

Chapter 2

2.1 Electrical conduction Na is a monovalent metal (BCC) with a density of 0.9712 g cm^{-3} . Its atomic mass is 22.99 g mol^{-1} . The drift mobility of electrons in Na is $53 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$.

- Consider the collection of conduction electrons in the solid. If each Na atom donates one electron to the electron sea, *estimate* the mean separation between the electrons. (Note: if n is the concentration of particles, then the particles' mean separation $d = 1/n^{1/3}$.)
- Estimate the mean separation between an electron (e^-) and a metal ion (Na^+), assuming that most of the time the electron prefers to be between two neighboring Na^+ ions. What is the approximate Coulombic interaction energy (in eV) between an electron and an Na^+ ion?
- How does this electron/metal-ion interaction energy compare with the average thermal energy per particle, according to the kinetic molecular theory of matter? Do you expect the kinetic molecular theory to be applicable to the conduction electrons in Na? If the mean electron/metal-ion interaction energy is of the same order of magnitude as the mean KE of the electrons, what is the mean speed of electrons in Na? Why should the mean kinetic energy be comparable to the mean electron/metal-ion interaction energy?
- Calculate the electrical conductivity of Na and compare this with the experimental value of $2.1 \times 10^7 \text{ } \Omega^{-1} \text{ m}^{-1}$ and comment on the difference.

Solution

a. If D is the density, M_a is the atomic mass and N_A is Avogadro's number, then the atomic concentration n_a is

$$n_a = \frac{DN_a}{M_a} = \frac{(971.2 \text{ kg})(6.022 \times 10^{23} \text{ mol}^{-1})}{(22.99 \times 10^{-3} \text{ kg mol}^{-1})} = 2.544 \times 10^{28} \text{ m}^{-3}$$

which is also the electron concentration, given that each Na atom contributes 1 conduction electron.

If d is the mean separation between the electrons then d and n_a are related by (see Chapter 1 Solutions, Q1.11; this is only an estimate)

$$d \approx \frac{1}{n_a^{1/3}} = \frac{1}{(2.544 \times 10^{28} \text{ m}^{-3})^{1/3}} = 3.40 \times 10^{-10} \text{ m or } 0.34 \text{ nm}$$

b. Na is BCC with 2 atoms in the unit cell. So if a is the lattice constant (side of the cubic unit cell), the density is given by

$$D = \frac{(\text{atoms in unit cell})(\text{mass of 1 atom})}{\text{volume of unit cell}} = \frac{2\left(\frac{M_a}{N_A}\right)}{a^3}$$

isolate for a ,
$$a = \left[\frac{2M_a}{DN_a} \right]^{1/3} = \left[\frac{2(22.99 \times 10^{-3} \text{ kg mol}^{-1})}{(0.9712 \times 10^3 \text{ kg m}^{-3})(6.022 \times 10^{23} \text{ mol}^{-1})} \right]^{1/3}$$

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Léo Pomar



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