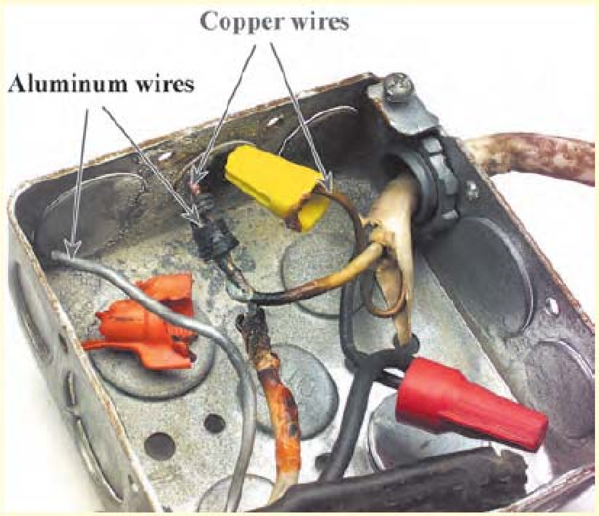
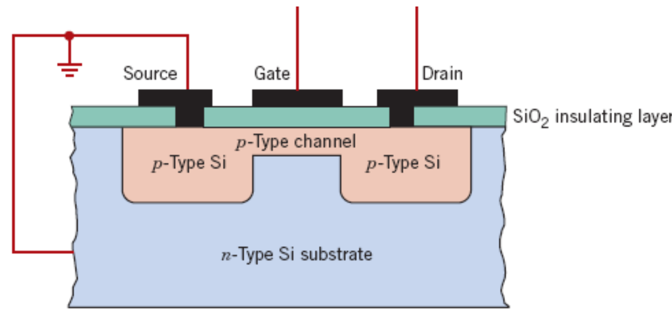
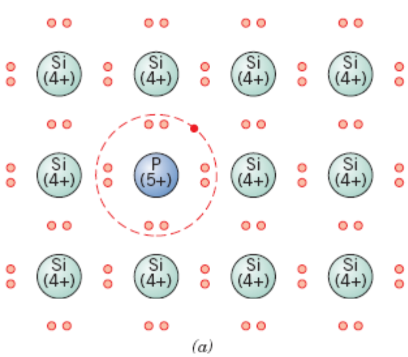
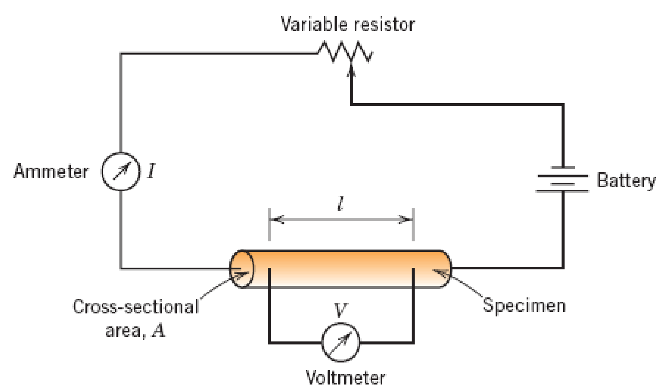




Electrical Properties

Chapter 18





18.1 (a) Compute the electrical conductivity of a 7.0-mm (0.28-in.) diameter cylindrical silicon specimen 57 mm (2.25 in.) long in which a current of 0.25 A passes in an axial direction. A voltage of 24 V is measured across two probes that are separated by 45 mm (1.75 in.).

(b) Compute the resistance over the entire 57 mm (2.25 in.) of the specimen.

(a) We use Equations 18.3 and 18.4 for the conductivity, as

$$\sigma = \frac{1}{\rho} = \frac{Il}{VA} = \frac{Il}{V\pi\left(\frac{d}{2}\right)^2}$$

$$\sigma = \frac{(0.25\ \text{A})(45\ \text{x}\ 10^{-3}\ \text{m})}{(24\ \text{V})(\pi)\left(\frac{7.0\ \text{x}\ 10^{-3}\ \text{m}}{2}\right)^2} = 12.2\ (\Omega\text{ - m})^{-1}$$

(b) The resistance, *R*, may be computed using Equations 18.2 and 18.4, as

$$R = \frac{l}{\sigma A} = \frac{l}{\sigma\pi\left(\frac{d}{2}\right)^2}$$

$$= \frac{57\ \text{x}\ 10^{-3}\ \text{m}}{\left[12.2\ (\Omega - \text{m})^{-1}\right](\pi)\left(\frac{7.0\ \text{x}\ 10^{-3}\ \text{m}}{2}\right)^2} = 121.4\ \Omega$$

18.2 An aluminum wire 10 m long must experience a voltage drop of less than 1.0 V when a current of 5 A passes through it. Using the data in Table 18.1, compute the minimum diameter of the wire.

Equations 18.3 and 18.4 and solving for the cross-sectional area A leads to

$$A = \frac{Il}{V\sigma}$$

From Table 18.1, for aluminum $\sigma = 3.8 \times 10^{7}\ (\Omega\text{-m})^{-1}$.

Furthermore, inasmuch as $A = \pi\left(\frac{d}{2}\right)^2$ for a cylindrical

$$\pi\left(\frac{d}{2}\right)^2 = \frac{Il}{V\sigma} \qquad d = \sqrt{\frac{4Il}{\pi V\sigma}}$$

$$d = \sqrt{\frac{(4)(5\ \text{A})(10\ \ \text{m})}{(\pi)(1.0\ \text{V})\left[3.8\ \times 10^{7}\ (\Omega-\text{m})^{-1}\right]}}$$

$$= 1.3 \times 10^{-3}\ \text{m} = 1.3\ \text{mm}$$

18.11 At room temperature the electrical conductivity and the electron mobility for aluminum are 3.8×10^7 $(\Omega\text{-m})^{-1}$ and 0.0012 $m^2/V\text{-s}$, respectively. **(a)** Compute the number of free electrons per cubic meter for aluminum at room temperature. **(b)** What is the number of free electrons per aluminum atom? Assume a density of 2.7 g/cm^3.

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

conductivity σ

μ_e is called the electron mobility.

where n is the number of free or conducting electrons per unit volume (e.g., per cubic meter), and $|e|$ is the absolute magnitude of the electrical charge on an electron (1.6×10^{-19} C). Thus, the electrical conductivity is proportional to both the number of free electrons and the electron mobility.

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

$$= \frac{3.8 \ \text{x}\ 10^{7}\ (\Omega - \text{m})^{-1}}{\left(1.602 \ \text{x}\ 10^{-19}\ \text{C}\right)\left(0.0012 \ \text{m}^2/\text{V-s}\right)}$$

$$= 1.98 \text{ x } 10^{29} \text{ m}^{-3}$$

$$N_{\text{Al}} = \frac{N_{\text{A}}\,\rho'}{A_{\text{Al}}}$$

$$= \frac{\left(6.023 \ \text{x}\ 10^{23}\ \text{atoms/mol}\right)\left(2.71 \ \text{g/cm}^3\right)\left(10^6 \ \text{cm}^3/\text{m}^3\right)}{26.98 \ \text{g/mol}}$$

$$= 6.03 \text{ x } 10^{28} \text{ m}^{-3}$$

(*Note*: in the above expression, density is represented by ρ' in order to avoid confusion with resistivity which is designated by ρ.) And, finally, the number of free electrons per aluminum atom is just n/N_{Al}

$$\frac{n}{N_{\text{Al}}} = \frac{1.98 \ \text{x}\ 10^{29}\ \text{m}^{-3}}{6.03 \ \text{x}\ 10^{28}\ \text{m}^{-3}} = 3.28$$

18.12 **(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.

$$n = 1.3N_{\mathrm{Ag}} = 1.3\left[\frac{\rho'_{\mathrm{Ag}}N_{\mathrm{A}}}{A_{\mathrm{Ag}}}\right]$$

$$= 1.3\left[\frac{(10.5\ \mathrm{g/cm^3})(6.023\ \mathrm{x}\ 10^{23}\ \mathrm{atoms/mol})}{107.87\ \mathrm{g/mol}}\right]$$

$$= 7.62\ \mathrm{x}\ 10^{22}\ \mathrm{cm^{-3}} = 7.62\ \mathrm{x}\ 10^{28}\ \mathrm{m^{-3}}$$

(b) Now we are asked to compute the electron mobility, μ_e. Using Equation 18.8

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

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

18.17 A cylindrical metal wire 3 mm (0.12 in.) in diameter is required to carry a current of 12 A with a minimum of 0.01 V drop per foot (300 mm) of wire. Which of the metals and alloys listed in Table 18.1 are possible candidates?

Table 18.1 Room-Temperature Electrical Conductivities for Nine Common Metals and Alloys

Metal	*Electrical Conductivity* $[(\Omega\text{-}m)^{-1}]$
Silver	6.8×10^7
Copper	6.0×10^7
Gold	4.3×10^7
Aluminum	3.8×10^7
Brass (70Cu–30Zn)	1.6×10^7
Iron	1.0×10^7
Platinum	0.94×10^7
Plain carbon steel	0.6×10^7
Stainless steel	0.2×10^7

$$\sigma = \frac{Il}{VA} = \frac{Il}{V\pi\left(\frac{d}{2}\right)^2}$$

$$= \frac{(12\ \text{A})\left(300\ \text{x}\ 10^{-3}\ \text{m}\right)}{(0.01\ \text{V})\ (\pi)\left(\frac{3\ \text{x}\ 10^{-3}\ \text{m}}{2}\right)^2} = 5.1\ \text{x}\ 10^7\ (\Omega\text{-m})^{-1}$$

Thus, from Table 18.1, only copper, and silver are candidates.