Chapter 18

5. (a) Let the reading on the Celsius scale be x and the reading on the Fahrenheit scale be y. Then $y = \frac{9}{5}x + 32$. For x = –71°C, this gives y = –96°F.

(b) The relationship between y and x may be inverted to yield $x = \frac{5}{9}(y - 32)$. Thus, for y = 134 we find $x \approx 56.7$ on the Celsius scale.

12. The volume at 30°C is given by

$$V' = V(1+\beta\Delta T) = V(1+3\alpha\Delta T) = (50.00\,\text{cm}^3)[1+3(29.00\times10^{-6}\,/\,\text{C}°)\,(30.00°\text{C} - 60.00°\text{C})]$$
$$= 49.87\,\text{cm}^3$$

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

32. While the sample is in its liquid phase, its temperature change (in absolute values) is $|\Delta T| = 30$ °C. Thus, with m = 0.40 kg, the absolute value of Eq. 18-14 leads to

$$|Q| = c\,m\,|\Delta T| = (3000)(0.40)(30) = 36000 \text{ J} .$$

The rate (which is constant) is $P = |Q| / t$ = 36000/40 = 900 J/min, which is equivalent to 15 Watts.

(a) During the next 30 minutes, a phase change occurs which is described by Eq. 18-16:

$$|Q| = P\,t = (900 \text{ J/min})(30 \text{ min}) = 27000 \text{ J} = L\,m .$$

Thus, with m = 0.40 kg, we find L = 67500 J/kg $\approx$ 68 kJ/kg.

(b) During the final 20 minutes, the sample is solid and undergoes a temperature change (in absolute values) of $|\Delta T| = 20$ C°. Now, the absolute value of Eq. 18-14 leads to

$$c = \frac{|Q|}{m\,|\Delta T|} = \frac{P\,t}{m\,|\Delta T|} = \frac{(900)(20)}{(0.40)(20)} = 2250\ \frac{\text{J}}{\text{kg}\cdot\text{C}°} \approx 2.3\ \frac{\text{kJ}}{\text{kg}\cdot\text{C}°} .$$

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

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

where the coefficients were chosen so that p = 10 Pa when V = 1.0 m^3 and p = 30 Pa when V = 4.0 m^3. The work done by the gas during this portion of the cycle is

$$\begin{aligned} W_{AB} &= \int_1^4 p\,dV = \int_1^4 \left(\frac{10}{3} + \frac{20}{3}V\right)dV = \left(\frac{10}{3}V + \frac{10}{3}V^2\right)\Bigg|_1^4 \\ &= \left(\frac{40}{3} + \frac{160}{3} - \frac{10}{3} - \frac{10}{3}\right)\text{J} = 60\ \text{J}. \end{aligned}$$

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

$$W_{BC} = p\Delta V = (30\ \text{Pa})(1.0\ \text{m}^3 - 4.0\ \text{m}^3) = -90\ \text{J}.$$

The CA portion of the cycle is at constant volume, so no work is done. The total work done by the gas is $W = W_{AB} + W_{BC} + W_{CA}$ = 60 J – 90 J + 0 = –30 J and the total heat absorbed is $Q = W$ = –30 J. This means the gas loses 30 J of energy in the form of heat.

51. The rate of heat flow is given by

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

where k is the thermal conductivity of copper (401 W/m·K), A is the cross-sectional area (in a plane perpendicular to the flow), L is the distance along the direction of flow between the points where the temperature is T_H and T_C. Thus,

$$P_{\text{cond}} = \frac{(401\,\text{W/m}\cdot\text{K})(90.0\times10^{-4}\ \text{m}^2)(125°\text{C} - 10.0°\text{C})}{0.250\,\text{m}} = 1.66\times10^3\ \text{J/s}.$$

The thermal conductivity is found in Table 18-6 of the text. Recall that a change in Kelvin temperature is numerically equivalent to a change on the Celsius scale.

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

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

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

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

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