Solutions to Lesson 09, 2024

The exercises are provided with reference to Callister volume 9. In the solutions below Equations and Tables are provided with reference to Callister volume 10.

SI units are used throughout.

19.2

Combining Eqs 18.3 and 18.4 gives a cross sectional area of $A = \frac{I\,l\,\varrho}{V} = \frac{I\,l}{\sigma}$.

In a cylindrical wire the relation to diameter D is $A = \pi(D/2)^2$. Combining these equations

$$D = \sqrt{\frac{4Il}{\pi V\sigma}}$$

From Table 18.1, for copper σ = 6.0 × 10^7 $(\Omega m)^{-1}$. Inserting we get D = 1.88 mm.

19.5

a) Combining Eqs 18.2 and 18.4 gives a resistance of $R = \frac{\varrho\, l}{A} = \frac{l}{\sigma A} = \frac{l}{\sigma\pi(D/2)^2}$

From Table 18.1, for copper σ = 6.0 × 10^7 $(\Omega m)^{-1}$. Inserting this we have 1.7 10^{-3} Ω.

b) I = V/R gives I = 29.4 A

c) $J = \frac{I}{A} = \frac{I}{\pi(D/2)^2}$ gives J = 1.5 10^6 A/m^2.

d) E = V/L gives E = 2.5 10^{-2} V/m.

19.11

a) According to Eq 18.8 $n = \frac{\sigma}{e\mu_e}$ Inserting n = 1.25 10^{29} m^{-3}.

b) First we find the number of copper atoms per cubic meter, N_{Cu}. Using the atomic weight value for Cu found inside the front cover: A_{Cu} = 63.55 g/mol we may derive

$$N_{Cu} = \frac{N_A\,\rho_{Cu}}{A_{Cu}}$$

Note that ρ_{Cu} here is the density not resistivity! Inserting N_{Cu} = 8.43 10^{28} m^{-3}.

The number of free electrons per Cu atom is then n/N_{Cu} = 1.48.

19.21

Using Eq. 18.15 $n_i = \frac{\sigma}{e\,(\mu_e + \mu_h)}$. Inserting $n_i = \frac{650}{1.602\;10^{-19}(0.16+0.080)}$ = 2.4 10^{22} m^{-3}.

19.25

First we calculate the mobility of the electrons from Eq 18.7: $\mu_e = \frac{v_d}{E}$.

Inserting μ_e = 0.167 m^2/(Vs). Then from Eq. 18.16 $\sigma = n\,e\,\mu_e$. Inserting σ = 0.08 $(\Omega m)^{-1}$

19.29

a) Using Eq. 18.13 we have $n = \frac{\sigma - p\,e\,\mu_h}{e\,\mu_e}$. Values for μ_h and μ_e (0.05 and 0.14 m^2/(Vs), respectively) can be found in Table 18.3 in Callister – not there in version 10. Inserting n = 1.44 10^{16} m^{-3}.

b) as p= 1.0 10^{17} m^{-3} is greater than n = 1.44 10^{16} m^{-3}, the material is p-type extrinsic.

20.2

From Table 19.1 c_p = 486 J/(kg K). From Eq 19.1 $\Delta T = \frac{\Delta Q}{m\, c_p}$, where m is the mass. Inserting ΔT = 24.3 C. Hence, $T_f = T_0 + \Delta T$ = 25.0 C + 24.3 C = 49.3 C.

20. 4

a) For aluminum, C_v at 50 K may be approximated by Eq 19.2, since this temperature is significantly below the Debye temperature (375 K). The value of C_v at 30 K is given – from this we can derive the constant $A = C_V/T^3$. Inserting A = 3.00 10^{-5} J/(mol K^4).

Therefore at 50 K: $C_v = A\,T^3$ = 3.75 J/(mol K). The specific heat c_v is defined per unit mass instead of per unit mole. Hence
c_v = (3.75 J mol^{-1} K^{-1})/ (26.98 g/mol)*(1000 g/kg) = 139 J/(kg K)

b) 425 K ia above the Debye temperature. Therefore to a good approximation
C_v = 3R = 3 * 8.31 J/(mol K) = 24.9 J/(mol K).

Converting this to specific heat c_v = (24.9 $Jmol^{-1}K^{-1}$)/ (26.98 g/mol)*(1000 g/kg) = 923 J/(kg K)

20.7

From Eq. 19.3b we have a change in length $\Delta l = l_o \alpha_l (T_f - T_0)$. The value for α_l can be found in Table 19.1: α_l = 23.6 10^{-6} K^{-1}. Inserting: $\Delta l =$ - 9.2 mm (it became shorter).

20.13

We can express the final diameters of both the rod and the hole by rearranging Eq 19.3a:

$$\frac{\mathrm{d}_f - \mathrm{d}_0}{\mathrm{d}_0} = \alpha_l \Delta T.$$

Let us use superscripts s for steel and W for Wolfram. Then we can solve the problem by requiring that $d_f^s = d_f^W$. This gives

$$d_0^s[1 + \alpha_l^s \Delta T] = d_0^W[1 + \alpha_l^W \Delta T]$$

Rearranging this gives

$$\Delta T = \frac{d_0^s - d_0^W}{d_0^W \alpha_l^W - d_0^s \alpha_l^s}$$

Inserting: ΔT = 104.5 C. Hence T_f = 129.5 C

20.14

a) The heat flux can be determined by inserting in Eq 19.5: $q = -k\frac{\Delta T}{\Delta x}$. The thermal conductivity for steel is listed in Table 19.1: 51.9 W/(mK). Inserting q = 1.04 10^6 W/m^2.

b) We have $\frac{dQ}{dt} = qAt$, where A is the cross sectional area, t is the time and dQ/dt the total heat loss. Inserting dQ/dt = 9.3 10^8 J/h.

c) The value for k for soda-lime glass is listed in Table 19.1: k = 1.7 W/(mK). Hence, $\frac{dQ}{dt} = -k\;A\;t\;\frac{\Delta T}{\Delta x}$. Inserting $\frac{dQ}{dt}$ = 3.06 10^7 J/h. (Note that ΔT is negative.)

d) Again we use $\frac{dQ}{dt} = -k\ A\ t\ \frac{\Delta T}{\Delta x}$, but with a new value for Δx. Inserting $\frac{dQ}{dt} = 4.7\ 10^8$ J/h.

20.26

We want to reduce the stress in the wire by 70 MPa – 35 MPa = 35 MPa. This will be a compressive stress, hence σ = - 35 MPa. We can determine T_f from Eq 19.8 and insert values for E from Table 6.1 (110 GPa) and α_l from Table 19.1 ($17.0\ 10^{-6}\ K^{-1}$). As a result $T_f = T_0 - \frac{\sigma}{E\alpha_l}$. Inserting: T_f = 39 C.