent to 1000 cal. The mass m of the water that must be consumed is

$$m = \frac{Q}{c\Delta T} = \frac{3500 \times 10^3 \text{ cal}}{(1 \text{ g/cal} \cdot \text{C}^\circ)(37.0^\circ\text{C} - 0.0^\circ\text{C})} = 94.6 \times 10^4 \text{ g},$$

which is equivalent to 9.46×10^4 g/(1000 g/liter) = 94.6 liters of water. This is certainly too much to drink in a single day!

27. **THINK** Silver is solid at 15.0° C. To melt the sample, we must first raise its temperature to the melting point, and then supply heat of fusion.

EXPRESS The melting point of silver is 1235 K, so the temperature of the silver must first be raised from 15.0° C (= 288 K) to 1235 K. This requires heat

$$Q_1 = cm(T_f - T_i) = (236\,\text{J/kg}\cdot\text{K})(0.130\,\text{kg})(1235°\text{C} - 288°\text{C}) = 2.91\times 10^4\ \text{J}.$$

Now the silver at its melting point must be melted. If L_F is the heat of fusion for silver this requires

$$Q_2 = mL_F = (0.130\,\text{kg})\left(105\times 10^3\ \text{J/kg}\right) = 1.36\times 10^4\ \text{J}.$$

ANALYZE The total heat required is

$$Q = Q_1 + Q_2 = 2.91\times 10^4\ \text{J} + 1.36\times 10^4\ \text{J} = 4.27\times 10^4\ \text{J}.$$

LEARN The heating process is associated with the specific heat of silver, while the melting process involves heat of fusion. Both the specific heat and the heat of fusion are chemical properties of the material itself.

31. Let the mass of the steam be m_s and that of the ice be m_i. Then

$$L_F m_c + c_w m_c (T_f - 0.0°\text{C}) = m_s L_s + m_s c_w (100°\text{C} - T_f),$$

where T_f = 50°C is the final temperature. We solve for m_s:

$$m_s = \frac{L_F m_c + c_w m_c (T_f - 0.0°\text{C})}{L_s + c_w (100°\text{C} - T_f)} = \frac{(79.7\,\text{cal/g})(150\,\text{g}) + (1\,\text{cal/g}\cdot°\text{C})(150\text{g})(50°\text{C} - 0.0°\text{C})}{539\,\text{cal/g} + (1\,\text{cal/g}\cdot\text{C}°)(100°\text{C} - 50°\text{C})}$$

$$= 33\,\text{g}.$$

37. We compute with Celsius temperature, which poses no difficulty for the J/kg·K values of specific heat capacity (see Table 18-3) since a change of Kelvin temperature is numerically equal to the corresponding change on the Celsius scale. If the equilibrium temperature is T_f, then the energy absorbed as heat by the ice is

$$Q_I = L_F m_I + c_w m_I (T_f - 0°\text{C}),$$

while the energy transferred as heat from the water is $Q_w = c_w m_w (T_f - T_i)$. The system is insulated, so $Q_w + Q_I = 0$, and we solve for T_f:

$$T_f = \frac{c_w m_w T_i - L_F m_I}{(m_I + m_C) c_w}.$$

(a) Now $T_i = 90°$C so

$$T_f = \frac{(4190\,\text{J/kg}\cdot\text{C°})(0.500\,\text{kg})(90°\text{C}) - (333\times 10^3\,\text{J/kg})(0.500\,\text{kg})}{(0.500\,\text{kg} + 0.500\,\text{kg})(4190\,\text{J/kg}\cdot\text{C°})} = 5.3°\text{C}.$$

(b) Since no ice has remained at $T_f = 5.3°C$, we have $m_f = 0$.

(c) If we were to use the formula above with $T_i = 70°$C, we would get $T_f < 0$, which is impossible. In fact, not all the ice has melted in this case, and the equilibrium temperature is $T_f = 0°$C.

(d) The amount of ice that melts is given by

$$m'_I = \frac{c_w m_w (T_i - 0°\text{C})}{L_F} = \frac{(4190\,\text{J/kg}\cdot\text{C°})(0.500\,\text{kg})(70\,\text{C°})}{333\times 10^3\,\text{J/kg}} = 0.440\,\text{kg}.$$

Therefore, the amount of (solid) ice remaining is $m_f = m_I - m'_I = 500$ g – 440 g = 60.0 g, and (as mentioned) we have $T_f = 0°$C (because the system is an ice-water mixture in thermal equilibrium).

43. (a) One part of path A represents a constant pressure process. The volume changes from 1.0 m^3 to 4.0 m^3 while the pressure remains at 40 Pa. The work done is

$$W_A = p\Delta V = (40\,\text{Pa})(4.0\,\text{m}^3 - 1.0\,\text{m}^3) = 1.2\times10^2\,\text{J}.$$

(b) The other part of the path represents a constant volume process. No work is done during this process. The total work done over the entire path is 120 J. To find the work done over path B we need to know the pressure as a function of volume. Then, we can evaluate the integral $W = \int p\,dV$. According to the graph, the pressure is a linear function of the volume, so we may write $p = a + bV$, where a and b are constants. In order for the pressure to be 40 Pa when the volume is 1.0 m^3 and 10 Pa when the volume is 4.00 m^3 the values of the constants must be a = 50 Pa and b = –10 Pa/m^3. Thus,

$$p = 50\ \text{Pa} - (10\ \text{Pa/m}^3)V$$

and

$$W_B = \int_1^4 p\,dV = \int_1^4 (50 - 10V)\,dV = \left(50V - 5V^2\right)\Big|_1^4 = 200\,\text{J} - 50\,\text{J} - 80\,\text{J} + 5.0\,\text{J} = 75\,\text{J}.$$

(c) One part of path C represents a constant pressure process in which the volume changes from 1.0 m^3 to 4.0 m^3 while p remains at 10 Pa. The work done is

$$W_C = p\Delta V = (10\,\text{Pa})(4.0\,\text{m}^3 - 1.0\,\text{m}^3) = 30\,\text{J}.$$

The other part of the process is at constant volume and no work is done. The total work is 30 J. We note that the work is different for different paths.

45. **THINK** Over a complete cycle, the internal energy is the same at the beginning and end, so the heat Q absorbed equals the work done: $Q = W$.

EXPRESS Over the portion of the cycle from A to B the pressure p is a linear function of the volume V and we may write $p = a + bV$. The work done over this portion of the cycle is

$$W_{AB} = \int_{V_A}^{V_B} p\,dV = \int_{V_A}^{V_B} (a + bV)\,dV = a(V_B - V_A) + \frac{1}{2}b\left(V_B^2 - V_A^2\right).$$

The BC portion of the cycle is at constant pressure and the work done by the gas is

$$W_{BC} = p_B \Delta V_{BC} = p_B(V_C - V_B).$$

The CA portion of the cycle is at constant volume, so no work is done. The total work done by the gas is

$$W = W_{AB} + W_{BC} + W_{CA}.$$

ANALYZE The pressure function can be written as

$$p = \frac{10}{3}\ \text{Pa} + \left(\frac{20}{3}\ \text{Pa/m}^3\right)V,$$

where the coefficients a and b were chosen so that $p = 10$ Pa when $V = 1.0\ \text{m}^3$ and $p = 30$ Pa when $V = 4.0\ \text{m}^3$. Therefore, the work done going from A to B is

$$W_{AB} = a(V_B - V_A) + \frac{1}{2}b\left(V_B^2 - V_A^2\right)$$
$$= \left(\frac{10}{3}\,\text{Pa}\right)\left(4.0\ \text{m}^3 - 1.0\ \text{m}^3\right) + \frac{1}{2}\left(\frac{20}{3}\ \text{Pa/m}^3\right)\left[(4.0\ \text{m}^3)^2 - (1.0\ \text{m}^3)^2\right]$$
$$= 10\ \text{J} + 50\ \text{J} = 60\ \text{J}$$

Similarly, with $p_B = p_C = 30\ \text{Pa}$, $V_C = 1.0\ \text{m}^3$ and $V_B = 4.0\ \text{m}^3$, we have

$$W_{BC} = p_B(V_C - V_B) = (30\ \text{Pa})(1.0\ \text{m}^3 - 4.0\ \text{m}^3) = -90\ \text{J}.$$

Adding up all contributions, we find the total work done by the gas to be

$$W = W_{AB} + W_{BC} + W_{CA} = 60\ \text{J} - 90\ \text{J} + 0 = -30\ \text{J}.$$

Thus, the total heat absorbed is $Q = W = -30$ J. This means the gas loses 30 J of energy in the form of heat.

LEARN Notice that in calculating the work done by the gas, we always start with Eq. 18-25: $W = \int p\,dV$. For isobaric process where p = constant, $W = p\Delta V$, and for isochoric process where V = constant, $W = 0$.

48. Since the process is a complete cycle (beginning and ending in the same thermodynamic state) the change in the internal energy is zero, and the heat absorbed by the gas is equal to the work done by the gas: $Q = W$. In terms of the contributions of the individual parts of the cycle $Q_{AB} + Q_{BC} + Q_{CA} = W$ and

$$Q_{CA} = W - Q_{AB} - Q_{BC} = +15.0\text{ J} - 20.0\text{ J} - 0 = -5.0\text{ J}.$$

This means 5.0 J of energy leaves the gas in the form of heat.

54. (a) We estimate the surface area of the average human body to be about 2 m^2 and the skin temperature to be about 300 K (somewhat less than the internal temperature of 310 K). Then from Eq. 18-37

$$P_r = \sigma \varepsilon A T^4 \approx \left(5.67\times10^{-8}\ \mathrm{W/m^2\cdot K^4}\right)(0.9)\left(2.0\mathrm{m}^2\right)(300\mathrm{K})^4 = 8\times10^2\ \mathrm{W}.$$

(b) The energy lost is given by $\Delta E = P_r \Delta t = \left(8\times10^2\ \mathrm{W}\right)(30\mathrm{s}) = 2\times10^4\ \mathrm{J}.$

57. (a) We use

$$P_{\text{cond}} = kA\frac{T_H - T_C}{L}$$

with the conductivity of glass given in Table 18-6 as 1.0 W/m·K. We choose to use the Celsius scale for the temperature: a temperature difference of

$$T_H - T_C = 72°\text{F} - (-20°\text{F}) = 92\ °\text{F}$$

is equivalent to $\frac{5}{9}(92) = 51.1\text{C}°$. This, in turn, is equal to 51.1 K since a change in Kelvin temperature is entirely equivalent to a Celsius change. Thus,

$$\frac{P_{\text{cond}}}{A} = k\frac{T_H - T_C}{L} = (1.0\,\text{W/m}\cdot\text{K})\left(\frac{51.1°\text{C}}{3.0\times10^{-3}\text{m}}\right) = 1.7\times10^4\ \text{W/m}^2.$$

(b) The energy now passes in succession through 3 layers, one of air and two of glass. The heat transfer rate P is the same in each layer and is given by

$$P_{\text{cond}} = \frac{A(T_H - T_C)}{\sum L/k}$$

where the sum in the denominator is over the layers. If L_g is the thickness of a glass layer, L_a is the thickness of the air layer, k_g is the thermal conductivity of glass, and k_a is the thermal conductivity of air, then the denominator is

$$\sum\frac{L}{k} = \frac{2L_g}{k_g} + \frac{L_a}{k_a} = \frac{2L_g k_a + L_a k_g}{k_a k_g}.$$

Therefore, the heat conducted per unit area occurs at the following rate:

$$\frac{P_{\text{cond}}}{A} = \frac{(T_H - T_C)k_a k_g}{2L_g k_a + L_a k_g} = \frac{(51.1°\text{C})(0.026\,\text{W/m}\cdot\text{K})(1.0\,\text{W/m}\cdot\text{K})}{2(3.0\times10^{-3}\text{m})(0.026\,\text{W/m}\cdot\text{K}) + (0.075\,\text{m})(1.0\,\text{W/m}\cdot\text{K})}$$

$$= 18\,\text{W/m}^2.$$

79. **THINK** The work done by the expanding gas is given by Eq. 18-24: $W = \int p\, dV$.

EXPRESS Let V_i and V_f be the initial and final volumes, respectively. With $p = aV^2$, the work done by the gas is

$$W = \int_{V_i}^{V_f} p dV = \int_{V_i}^{V_f} aV^2 dV = \frac{1}{3}a\left(V_f^3 - V_i^3\right).$$

ANALYZE With $a = 10\ \text{N/m}^8$, $V_i = 1.0\ \text{m}^3$ and $V_f = 2.0\ \text{m}^3$, we obtain

$$W = \frac{1}{3}a\left(V_f^3 - V_i^3\right) = \frac{1}{3}\left(10\ \text{N/m}^8\right)\left[(2.0\ \text{m}^3)^3 - (1.0\ \text{m}^3)^3\right] = 23\ \text{J}.$$

LEARN In this problem, the initial and final pressures are

$$p_i = aV_i^2 = (10\ \text{N/m}^8)(1.0\ \text{m}^3)^2 = 10\ \text{N/m}^2 = 10\ \text{Pa}$$
$$p_f = aV_f^2 = (10\ \text{N/m}^8)(2.0\ \text{m}^3)^2 = 40\ \text{N/m}^2 = 40\ \text{Pa}$$

In this case, since $p \sim V^2$, the work done would be proportional to V^3 after volume integration.

106. Recalling that 1 W = 1 J/s, the heat Q which is added to the room in 6.9 h is

$$Q = 4(100\text{ W})(0.73)(6.9\text{ h})\left(\frac{3600\text{ s}}{1.00\text{ h}}\right) = 7.25\times10^{6}\text{ J}.$$

108. The initial speed of the car is $v_i = 83\text{ km/h} = (83\text{ km/h})\left(\frac{1000\text{ m/km}}{3600\text{ s/h}}\right) = 23.056\text{ m/s}.$

The deceleration a of the car is given by $v_f^2 - v_i^2 = -v_i^2 = 2ad$, or

$$a = -\frac{(23.056\text{ m/s})^2}{2(93\text{ m})} = -2.86\text{ m/s}^2.$$

The time Δt it takes for the car to stop is then

$$\Delta t = \frac{v_f - v_i}{a} = \frac{-23.056\text{ m/s}}{-2.86\text{ m/s}^2} = 8.07\text{ s}.$$

The change in kinetic energy of the car is

$$\Delta K = -\frac{1}{2}mv_i^2 = -\frac{1}{2}(1700\text{ kg})(23.056\text{ m/s})^2 = -4.52\times10^{5}\text{ J}.$$

Thus, the average rate at which mechanical energy is transferred to thermal energy is

$$P = \frac{\Delta E_{\text{th}}}{\Delta t} = \frac{-\Delta K}{\Delta t} = \frac{4.52\times10^{5}\text{ J}}{8.07\text{ s}} = 5.6\times10^{4}\text{ W}.$$