(v) $\sigma_p = n_a \cdot e \cdot \mu_h$ for P-type semiconductor

Hall voltage $= V_H = \frac{BI}{\rho w}$

Hall angle $= \theta_H = \tan^{-1}(\mu B)$

Resistivity $= R = \rho \frac{l}{A}$

Solved Examples

Ex. 5.23.1 : Determine the mobility of electrons in copper assuming that each atom contributes one free electron for conduction.

For copper : resistivity $= 1 \cdot 7 \times 10^{-6}$ ohm.cm. density $= 8 \cdot 96$ gm/cc

At. Wt. = 63.5, Avogadro number $= 6 \cdot 02 \times 10^{23}$ /gm. mole

Soln. :

Given : Resistivity $\rho = 1 \cdot 7 \times 10^{-6}\ \Omega$ cm., density $d = 8.96$ gm/cc,

Avogadro no. $N = 6 \cdot 02 \times 10^{23}$ At. wt . $A = 63.5$

Formula required : $\sigma = n \cdot e \cdot \mu_e$

Number of atoms of copper present per unit volume is

$$= \frac{6 \cdot 02 \times 10^{23}}{63 \cdot 5} \times 8 \cdot 96 = 8 \cdot 496 \times 10^{22}$$

As every atom contributes one free electron, the number of free electrons per unit volume, i.e. the electron density is $8 \cdot 496 \times 10^{22}$ per c.c.

∴ The conductivity is

$$\sigma = n \cdot e \cdot \mu_e$$

The mobility of electrons is $\mu_e = \frac{\sigma}{n \cdot e}$

$$\text{or } \mu_e = \frac{1}{\rho \cdot n \cdot e} \qquad \left(\because \text{ if } \sigma = \frac{1}{\rho}\right)$$

$$= \frac{1}{(1 \cdot 7 \times 10^{-6} \times 8 \cdot 496 \times 10^{22} \times 1 \cdot 6 \times 10^{-19})}$$

$$= 43 \cdot 273 \text{ cm}^2/\text{volt} \cdot \text{sec.}$$

$$\therefore \quad \mu_e = 43.273 \text{ cm}^2/\text{volt} \cdot \text{sec.}$$

A copper wire 0.1 m long and 1.7 mm² cross-section has a resistance 0.1 ohm when subjected to 1 Volt potential difference between its ends. Calculate the density of free electrons in the metal and the mobility of these electrons.

Assume that
Density of copper = 8.96 gm/cc
Atomic weight of copper = 63.5
Avogadro number = 6.02×10^{23} / gm mole

Soln. :

Data : Length $l = 0.1$ m

Cross –section $A = 1.7\ \text{mm}^2 = 1.7 \times 10^{-6}\ \text{m}^2$

Resistance $R = 0.1\ \Omega$

63.5 gm. of copper contain 6.02×10^{23} atoms

Density of copper = 8.96 gm/cc

Formulae required : $R = \rho \cdot \dfrac{l}{A}$, $\sigma = n \cdot e \cdot \mu_e$

Therefore number of copper atoms per unit volume are :

$$= \frac{6.02 \times 10^{23}}{63.5} \times 8.96 = 8.49 \times 10^{22} \text{ per c.c.}$$

$$= 8.49 \times 10^{28} \text{ per m}^3$$

Each copper atom contributes one free electron for conduction.

$\therefore$ The number of free electrons per unit volume $= 8.49 \times 10^{28}\ /\ \text{m}^3$

Now resistance of copper is $\quad R = \rho \cdot \dfrac{l}{A}$

where $\rho \rightarrow$ resistivity of copper

$$\therefore \rho = \frac{R \times A}{l} = \frac{0.1 \times 1.7 \times 10^{-6}}{0.1}$$

$$\therefore \rho = 1.7 \times 10^{-6}\ \Omega \cdot \text{m}$$

$\therefore$ Conductivity of copper is

$$\sigma = \frac{1}{\rho} = \frac{1}{1.7 \times 10^{-6}} \text{ mho/m}$$

Now $\sigma = n \cdot e \cdot \mu_e$

where $n \rightarrow$ electron concentration

$\mu_e \rightarrow$ electron mobility

$$\therefore \text{Mobility } \mu_e = \frac{\sigma}{n \cdot e}$$

$$= \frac{1}{1.7 \times 10^{-6} \times 8.49 \times 10^{28} \times 1.6 \times 10^{-19}}$$

$$\text{or } \mu_e = 0.0433 \times 10^{-3}\ \text{m}^2\ /\ \text{V.sec}$$

Ex. 5.23.3 : **Find the drift velocity for an electron in silver wire of radius 1 mm and carrying a current of 2 A. Density of silver is 10.5 gm/cc.**

Avogadro number = 6.025×10^{23} / gm mole.

Soln. :

Given : Density of silver = 10.5 gm/cc.

At. wt. of silver = 108

Formula required : $I = q \cdot n \cdot v \cdot A$

Therefore number of electrons per unit volume $= n = \frac{6 \times 10^{23}}{108} \times 10.5$

$$\therefore \quad n = \frac{6 \times 10^{23}}{10.3} = 6 \times 10^{22} \text{ per cm}^3$$

$$\text{or} \quad n = 6 \times 10^{28} \text{ per m}^3$$

$$\text{Cross sectional area } A = \pi r^2 = \pi \times (10^{-3})^2 = 3 \times 10^{-6} \text{ m}^2$$

$$\therefore \text{Now current } I = q \cdot n \cdot v \cdot A$$

$$\therefore v = \frac{I}{nqA} = \frac{2}{(6 \times 10^{28}) \times (1.6 \times 10^{-19}) \times (3 \times 10^{-6})}$$

$$= 7 \times 10^{-4} \text{ m/s.}$$

Ex. 5.23.4 : The resistance of copper wire of diameter 1.03 mm is 6.51 ohm per 300 m. The concentration of free electrons in copper is $8.4 \times 10^{28}/\text{m}^3$. If the current is 2 Amp., find the mobility of charge carriers and the conductivity of copper.

Soln. :

Given : Diameter $d = 1.03 \text{ mm} = 1.03 \times 10^{-3}$ m

$\therefore$ radius $r = \frac{1.03}{2} \times 10^{-3}$ m

$R = 6.51\ \Omega$

$l = 300$ mm

$n = 8.4 \times 10^{28}/\text{m}^3$

Formulae required : $R = \rho \cdot \frac{l}{A}$, $\mu_e = \frac{\sigma}{n \cdot e}$

The resistance R of a wire of length l and cross-section A is given by,

$$R = \rho \cdot \frac{l}{A}$$

where $\rho \rightarrow$ resistivity of copper

$$\therefore \quad \rho = \frac{R \times A}{l} \qquad (A = \pi r^2)$$

$$= \frac{6.51 \times 3.14 \times \left(\frac{1.03}{2} \times 10^{-3}\right)^2}{300}$$

$$= \frac{7.228}{4} \times 10^{-8}\ \Omega \text{ m}$$

$\therefore$ conductive $\quad \sigma = \frac{1}{\rho} = \frac{4}{7.228} \times 10^{8} = 55.34 \times 10^{6}$ mho/m

Now $\sigma = n \cdot e \cdot \mu_e$

where $n \rightarrow$ carrier concentration

μ_e = mobility

$$\therefore \text{ Mobility } \quad \mu_e = \frac{\sigma}{n \cdot e} = \frac{55.34 \times 10^6}{8.4 \times 10^{28} \times 1.6 \times 10^{-19}}$$

$$= 4.117 \times 10^{-3} \text{ m}^2 / \text{volt.sec}$$

Ex. 5.23.5 : Find the resistivity of copper if each atom of copper contributes one free electron for conduction, when the following data is given.

Soln. :

Given : Atomic weight of Cu = 63.5

Density of Cu = 8.96 gm/cc

Electron mobility in Cu = 43.28 cm^2 / V.sec

Avogadro number = 6.02×10^{23} per gm mole

Formulae required : $\sigma = n \cdot e \cdot \mu_e$, $\rho = \frac{1}{\sigma}$

The number of copper atoms per unit volume is

$$= \frac{N}{\text{Automic weight}} \times \text{density}$$

$$= \frac{6.03 \times 10^{23}}{63.5} \times 8.96 = 8.49 \times 10^{22} \text{ atoms}$$

Each atom of Cu contributes one free electron.

$\therefore$ Electron concentration is 8.49×10^{22} per c.c. or 8.49×10^{28} per m^3

The conductivity is $\sigma = n \cdot e \cdot \mu_e$

$\therefore$ Resistivity of copper is

$$\rho = \frac{1}{\sigma} = \frac{1}{n \cdot e \cdot \mu_e}$$

$$\therefore \quad \rho = \frac{1}{8.49 \times 10^{22} \times 1.6 \times 10^{-19} \times 43.28}$$

$$= 1.7 \times 10^{-6} \text{ ohm.cm}$$

Ex. 5.23.6 : Calculate the conductivity of pure silicon at room temperature when the concentration of carriers is $1 \cdot 6 \times 10^{10}$ per cm^3. Take μ_e = 1500 cm^2 / volt. sec. and μ_h = 500 cm^2/volt.sec. at room temperature.

Soln. :

Given : μ_e = 1500 cm^2/volt sec. μ_h = 500 cm^2 / volt sec.

$n = p = n_i = 1 \cdot 6 \times 10^{10}$ per cm^3.

Formula required : $\sigma_i = n_i (\mu_e + \mu_h) \cdot e$

The conductivity of pure semiconductor is given by,

$$\sigma_i = n_i (\mu_e + \mu_h) \cdot e$$

$$\therefore \quad \sigma_i = 1.6 \times 10^{10} (1500 + 500) \times 1.6 \times 10^{-19}$$

$$\text{or} \quad \sigma_i = 5.12 \times 10^{-6} \text{ mho/cm.}$$

$$\therefore \quad \sigma = 5.12 \times 10^{-6} \text{ mho/cm.}$$

Ex. 5.23.7 : An n-type semi-conductor is to have a resistivity 10 Ω cm. Calculate the number of donor atoms which must be added to achieve this.
Given that $\mu_d = 500 \text{ cm}^2 / \text{V.S}$

Soln. :

Given : Resistivity $\rho = 10\ \Omega$ cm., $\mu_d = 500 \text{ cm}^2/\text{v.s.}$

Formulae required : Conductivity $\sigma = \frac{1}{\rho}$ and $\sigma = n_d \cdot e \cdot \mu_d$

$$n_d = \frac{\sigma}{e \cdot \mu_d} = \frac{1}{\rho \cdot e \cdot \mu_d} = \frac{1}{10 \times 1.6 \times 10^{-19} \times 500}$$

$$= 1.25 \times 10^{15} \text{ per cm}^3$$

Ex. 5.23.8 : (Dec. 09, 4 Marks)

Calculate the conductivity of specimen if a donor impurity is added to an extent of one part in 10^8 Ge atoms at room temperature ?

Soln. :

Given : Avogadro number $= 6.02 \times 10^{23}$ atoms/gm.mole. At·wt.·of Ge = 72 · 6,

Density of Ge = 5· 32 gm/c.c., mobility μ = 3800 cm^2/v.s.

Formula required : $\sigma = n \cdot d \cdot \mu_e$

$$\text{Concentration of Ge atoms} = \frac{6.02 \times 10^{23}}{72.6} \times 5.32 = 4.41 \times 10^{22} \text{ per cm}^3$$

As there is one donar atom per 10^8 atoms of Ge

$$n_d = \frac{4.41 \times 10^{22}}{10^8} = 4.41 \times 10^{14} \text{ per cc}$$

$$\text{conductivity} \quad \sigma = n_d \cdot \mu_e \cdot e$$

$$= 4.41 \times 10^{14} \times 3800 \times 1.6 \times 10^{-19} = 0.268 \text{ mho/cm.}$$

Ex. 5.23.9 : A germanium crystal is doped with a pentavalent impurity of concentration 1 ppm. If the resistivity of doped germanium is 0.3623×10^{-3} ohm-m, find the mobility of electrons in germanium. Assume that all the impurity atoms are ionised and the density of germanium atoms is 4.42×10^{28} per m^3.

Soln. :

Given : Resistivity $\rho = 0.3623 \times 10^{-3}\ \Omega$ m

Ge density $= 4.42 \times 10^{28}$ atoms / m^3

Rate of doping = 1 ppm = 1 impurity atom per 10^6 Ge atoms.

Scanned by CamScanner

Formulae required : $\sigma = \frac{1}{\rho}$ $\mu = \frac{\sigma}{n_d \cdot e}$.

Conductivity of germanium is $\sigma = \frac{1}{\rho} = \frac{1}{0.3623 \times 10^{-3}}$ mho/m

or $\sigma = 2760$ mho/m

The rate of impurity doping is 1 impurity atom per 10^6 Ge atoms and density of Ge atoms is 4.42×10^{28} /m^3.

All the impurity atoms are ionised. Therefore the concentration of impurity atoms is

$$n_d = \frac{4.42 \times 10^{28}}{10^6} = 4.42 \times 10^{22} \text{ atoms/m}^3$$

Conductivity $\sigma = n_d \cdot e \cdot \mu$

$\therefore$ Electron mobility is $\mu = \frac{\sigma}{n_d \cdot e} = \frac{2760}{4.42 \times 10^{22} \times 1.6 \times 10^{-19}}$

or $\mu = 0.39$ m^2 / V.sec

Ex. 5.23.10 : A germanium semiconductor contains 10^{-6} % Boron and has a resistivity of 0.42 ohm. m. Calculate the density and mobility of holes in the semiconductor.

Assume density of germanium = 5.36×10^3 kg/m^3

Atomic weight of germanium = 72.59

Avogadro number = 6.025×10^{26} / kg – mole

Soln. :

Given : Resistivity = 0.42 Ω m

Boron impurity = 10^{-6}%

Density of Ge = 5.36×10^3 kg/m^3

At. wt. of Ge = 72.59

Formula required : Conductivity $= \frac{1}{\text{resistivity}}$

Avogadro number = 6.025×10^{26} / kg. Mole.

$\therefore$ 72.59 kg of Ge contains 6.025×10^{26} atoms

Density = Mass per unit volume

$\therefore$ Number of Ge atoms present per unit volume will be $= \frac{6.025 \times 10^{26}}{72.59} \times 5.36 \times 10^3 = 0.445 \times 10^{29}$

Rate of Boron impurity is 10^{-6} % i.e. 10^{-8}

$\therefore$ 1 Boron atom is present per 10^8 Ge atoms.

If the impurity atoms are completely ionised then, the number of holes per unit volume will be

$$= \frac{0.445 \times 10^{29}}{10^8} = 4.45 \times 10^{20}$$

$\therefore$ Holes per unit volume $= 4.45 \times 10^{20}$

Now one hole is available per acceptor Boron atom.

∴ Concentration of acceptor atoms is $n_a = 4.45 \times 10^{20}/\text{m}^3$

The conductivity of p-type semiconductor is $\sigma_p = n_a \cdot e \cdot \mu_h$

$$\text{and conductivity} = \frac{1}{\text{resistivity}} = \frac{1}{0.42} \text{ mho/m}$$

$$\therefore \frac{1}{0.42} = (4.45 \times 10^{20}) \times (1.6 \times 10^{-19}) \times \mu_h$$

$$\therefore \text{Mobility of holes} = \frac{1}{0.42 \times 4.45 \times 10^{20} \times 1.6 \times 10^{-19}} = 0.0334 \text{ m}^2/\text{V.sec}$$

Ex. 5.23.11 : Calculate the current produced in a small germanium plate of area 1 cm^2 and of thickness 0.3 mm when a potential difference of 2V is applied across the faces. Given that the concentration of free electrons is Ge is $2 \times 10^{19}/\text{m}^3$ and mobilities of electrons and holes are $0.36 \text{ m}^2/\text{v} \cdot \text{s}$ and $0 \cdot 17 \text{ m}^2/\text{v} \cdot \text{s}$ respectively.

Soln. :

Given : $n_i = 2 \times 10^{19}/\text{m}^3$ $\mu_e = 0 \cdot 36 \text{ m}^2/\text{v} \cdot \text{s} \cdot$

$\mu_h = 0 \cdot 17 \text{ m}^2/\text{v} \cdot \text{s} \cdot$, Area $A = 1 \times 10^{-4} \text{ m}^2$

Voltage $V = 2$ volts.

Length $l = 0 \cdot 3 \text{ mm} = 3 \times 10^{-4}$ m.

Formula required : $J = \sigma E$

$$I = \frac{\sigma_i \times V \times A}{l}$$

$$\text{The current density } J = \sigma E$$

$$\text{Or} \quad J = \sigma \cdot \frac{V}{l}; \qquad \text{Also } J = \frac{I}{A}$$

$$\therefore \frac{I}{A} = \sigma \cdot \frac{V}{l}$$

$$\therefore I = \frac{\sigma_i \times V \times A}{l}$$

$$\text{Now } \sigma_i = n_i \cdot e \cdot (\mu_e + \mu_h)$$

$$= 2 \times 10^{19} \times 1 \cdot 6 \times 10^{-19} (0 \cdot 36 + 0 \cdot 17) = 1 \cdot 696 \text{ mho/m.}$$

$$\therefore \text{current} \quad I = \frac{1 \cdot 696 \times 2 \times 10^{-4}}{3 \times 10^{-4}}$$

$$\text{or} \quad I = 1 \cdot 13 \text{ amp.}$$

Ex. 5.23.12 : A specimen of pure Germanium at 300°K has a density of charge carriers of $2.5 \times 10^{19}/\text{m}^3$. It is doped with donor impurity atoms at the rate of one impurity atom for every 10^6 atoms of germanium. All impurity atoms may be supposed to be ionized. The density of germanium atoms is 4.2×10^{28} atoms/m^3. Find the resistivity of doped germanium if the electron mobility is $0.36 \text{ m}^2/\text{vs}$.

Soln. :

Given : Density of charge carriers at 300°K $= 2.5 \times 10^{19}/\text{m}^3$

Formulae required : $\sigma_n = N_d \cdot e \cdot \mu_e$ $\quad \rho_n = \frac{1}{\sigma_n}$

Intrinsic carrier concentration $= 2.5 \times 10^{19}/m^3$

Density of added impurity atoms i.e.

$$N_d = \frac{4.2 \times 10^{28}}{10^6} = 4.2 \times 10^{22} \text{ atoms/m}^3$$

The donor concentration is very large as compared to intrinsic carrier concentration and hence the intrinsic concentration can be neglected.

The conductivity of doped material is therefore

$$\sigma_n = N_d \cdot e \cdot \mu_e = 4.2 \times 10^{22} \times 1.6 \times 10^{-19} \times 0.36 = 2.492 \times 10^3 \text{ mho/m}$$

Hence the resistivity is $\quad \rho_n = \frac{1}{\sigma_n} = \frac{1}{2.4192 \times 10^3} \text{ ohm m.}$

or $\quad \rho_n = 0.4133 \times 10^{-3}\ \Omega \text{ m.}$

Ex. 5.23.13 : Calculate the current produced in a germanium sample of area 2 sq.cm and thickness 0.1 mm when a potential difference of 4 Volts is applied across it.

Soln. :

Given : $n_i = 1 \times 10^{19} / m^3$

$\mu_e = 0.36 \text{ m}^2/\text{volt.sec}$

$\mu_h = 0.17 \text{ m}^2 / \text{volt.sec}$

Data. : Area $A = 2 \text{ cm}^2 = 2 \times 10^{-4} \text{ m}^2$

Thickness $t = 0.1\text{mm} = 10^{-4}$ m

$V = 4$ volts

Formula required : $\sigma_I = n_i \cdot e \cdot (\mu_e + \mu_h)$

The conductivity is

$$\sigma_i = n_i \cdot e \cdot (\mu_e + \mu_h) = 1 \times 10^{19} \times 1.6 \times 10^{-19}(0.36 + 0.17) = 1.6 \times 0.53 = 0.848 \text{ mho/m}$$

$$\therefore \text{ current density } J = \sigma_i \times E = \sigma_i \times \frac{V}{t}$$

$$\therefore J = 0.848 \times \frac{4}{10^{-4}} \text{ Amp / m}^2$$

$$\therefore \text{ Current produce is } I = J \times A$$

$$\therefore I = 0.848 \times \frac{4}{10^{-4}} \times 10^{-4} \times 2$$

or $\quad I = 6.784$ Amp.

Ex. 5.23.14 : A silver wire is in the form of a ribbon 0.50 cm. wide and 0.10 mm thick. When a current of 2 amp passes through the ribbon, perpendicular to 0.80 Tesla magnetic field calculate the Hall voltage produced. The density of silver = 10 · 5 gm/cc.

Soln. :

Given : B = 0.8 Tesla, Density = 10.5 gm/cc

Formula required : $V_H = B.v.d.$ $\quad v = \frac{I}{nAq}$

The number of electrons in 1cc of silver are :

$$n = 6 \cdot 025 \times 10^{23} \times \frac{10 \cdot 5}{108} \approx 6 \times 10^{22} \text{ per c.c.}$$

As each silver atom contributes one electron, the number of electrons per $m^3 = 6 \times 10^{28}$

$$\text{Area } A = 0.5 \times 10^{-2} \times 0.1 \times 10^{-3} = 5 \times 10^{-7} \text{ m}^2.$$

$$\therefore \text{Hall voltage } V_H = B.v.d.$$

$$\text{The drift vel } v = \frac{I}{n\,A\,q}$$

$$\therefore \quad V_H = \frac{I}{n \cdot q} \cdot \frac{B \cdot I \cdot d}{A}$$

$$= \frac{1}{6 \times 10^{28} \times 1 \cdot 6 \times 10^{-19}} \times \frac{0 \cdot 8 \times 2 \times 0.1 \times 10^{-3}}{5 \times 10^{-7}}$$

$$= 0.333 \times 10^{-7} \text{ volts}$$

Ex. 5.23.15 : A copper specimen having length 1 metre, width 1 cm and thickness 1 mm is conducting 1 amp. current along its length and is applied with a magnetic field of 1 Tesla along its thickness. It experiences Hall effect and a hall voltage of 0.074 microvolts appears along its width. Calculate the Hall coefficient and the mobility of electrons in copper.

(Conductivity of copper is $\sigma = 5.8 \times 10^7\ (\Omega m)^{-1}$]

Soln. :

Given : $l = 1$ m, $\quad d = 1\text{cm} = 10^{-2}$m

$W = 1 \text{ mm} = 10^{-3}$ m, $\quad I = 1$ Amp

$B = 1$ Tesla, $\quad V_H = 0.074 \times 10^{-6}$ Volts

$\sigma = 5.8 \times 10^7$ mho/m

Formulae required : $V_H = \frac{1}{n_q} \cdot \frac{B \cdot I \cdot d}{A}$

The Hall voltage is

$$V_H = \left(\frac{1}{n_q}\right) \cdot \frac{B \cdot I \cdot d}{A}$$

$$\text{or} \quad V_H = R_H \times \frac{B \cdot I \cdot d}{A}$$

$$\therefore R_H = \frac{V_H \times A}{B \cdot I \cdot D}$$

$$= \frac{0.074 \times 10^{-6} \times (10^{-2} \times 10^{-3})}{1 \times 1 \times 10^{-2}}$$

$$\therefore R_H = 7.4 \times 10^{-11} \ m^3/c$$

$$\therefore \text{Mobility} \ \mu = \sigma \cdot R_H = 5.8 \times 10^7 \times 7.4 \times 10^{-11}$$

$$\therefore \ \mu = 4.3 \times 10^{-3} \ m^2/\text{volt.sec}$$

Ex. 5.23.16 : Determine the concentration of holes in Si crystals having donor concentration of $1.4 \times 10^{24}/m^3$ when the intrinsic carrier is $1.4 \times 10^{18}/m^3$. find the ratio of electron to hole concentration.

Soln. : Intrinsic carrier concentration

$$n_i = 1.4 \times 10^{18}/m^3$$

$$\text{Donor concentration } n_D = 1.4 \times 10^{24}/m^3$$

$$\text{Concentration of electron, } n = N_D = 1.4 \times 10^{24}/m^3$$

$$\text{Concentration of holes, } p = \frac{n_i^2}{n} = \frac{(1.4 \times 10^{18})^2}{1.4 \times 10^{24}} = 1.4 \times 10^{12}/m^3$$

$$\text{Ratio of electron to hole concentration} = \frac{n}{p} = \frac{1.4 \times 10^{24}}{1.4 \times 10^{12}} = 1 \times 10^{12}$$

Ex. 5.23.17 : The resistivity of semiconductor material was known to $0.00912 \ \Omega - m$ at room temperature. The flux density in the Hall model was $0.48 \ Wb/m^2$. Calculate the Hall angle for a Hall coefficient of $3.55 \times 10^{-4} \ m^3$ / coulomb.

Soln. :

$$\text{Flux density in Hall Model } B = 0.48 \ wb/m^2$$

$$\text{Hall coefficient } R_H = 3.55 \times 10^{-4} \ m^3/c$$

$$\text{Conductivity } \sigma = \frac{1}{\text{resistivity}} = \frac{1}{0.00912} = 109.65 \ (\text{ohm-m})^{-1}$$

$$\text{Hall angle } \theta_H = \tan^{-1}(\sigma B R_H)$$

$$= \tan^{-1}(109.65 \times 0.48 \times 3.55 \times 10^{-4}) = \tan^{-1}(0.01868)$$

$$= 1.0704°$$

Ex. 5.23.18 : The resistivity of doped silicon material is 9×10^{-3} ohm– m. The Hall Co-efficient is $3.6 \times 10^{-4} \ m^3 \ \text{coulomb}^{-1}$. Assuming single carrier conduction, find the mobility and density of charge carriers, $e = 1.6 \times 10^{-19}$ C.

Soln. :

$$\text{Conductivity } \sigma = \frac{1}{\text{resistivity}} = \frac{1}{9 \times 10^{-3}} = 111.11 \ (\text{ohm-m})^{-1}$$

$$\text{Charge density } \rho = \frac{1}{R_H} = \frac{1}{3.6 \times 10^{-4}} = 2{,}778 \ \text{coulomb}/m^3$$

$$\text{Density of charge carriers } n = \frac{\text{charge density}}{e} = \frac{2{,}778}{1.6 \times 10^{-19}} = 1.73625 \times 10^{22}/m^3$$

...Ans.

$$\text{Mobility } \mu = \sigma R_H = 111.11 \times 3.6 \times 10^{-4} = 0.04 \ m^2/v\text{-s}$$

Ex. 5.23.19 : (May 06, 4 Marks)

A slab of copper 2.0 mm in length and 1.5 cm wide is placed in a uniform magnetic field with magnitude 0.40 T. When a current of 75 amp flows along the length, the voltage measured across the width is 0.81 μV, determine the concentration of mobile electrons in copper.

Soln. :

$$V_H = R_H \frac{BId}{A}$$

$$R_H = \frac{V_H \cdot A}{B \cdot I \cdot d} = \frac{0.8 \times 10^{-6} \times 2.0 \times 1.5 \times 10^{-5}}{0.4 \times 75 \times 1.5 \times 10^{-2}}$$

$$= 0.053 \times 10^{-19}$$

$$\frac{1}{nq} = 0.053 \times 10^{-9}$$

$$n = \frac{1}{1.6 \times 10^{-19} \times 0.053 \times 10^{-9}}$$

$$= 11.79 \times 10^{28} / \text{cu.m}$$

Ex. 5.23.20 : (Dec. 06, 4 Marks)

Calculate the conductivity of a germanium sample if a donor impurity is added to the extent of one part in 10^7 Ge atoms at room temperature.

Soln. :

Given : Avogadro number $N_a = 6.02 \times 10^{23}$ atoms/gm-mole

Atomic weight of Ge = 72.6

Mobility $\mu_e = 3800\ \text{cm}^2 / \text{V-sec}$

Density of Ge = 5.32 gm/cc

$$\text{Concentration of Ge atoms} = \frac{6.02 \times 10^{23} \times 5.32}{72.6} = 4.41 \times 10^{22} / \text{cc}$$

As donor impurity is added to the extent of one part in 10^7 Ge atoms,

$$n_d = \frac{4.41 \times 10^{22}}{10^7} = 4.41 \times 10^{15} / \text{cc}$$

Conductivity of N-type secmiconductor

$$\sigma_n = e\, n_d\, \mu_e = 1.6 \times 10^{-19} \times 4.41 \times 10^{15} \times 3800 = 2.6813\ \text{mho/cm}$$

Ex. 5.23.21 : (Dec. 06, 4 Marks)

A silver wire is in form of a ribbon 0.50 cm. Wide and 0.10 thick. When a current of 2 amp passes through the ribbon, perpendicular to 0.80 Telsa magnetic field, Calculate the Hall voltage produced. The density of silver 10.5 gm/cc. And atomic weight of Ag = 108.

Soln. :

Given : Number of electrons $n = 6.025 \times 10^{23} \times \frac{10.5}{108} \approx 5.857 \times 10^{22}$ per c.c.

$$= 5.857 \times 10^{28} \text{ per m}^3$$

Formula :

$$V_H = \frac{1}{n \cdot q} \cdot \frac{B \cdot I}{w} = \frac{1}{5.857 \times 10^{28} \times 1.6 \times 10^{-19}} \cdot \frac{0.8 \times 2}{0.1 \times 10^{-3}}$$

$$V_H = 1.70 \times 10^{-6} V = 1.7 \mu V \text{ (Assuming 0.10 mm thick)}$$

...Ans.

Ex. 5.23.22 : (May 09, 4 Marks)

☞ Calculate the mobility of charge carriers in a dopped silicon whose conductivity is 100 per Ω-m and the Hall Coefficient is 3.6×10^{-4} m^3 / Coulomb.

Soln. :

Given : $\sigma = 100 \Omega$ m

$$R_H = \frac{1}{ne} = 3.6 \times 10^{-4} \text{ m}^3/\text{c}$$

Formula :

$$\sigma = ne\mu$$

$$\mu = \frac{\sigma}{ne} = 100 \times 3.6 \times 10^{-4} = 0.036 \text{ m}^2/\text{v-s}$$

Ex. 5.23.23 : (Dec. 09, 4 Marks)

☞ In an N-type semi-conductor the Fermi level lies 0.3 eV below the conduction band at room temperature. If the temperature zis raised to 330 k, find the position of term level.

Soln. :

The number of electrons in C.B. having energy E_C at room temp. T = 300°K is

$$N_C = \frac{N}{1 + e^{\left(\frac{E_C - E_F}{KT}\right)}}$$

Hence approximately we can write

$$E_C - E_F = KT. \log \frac{N}{N_C}$$

$$\text{or } 0.3 = K (300) \log \frac{N}{N_C}$$

Fermi–level at $T' = 330$°K is given by

$$E_C - E_F = K(330) \log \frac{N}{N_C}$$

Equation (2) divided by Equation (1) gives

$$\frac{E_C - E_F}{0.3} = \frac{330}{300}$$

$$\text{or} \quad E_C - E_F = 0.33 \text{ eV.}$$

Thus the Fermi level will be 0.33 eV below the conduction band.

Ex. 5.23.24 : (May 11, 4 Marks)

☞ Calculate the mobility of charge carriers in a doped silicon of which conductivity is 100 mho/m and the Hall coefficient is 3.6×10^{-4} m^3/c.

Soln. :

Given :

Hall Co-efficient $\quad R_H = \frac{1}{ne} = 3.6 \times 10^{-4}\ m^3/c$

Conductienty $\quad \sigma = 100$ mho/m

Formulae : $\quad \sigma = ne\,\mu$

$$= \frac{\sigma}{ne} = \frac{100}{1/3.6 \times 10^{-4}} = \mathbf{0.036\ m^2/\ V\text{-}s}$$

Ex. 5.23.25 : (Dec. 11, 4 Marks)

☞ Intrinsic Silicon is doped with Phosphorus, with the atomic ratio of 10^8 (Si) : 1 (P). Calculate the conductivity of N type of Silicon thus formed. Given mobility of electrons in Silicon $\mu_e = 1400\ cm^2\ Vs^{-1}$. Atomic weight of intrinsic Silicon = 28.085, Avogadro's Number = 6.022×10^{23} atoms mole, Density of Silicon = 2.33 gm/cm^3.

Soln. :

Formulae : $\quad \sigma = n_d\, e\, \mu_e$

$$\text{Concentration of Si atoms} = \frac{6.022 \times 10^{23}}{28.085} \times 2.33$$

$$= 4.99 \times 10^{22} / cm^3$$

As there is one donor atom per 10^8 atoms of Si

$$n_d = \frac{4.99 \times 10^{22}}{10^8}$$

$$= 4.99 \times 10^{14} / cm^3$$

$$\text{So, conductivity } \sigma = n_d e \cdot \mu_e$$

$$= 4.99 \times 10^{14} \times 1.6 \times 10^{-19} \times 1400$$

$$= \mathbf{0.1119\ mho/cm.}$$

Ex. 5.23.26 : (Dec. 11, 5 Marks)

A specimen having length 1.00 cm, width 1.00 mm and thickness 0.1 mm is made to conduct with 1.00 mA current and is placed in a magnetic field of 1.0 Wb/m^2, acting the thickness. Calculate the Hall Voltage in case of (i) N type semiconductor with Hall Coefficient of -3.44×10^{-8} m^3/C and (ii) Aluminum with Hall Coefficient of -0.3×10^{-10} m^3/C. Which of these materials is more sensitive to Hall Effect ? Why ?

Soln. :

i) Hall voltage $V_H = R_H \cdot \frac{B\,I}{W} = 3.44 \times 10^{-8} \cdot \frac{1 \times 1 \times 10^{-3}}{1 \times 10^{-3}}$

$$= 3.44 \times 10^{-8}\ V$$

ii) $V_H = R_H \cdot \frac{BI}{W} = 0.3 \times 10^{-10} \times \frac{1 \times 1 \times 10^{-3}}{1 \times 10^{-3}}$

$$= 0.3 \times 10^{-10}\ V$$

N-type semiconductor in more sensitive due to the higher value of V_H.