47. (a) The change in internal energy ΔE_{int} is the same for path *iaf* and path *ibf*. According to the first law of thermodynamics, $\Delta E_{\text{int}} = Q - W$, where Q is the heat absorbed and W is the work done by the system. Along *iaf* ,

$$\Delta E_{\text{int}} = Q - W = 50 \text{ cal} - 20 \text{ cal} = 30 \text{ cal}.$$

Along *ibf* ,

$$W = Q - \Delta E_{\text{int}} = 36 \text{ cal} - 30 \text{ cal} = 6.0 \text{ cal}.$$

(b) Since the curved path is traversed from f to i the change in internal energy is –30 cal and $Q = \Delta E_{\text{int}} + W = -30 \text{ cal} - 13 \text{ cal} = -43 \text{ cal}$.

(c) Let $\Delta E_{\text{int}} = E_{\text{int},\,f} - E_{\text{int},\,i}$. Then, $E_{\text{int},\,f} = \Delta E_{\text{int}} + E_{\text{int},\,i} = 30 \text{ cal} + 10 \text{ cal} = 40 \text{ cal}$.

(d) The work W_{bf} for the path *bf* is zero, so $Q_{bf} = E_{\text{int},\,f} - E_{\text{int},\,b} = 40 \text{ cal} - 22 \text{ cal} = 18 \text{ cal}$.

(e) For the path *ibf*, $Q = 36$ cal so $Q_{ib} = Q - Q_{bf} = 36 \text{ cal} - 18 \text{ cal} = 18 \text{ cal}$.

61. Let h be the thickness of the slab and A be its area. Then, the rate of heat flow through the slab is

$$P_{\text{cond}} = \frac{kA\left(T_H - T_C\right)}{h}$$

where k is the thermal conductivity of ice, T_H is the temperature of the water (0°C), and T_C is the temperature of the air above the ice (–10°C). The heat leaving the water freezes it, the heat required to freeze mass m of water being $Q = L_F m$, where L_F is the heat of fusion for water. We differentiate with respect to time and recognize that $dQ/dt = P_{\text{cond}}$ to obtain

$$P_{\text{cond}} = L_F \frac{dm}{dt}.$$

Now, the mass of the ice is given by $m = \rho A h$, where ρ is the density of ice and h is the thickness of the ice slab, so $dm/dt = \rho A(dh/dt)$ and

$$P_{\text{cond}} = L_F \rho A \frac{dh}{dt}.$$

We equate the two expressions for P_{cond} and solve for dh/dt:

$$\frac{dh}{dt} = \frac{k\left(T_H - T_C\right)}{L_F \rho h}.$$

Since 1 cal = 4.186 J and 1 cm = 1×10^{-2} m, the thermal conductivity of ice has the SI value

$$k = (0.0040 \text{ cal/s}\cdot\text{cm}\cdot\text{K})\,(4.186 \text{ J/cal})/(1 \times 10^{-2} \text{ m/cm}) = 1.674 \text{ W/m}\cdot\text{K}.$$

The density of ice is $\rho = 0.92 \text{ g/cm}^3 = 0.92 \times 10^3 \text{ kg/m}^3$. Thus,

$$\frac{dh}{dt} = \frac{\left(1.674 \text{ W/m}\cdot\text{K}\right)\left(0°\text{C} + 10°\text{C}\right)}{\left(333\times10^3 \text{ J/kg}\right)\left(0.92\times10^3 \text{ kg/m}^3\right)\left(0.050 \text{ m}\right)} = 1.1\times10^{-6} \text{ m/s} = 0.40 \text{ cm/h}.$$

21. Consider half the bar. Its original length is $\ell_0 = L_0/2$ and its length after the temperature increase is $\ell = \ell_0 + \alpha\ell_0\Delta T$. The old position of the half-bar, its new position, and the distance *x* that one end is displaced form a right triangle, with a hypotenuse of length ℓ, one side of length ℓ_0, and the other side of length *x*. The Pythagorean theorem yields

$$x^2 = \ell^2 - \ell_0^2 = \ell_0^2(1+\alpha\Delta T)^2 - \ell_0^2.$$

Since the change in length is small, we may approximate $(1 + \alpha\,\Delta T)^2$ by $1 + 2\alpha\,\Delta T$, where the small term $(\alpha\,\Delta T)^2$ was neglected. Then,

$$x^2 = \ell_0^2 + 2\ell_0^2\alpha\,\Delta T - \ell_0^2 = 2\ell_0^2\alpha\,\Delta T$$

and

$$x = \ell_0\sqrt{2\alpha\,\Delta T} = \frac{3.77\,\text{m}}{2}\sqrt{2\left(25\times10^{-6}/\text{C}^\circ\right)\left(32^\circ\,\text{C}\right)} = 7.5\times10^{-2}\ \text{m}.$$

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.

42. If the ring diameter at 0.000°C is D_{r0}, then its diameter when the ring and sphere are in thermal equilibrium is

$$D_r = D_{r0}(1 + \alpha_c T_f),$$

where T_f is the final temperature and α_c is the coefficient of linear expansion for copper. Similarly, if the sphere diameter at T_i (= 100.0°C) is D_{s0}, then its diameter at the final temperature is

$$D_s = D_{s0}[1+\alpha_a(T_f - T_i)],$$

where α_a is the coefficient of linear expansion for aluminum. At equilibrium the two diameters are equal, so

$$D_{r0}(1 + \alpha_c T_f) = D_{s0}[1 + \alpha_a(T_f - T_i)].$$

The solution for the final temperature is

$$\begin{aligned} T_f &= \frac{D_{r0} - D_{s0} + D_{s0}\alpha_a T_i}{D_{s0}\alpha_a - D_{r0}\alpha_c} \\ &= \frac{2.54000\,\text{cm} - 2.54508\,\text{cm} + (2.54508\,\text{cm})(23\times10^{-6}/\text{C°})(100.0°\text{C})}{(2.54508\,\text{cm})(23\times10^{-6}/\text{C°}) - (2.54000\,\text{cm})\,(17\times10^{-6}/\text{C?}} \\ &= 50.38°\text{C}. \end{aligned}$$

The expansion coefficients are from Table 18-2 of the text. Since the initial temperature of the ring is 0°C, the heat it absorbs is $Q = c_c m_r T_f$, where c_c is the specific heat of copper and m_r is the mass of the ring. The heat released by the sphere is

$$|Q| = c_a m_s (T_i - T_f)$$

where c_a is the specific heat of aluminum and m_s is the mass of the sphere. Since these two heats are equal,

$$c_c m_r T_f = c_a m_s (T_i - T_f),$$

we use specific heat capacities from the textbook to obtain

$$m_s = \frac{c_c m_r T_f}{c_a(T_i - T_f)} = \frac{(386\,\text{J/kg}\cdot\text{K})(0.0200\,\text{kg})(50.38°\text{C})}{(900\,\text{J/kg}\cdot\text{K})(100°\text{C} - 50.38°\text{C})} = 8.71\times10^{-3}\,\text{kg}.$$

34. We note that the heat capacity of sample B is given by the reciprocal of the slope of the line in Figure 18-33(b) (compare with Eq. 18-14). Since the reciprocal of that slope is 16/4 = 4 kJ/kg·C°, then c_B = 4000 J/kg·C° = 4000 J/kg·K (since a change in Celsius is equivalent to a change in Kelvins). Now, following the same procedure as shown in Sample Problem —"Hot slug in water, coming to equilibrium," we find

$$c_A m_A (T_f - T_A) + c_B m_B (T_f - T_B) = 0$$

$$c_A (5.0 \text{ kg})(40°\text{C} - 100°\text{C}) + (4000 \text{ J/kg·C°})(1.5 \text{ kg})(40°\text{C} - 20°\text{C}) = 0$$

which leads to $c_A = 4.0\times10^2$ J/kg·K.