Halliday ♦ Resnick ♦ Walker

FUNDAMENTALS OF PHYSICS
SIXTH EDITION

Selected Solutions

Chapter 19

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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,

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

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

37. Mass m of water must be raised from an initial temperature $T_i = 59°\text{F} = 15°\text{C}$ to a final temperature $T_f = 100°\text{C}$. 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 $1.0\,\text{ft} = 0.3048\,\text{m}$. Consequently,

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

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 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 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 $1.0\,\mathrm{m}^3$ and 10 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 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 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 $k = (0.0040\,\text{cal/s}\cdot\text{cm}\cdot\text{K})(4.186\,\text{J/cal})/(1\times10^{-2}\,\text{m/cm}) = 1.674\,\text{W/m}\cdot\text{K}$. The density of ice is $\rho = 0.92\,\text{g/cm}^3 = 0.92 \times 10^3\,\text{kg/m}^3$. Thus,

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