Q1. Calculate the **drift mobility** and the **mean scattering time** of conduction electrons in copper at room temperature, given that the **conductivity** of copper is $5.9 \times 10^{5}\ \Omega^{-1}\ cm^{-1}$. The density of copper is $8.96\ g\ cm^{-3}$ and its atomic mass is $63.5\ g\ mol^{-1}$.

- Solve for (**M**) material as (**M**) atom donates 2 electrons to the conduction electron gas in the material.

Note: ($N_A = 6.02 \times 10^{23}$), ($e = 1.6 \times 10^{-19}$ C), ($m_e = 9.1 \times 10^{-31}$ kg), ($u = 1.5 \times 10^{6}\ ms^{-1}$).

Q2. What is the applied **electric field** that will impose a **drift velocity** equal 0.1 percent of the **mean speed** u (~ $10^{6}\ m\ s^{-1}$) of conduction electrons in copper? What is the corresponding **current density** and **current** through a Cu wire of diameter 1mm?

Q3. Given that the **mean speed** of conduction electrons in copper is $1.5 \times 10^{6}\ m\ s^{-1}$ and the frequency of vibration of the copper per atoms is about4 x $10^{12}\ s^{-1}$, estimate **the drift mobility** of electrons and the **conductivity of copper**. The density d of copper is $8.96\ g\ cm^{-3}$ and the atomic mass M_{at} is $63.56\ gmol^{-1}$.

- Consider simple harmonic motion as the average kinetic energy of the oscillations is $\mathbf{KE_{av}=1/4(M\ a^2\ \omega^2)}$ and from kinetic theory of matter, this average kinetic energy must be **½(kT**

Note: ($k = 1.38 \times 10^{-23}\ J\ K^{-1}$), (**experimentally** $\sigma = 5.9 \times 10^{5}\ \Omega^{-1}\ cm^{-1}$).

Q4)

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 $53\ cm^2\ V^{-1}\ s^{-1}$.

a. 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 $d = 1/n^{1/3}$.)

b. 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?

c. 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?

d. Calculate the electrical conductivity of Na and compare this with the experimental value of $2.1 \times 10^{7}\ \Omega^{-1}\ m^{-1}$ and comment on the difference.

Q5)

2.2 Electrical conduction The resistivity of aluminum at 25 °C has been measured to be 2.72×10^{-8} Ω m. The thermal coefficient of resistivity of aluminum at 0 °C is 4.29×10^{-3} K^{-1}. Aluminum has a valency of 3, a density of 2.70 g cm^{-3}, and an atomic mass of 27.

a. Calculate the resistivity of aluminum at —40ºC.

b. What is the thermal coefficient of resistivity at —40ºC?

c. Estimate the mean free time between collisions for the conduction electrons in aluminum at 25 °C, and hence estimate their drift mobility.

d. If the mean speed of the conduction electrons is about 2×10^6 m s^{-1}, calculate the mean free path and compare this with the interatomic separation in Al (Al is FCC). What should be the thickness of an Al film that is deposited on an IC chip such that its resistivity is the same as that of bulk Al?

e. What is the percentage change in the power loss due to Joule heating of the aluminum wire when the temperature drops from 25 °C to —40 ºC?

Q6)

2.3 Conduction in gold Gold is in the same group as Cu and Ag. Assuming that each Au atom donates one conduction electron, calculate the drift mobility of the electrons in gold at 22° C. What is the mean free path of the conduction electrons if their mean speed is 1.4×10^6 m s^{-1}? (Use ρ_o and α_o in Table 2.1.)

Q7)

***2.7 TCR of isomorphous alloys** Determine the composition of the Cu-Ni alloy that will have a TCR of 4×10^{-4} K^{-1}, that is, a TCR that is an order of magnitude less than that of Cu. Over the composition range of interest, the resistivity of the Cu-Ni alloy can be calculated from $\rho_{CuNi} \approx \rho_{Cu} + C_{eff}X(1\text{-}X)$, where C_{eff}, the effective Nordheim coefficient, is about 1310 nΩ m.

Q8)

2.16 Electrical and thermal conductivity of In Electron drift mobility in indium has been measured to be 6 cm2 V^{-1} s^{-1}. The room temperature (27 °C) resistivity of In is 8.37×10^{-8} Ωm, and its atomic mass and density are 114.82 amu or g mol^{-1} and 7.31 g cm^{-3}, respectively.

a. Based on the resistivity value, determine how many free electrons are donated by each In atom in the crystal. How does this compare with the position of In in the Periodic Table (Group IIIB)?

b. If the mean speed of conduction electrons in In is 1.74×10^8 cm s^{-1}, what is the mean free path?

c. Calculate the thermal conductivity of In. How does this compare with the experimental value of 81.6 W m^{-1} K^{-1}?

Q9)

2.18 Mixture rules A 70% Cu - 30% Zn brass electrical component has been made of powdered metal and contains 15 vol. % porosity. Assume that the pores are dispersed randomly. Given that the resistivity of 70% Cu-30% Zn brass is 62 nΩ m, calculate the effective resistivity of the brass component using the simple conductivity mixture rule, Equation 2.26 and the Reynolds and Hough rule.

Q10)

A certain carbon electrode used in electrical arcing applications is 47 percent porous. Given that the resistivity of graphite (in polycrystalline form) at room temperature is about 9.1 μΩ m, estimate the effective resistivity of the carbon electrode using the appropriate Reynolds and Hough rule

b. Silver particles are dispersed in a graphite paste to increase the effective conductivity of the paste. If the volume fraction of dispersed silver is 30 percent, what is the effective conductivity of this paste?

Q11)

2.27 Thermal conduction Consider brass alloys with an X atomic fraction of Zn. These alloys form a solid solution up to 30 at. %, and we can use the combined Matthiessen-Nordhein rule in Equation 2.21 to calculate the resistivity of the alloy. Take $C = 300$ nΩ m and $\rho_o = \rho_{Cu} = 17\ \text{n}\Omega\ \text{m}$.

a. An 80 at .% Cu—20 at. % Zn brass disk of 40 mm diameter and 5 mm thickness is used to conduct heat from a heat source to a heat sink.

(1) Calculate the thermal resistance of the brass disk.

(2) If the disk is conducting heat at a rate of 100 W, calculate the temperature drop along the disk.

b. What should be the composition of brass if the temperature drop across the disk is to be halved?