18.7 *(a) Calculate the number of free electrons per cubic meter for silver, assuming that there are 1.3 free electrons per silver atom. The electrical conductivity and density for Ag are 6.8×10^7 $(\Omega\text{-m})^{-1}$ and 10.5 g/cm^3, respectively.*

(b) Now compute the electron mobility for Ag.

Solution

(a) This portion of the problem asks that we calculate, for silver, the number of free electrons per cubic meter (n) given that there are 1.3 free electrons per silver atom, that the electrical conductivity is 6.8×10^7 $(\Omega\text{-m})^{-1}$, and that the density (ρ'_{Ag}) is 10.5 g/cm^3. (Note: in this discussion, the density of silver is represented by ρ'_{Ag} in order to avoid confusion with resistivity, which is designated by ρ.) Since $n = 1.3N_{\text{Ag}}$, and N_{Ag} is defined in Equation 4.2 (and using the atomic weight of Ag, 107.87 g/mol), we compute the value of n as follows:

$$n = 1.3N_{\text{Ag}} = 1.3\left(\frac{\rho'_{\text{Ag}}N_{\text{A}}}{A_{\text{Ag}}}\right)$$

$$= 1.3\left[\frac{(10.5 \text{ g/cm}^3)(6.022 \times 10^{23} \text{ atoms/mol})}{107.87 \text{ g/mol}}\right]$$

$$= 7.62 \times 10^{22} \text{ cm}^{-3}$$

$$= (7.62 \times 10^{22} \text{ cm}^{-3})\left(\frac{10^2 \text{ cm}}{\text{m}}\right)^3 = 7.62 \times 10^{28} \text{ m}^{-3}$$

(b) Now we are asked to compute the electron mobility, μ_e. Using Equation 18.8, and incorporating this value of n and the value of σ given in the problem statement, the electron mobility is determined as follows:

$$\mu_e = \frac{\sigma}{n|e|}$$

$$= \frac{6.8 \times 10^7 \ (\Omega\text{-m})^{-1}}{(7.62 \times 10^{28} \text{ m}^{-3})(1.602 \times 10^{-19} \text{ C})} = 5.57 \times 10^{-3} \text{ m}^2\text{/V-s}$$

18.16 *Germanium to which* 10^{24} m^{-3} *As atoms have been added is an extrinsic semiconductor at room temperature, and virtually all the As atoms may be thought of as being ionized (i.e., one charge carrier exists for each As atom).*

(a) Is this material n-type or p-type?

(b) Calculate the electrical conductivity of this material, assuming electron and hole mobilities of 0.1 and 0.05 m^2*/V-s, respectively.*

Solution

(a) This germanium material to which has been added 10^{24} m^{-3} As atoms is *n*-type since As is a donor in Ge. (Arsenic is from group VA of the periodic table--Ge is from group IVA.)

(b) Since this material is *n*-type extrinsic, Equation 18.16 is valid. Furthermore, each As atom will donate a single electron, or the electron concentration is equal to the As concentration since all of the As atoms are ionized at room temperature; that is $n = 10^{24}$ m^{-3}, and, as given in the problem statement, $\mu_e = 0.1$ m^2/V-s. Thus, the conductivity is equal to

$$\sigma = n|e|\mu_e$$

$$= (10^{24}\ \text{m}^{-3})(1.602 \times 10^{-19}\ \text{C})(0.1\ \ \text{m}^2/\text{V-s})$$

$$= 1.60 \times 10^4\ (\Omega\text{-m})^{-1}$$

18.18 *At temperatures near room temperature, the temperature dependence of the conductivity for intrinsic germanium is found to be given by*

$$\sigma = CT^{-3/2} \exp\left(-\frac{E_g}{2kT}\right) \qquad (18.36)$$

where C is a temperature-independent constant and T is in Kelvins. Using Equation 18.35, calculate the intrinsic electrical conductivity of germanium at 175°C.

Solution

In order to solve this problem, it is first necessary to solve for C in Equation 18.36 using the room-temperature (298 K) conductivity for Ge [2.2 $(\Omega\text{-m})^{-1}$] (Table 18.3). This is accomplished by taking natural logarithms of both sides of Equation 18.36 as

$$\ln \sigma = \ln C - \frac{3}{2}\ln T - \frac{E_g}{2kT} \qquad (18.36a)$$

and after rearranging this expression and substitution of values for E_g (0.67 eV, Table 18.3), and the room-temperature conductivity [2.2 $(\Omega\text{-m})^{-1}$], we get the following value for ln C:

$$\ln C = \ln \sigma + \frac{3}{2}\ln T + \frac{E_g}{2kT}$$

$$= \ln (2.2) + \frac{3}{2}\ln (298) + \frac{0.67 \text{ eV}}{(2)(8.62 \times 10^{-5} \text{ eV/K})(298 \text{ K})}$$

$$= 22.38$$

Now, using Equation 18.36a, we are able to compute the conductivity at 448 K (175°C) as follows:

$$\ln \sigma = \ln C - \frac{3}{2}\ln T - \frac{E_g}{2kT}$$

$$= 22.38 - \frac{3}{2}\ln (448 \text{ K}) - \frac{0.67 \text{ eV}}{(2)(8.62 \times 10^{-5} \text{ eV/K})(448 \text{ K})}$$

$$= 4.548$$

which leads to

$$\sigma = e^{4.548} = 94.4 \ (\Omega\text{-m})^{-1}$$

18.28 *Consider a parallel-plate capacitor having an area of 3225 mm^2, a plate separation of 1 mm, and a material having a dielectric constant of 3.5 positioned between the plates.*

(a) What is the capacitance of this capacitor?

(b) Compute the electric field that must be applied for 2×10^{-8} C to be stored on each plate.

Solution

(a) We are first asked to compute the capacitance. Combining Equations 18.26 and 18.27 leads to the following expression:

$$C = \varepsilon \frac{A}{l}$$

$$= \frac{\varepsilon_r \varepsilon_0 A}{l}$$

Incorporation of values given in the problem statement for parameters on the right-hand side of this expression, and solving for C yields

$$C = \frac{\varepsilon_r \varepsilon_0 A}{l}$$

$$= \frac{(3.5)(8.85 \times 10^{-12}\,\text{F/m})(3225\ \text{mm}^2)(1\ \text{m}^2/10^6\,\text{mm}^2)}{10^{-3}\,\text{m}}$$

$$= 10^{-10}\ \text{F} = 100\ \text{pF}$$

(b) Now we are asked to compute the electric field that must be applied in order for 2×10^{-8} C to be stored on each plate. First, we need to solve for V in Equation 18.24 as

$$V = \frac{Q}{C} = \frac{2 \times 10^{-8}\,\text{C}}{10^{-10}\,\text{F}} = 200\ \text{V}$$

The electric field E may now be determined using Equation 18.6, as follows:

$$E = \frac{V}{l} = \frac{200\ \text{V}}{10^{-3}\ \text{m}} = 2.0 \times 10^5\ \text{V/m}$$

18.23 *A metal alloy is known to have electrical conductivity and electron mobility values of 1.2 × 10^7 $(\Omega\cdot m)^{-1}$ and 0.0050 $m^2/V\cdot s$, respectively. A current of 40 A is passed through a specimen of this alloy that is 35 mm thick. What magnetic field would need to be imposed to yield a Hall voltage of –3.5 × 10^{-7} V?*

Solution

In this problem we are asked to determine the magnetic field required to produce a Hall voltage of –3.5 × 10^{-7} V, given that $\sigma = 1.2 \times 10^7$ $(\Omega\text{-m})^{-1}$, $\mu_e = 0.0050$ $\text{m}^2/\text{V-s}$, $I_x = 40$ A, and $d = 35$ mm. We now take a rearranged form of Equation 18.20b

$$|R_\text{H}| = \frac{\mu_e}{\sigma}$$

and we incorporate it into Equation 18.18 as follows:

$$V_\text{H} = \frac{R_\text{H} I_x B_z}{d}$$

$$= \frac{\mu_e I_x B_z}{\sigma d}$$

We now rearrange this expression such that B_z is the dependent variable, and after inserting values for the remaining parameters that were given in the problem statement, the value of B_z is determined as follows:

$$B_z = \frac{|V_H|\sigma d}{I_x \mu_e}$$

$$= \frac{\left(\left|-3.5 \times 10^{-7}\ \text{V}\right|\right)\left[1.2 \times 10^7\ (\Omega\text{-m})^{-1}\right]\left(35 \times 10^{-3}\ \text{m}\right)}{(40\ \text{A})(0.0050\ \text{m}^2/\text{V-s})}$$

$$= 0.735 \text{ tesla}$$