Halliday ♦ Resnick ♦ Walker

FUNDAMENTALS OF PHYSICS
SIXTH EDITION

Selected Solutions

<u>Chapter 19</u>

19.19
19.37
19.49
19.65

19. After the change in temperature the diameter of the steel rod is $D_s = D_{s0} + \alpha_s D_{s0}\,\Delta T$ and the diameter of the brass ring is $D_b = D_{b0} + \alpha_b D_{b0}\,\Delta T$, where D_{s0} and D_{b0} are the original diameters, α_s and α_b are the coefficients of linear expansion, and ΔT is the change in temperature. The rod just fits through the ring if $D_s = D_b$. This means $D_{s0} + \alpha_s D_{s0}\,\Delta T = D_{b0} + \alpha_b D_{b0}\,\Delta T$. Therefore,

$$\begin{aligned}\Delta T &= \frac{D_{s0} - D_{b0}}{\alpha_b D_{b0} - \alpha_s D_{s0}}\\ &= \frac{3.000\,\mathrm{cm} - 2.992\,\mathrm{cm}}{(19 \times 10^{-6}\,/\mathrm{C}^\circ)(2.992\,\mathrm{cm}) - (11 \times 10^{-6}\,/\mathrm{C}^\circ)(3.000\,\mathrm{cm})} = 335\,\mathrm{C}^\circ\ .\end{aligned}$$

The temperature is $T = 25^\circ\mathrm{C} + 335\,\mathrm{C}^\circ = 360^\circ\mathrm{C}$.

37. Mass m of water must be raised from an initial temperature $T_i = 59°\mathrm{F} = 15°\mathrm{C}$ to a final temperature $T_f = 100°\mathrm{C}$. If c is the specific heat of water then the energy required is $Q = cm(T_f - T_i)$. Each shake supplies energy mgh, where h is the distance moved during the downward stroke of the shake. If N is the total number of shakes then $Nmgh = Q$. If t is the time taken to raise the water to its boiling point then $(N/t)mgh = Q/t$. We note that N/t is the rate R of shaking (30 shakes/min). This leads to $Rmgh = Q/t$. The distance h is $1.0\,\mathrm{ft} = 0.3048\,\mathrm{m}$. Consequently,

$$\begin{aligned} t &= \frac{Q}{Rmgh} = \frac{cm(T_f - T_i)}{Rmgh} = \frac{c(T_f - T_i)}{Rgh} \\ &= \frac{(4190\,\mathrm{J/kg{\cdot}K})(100°\mathrm{C} - 15°\mathrm{C})}{(30\,\mathrm{shakes/min})(9.8\,\mathrm{m/s^2})(0.3048\,\mathrm{m})} \\ &= 3.97 \times 10^3\,\mathrm{min} = 2.8\ \mathrm{days}\ . \end{aligned}$$

49. One part of path A represents a constant pressure process. The volume changes from $1.0\,\mathrm{m}^3$ to $4.0\,\mathrm{m}^3$ while the pressure remains at $40\,\mathrm{Pa}$. The work done is

$$W_A = p\,\Delta V = (40\,\mathrm{Pa})\left(4.0\,\mathrm{m}^3 - 1.0\,\mathrm{m}^3\right) = 120\ \mathrm{J}\ .$$

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 $120\,\mathrm{J}$. 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 $40\,\mathrm{Pa}$ when the volume is $1.0\,\mathrm{m}^3$ and $10\,\mathrm{Pa}$ when the volume is $4.00\,\mathrm{m}^3$ the values of the constants must be $a = 50\,\mathrm{Pa}$ and $b = -10\,\mathrm{Pa/m}^3$. Thus $p = 50\,\mathrm{Pa} - (10\,\mathrm{Pa/m}^3)V$ and

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

One part of path C represents a constant pressure process in which the volume changes from $1.0\,\mathrm{m}^3$ to $4.0\,\mathrm{m}^3$ while p remains at $10\,\mathrm{Pa}$. The work done is

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

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

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

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

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. 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 $dh/\mathrm{d}t$:

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

Since $1\,\text{cal} = 4.186\,\text{J}$ and $1\,\text{cm} = 1 \times 10^{-2}\,\text{m}$, the thermal conductivity of ice has the SI value $k = (0.0040\,\text{cal/s·cm·K})(4.186\,\text{J/cal})/(1{\times}10^{-2}\,\text{m/cm}) = 1.674\,\text{W/m·K}$. The density of ice is $\rho = 0.92\,\text{g/cm}^3 = 0.92 \times 10^3\,\text{kg/m}^3$. Thus,

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