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Semester 4
PHYSICS
paperPHS-A-CC-4-10-TH (OLD SYLLABUS)
CONDUCTIVITY AND MOBILITY

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BASIC IDEA OF CONDUCTIVITYM MOBILITY AND DRIFT VELOCITY

OLD SYLLABUS

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1)(a) CONDUCTIVITY & MOBILITY

• CONDUCTIVITY

① Conductivity can be defined as the material's ability to conduct heat, sound or electricity.

② Or in otherwords, conductivity is the measure ~~of the~~ at which ~~an~~ electric charges can flow from one place to another.

• Mobility

① Mobility can be defined as the drift velocity per unit electric field.

② In solid-state physics, the electron mobility can be defined as how quickly an electron can move through a metal or semiconductor under electric field.

③ In semiconductor physics, the movement/drift velocity of the holes per unit electric field is the mobility of holes.

• Drift Velocity :-

① Drift velocity is the average velocity attained by charged particles under an electric field.

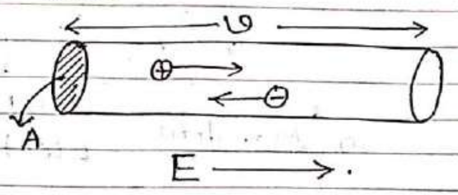
② Drift velocity $\propto$ current.

EXPRESSION FOR CONDUCTIVITY

• Expression for CONDUCTIVITY

Consider a cylindrical shaped semiconductor having uniform cross-sectional area.

A = cross-sectional area
v = drift velocity
E = electric field



Since v is the drift velocity, then the carriers travel a distance v in 1 sec through cross-sectional area A.

n = number of charge carriers passing/sec.

volume of the cylinder V = area × length
$= A \times v$
$= Av$.

If e = charge of 1 charge-carriers. then, for n-number of charge carriers, the total ~~number~~ charge = ne

∴ Electric current I = total charge × volume
$= ne \times Av$

$$\boxed{I = nevA} \quad \text{--- (1)}$$

∴ Current Density $J = \frac{\text{current}}{\text{Area}}$

$$= \frac{I}{A} = \frac{nev\cancel{A}}{\cancel{A}}$$

$$\boxed{J = nev} \quad \text{--- (2)}$$

In case of low electric field,
average drift velocity $\propto$ electric field
or, $v \propto E$

or, $v = \mu E$, where μ = mobility of the charge carriers

or, $\boxed{\mu = \frac{v}{E}}$ —— (3)

or, $\boxed{\text{Mobility} = \frac{\text{drift velocity}}{\text{Electric field}}}$ (*)

EXTRA NOTES

- **Expression for Mobility:—**

If m = mass of the charge carrier
e = charge of the " "
τ = relaxation time,
then $\boxed{\mu = me\tau} \rightarrow \boxed{\mu \propto m}$

- **Why electron mobility is more than the hole mobility?**

$\because$ effective mass of e^- < effective mass of hole
$\boxed{m_e^* < m_h^*}$
$\therefore$ electron mobility > hole mobility.
$\boxed{\mu_n > \mu_p}$

- **What is effective mass?**

(I) Effective mass is the quantity of the charge particle in the crystal under periodic potential.

(2) Effective mass is a new concept. The response of an electron within the crystal under an applied electric field is not determined by its actual gravitational mass, but its effective mass.

(3) This concept arises due to the interaction of electron with the periodic lattice.

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(4) From eqn (3)

$$v = \mu E.$$

putting this in eqn (2), we get,

$$\boxed{J = ne\mu E} \quad \text{--- (4)}.$$

For electrons, $J_e = ne\mu_n E$ --- (5).

For holes, $J_h = \cancel{p}pe\mu_p E$ --- (6).

In case of semiconductor, both electrons and holes movement contribute in current flow,

∴ Total drift current density

$$J = J_e + J_h.$$

$$= ne\mu_n E + pe\mu_p E$$

$$\boxed{J = eE(n\mu_n + p\mu_p)} \quad \text{--- (7)}.$$

Electrical conductivity = $\dfrac{\text{current density}}{\text{electric field.}}$

or, $\sigma = \dfrac{J}{E}.$

$$= \frac{e\cancel{E}(n\mu_n + p\mu_p)}{\cancel{E}}$$

$$\boxed{\sigma = e(n\mu_n + p\mu_p)} \quad \text{--- (8)}$$

or, $\sigma_{total} = \sigma_{electron} + \sigma_{holes}$. --- (9)

Comparing eqn. (8) & (9), we get.

$$\boxed{\begin{aligned} \sigma_{electron} &= \sigma_n = en\mu_n \\ \sigma_{holes} &= \sigma_p = ep\mu_p \end{aligned}} \quad \text{--- (10)}$$

Conductivity Equation

<u>General Form</u>

$$\boxed{\sigma = \frac{1}{\rho} = n\, q\, \mu}$$

σ = conductivity	(ohm-m)$^{-1}$
ρ = resistivity	(ohm-m)
n = carrier density	(# of carriers/m^3)
q = electric charge	1.6×10^{-19} (C)
μ = mobility	(m^2/(V-s))

CONDUCTIVITY EQUATION CONSIDERING ELECTRONS AND HOLES

Conductivity Equation (Cont.)

Insulators (n=p)

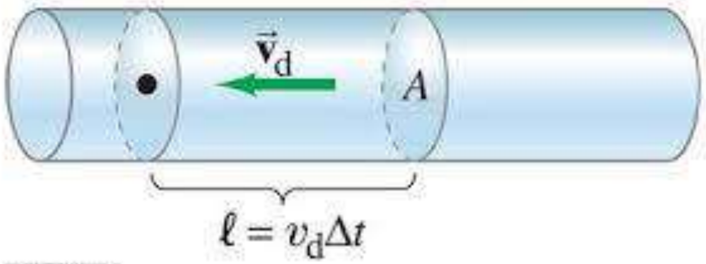
$$\sigma = nq\mu_e + pq\mu_h \longrightarrow \boxed{\sigma = n_i q(\mu_e + \mu_h)}$$

σ = conductivity	$(\text{ohm-m})^{-1}$
n_i = intrinsic carrier density	(# of carriers/m^3)
q = electric charge	$1.6\text{x}10^{-19}$ (C)
μ_e = electron mobility	$(m^2/(V\text{-}s))$
μ_h = electron hole mobility	$(m^2/(V\text{-}s))$

*There will not be an insulator example calculation due to extremely low conductivity.

SOME MORE IDEA ABOUT DRIFT VELOCITY

Drift Velocity Calculation



- *n* - Free electrons (of charge *e*) travel a displacement *l*, in a time Δt, through a cross-sectional area *A*, at a current density *j*, The drift velocity is:

$$\boxed{\vec{v}_D = -\frac{\vec{j}}{ne} \text{ or } -\frac{I}{neA}}$$

- *Note:* the (-) sign indicates the direction of (positive - conventional) current, which is opposite to the direction of the velocity of the electrons

CONCEPT OF PERIODIC POTENTIAL

state splits into two distinct states when the two atoms are brought nearer. If now N atoms are brought close together, each energy state will split into N-energy states. If $N \to$ a large value, the separation between the energy states is very small so as to develop a *quasi-continuous band*. Thus, each energy level splits into a *band* of energy levels. The formation of band for $1s$ and $2s$ states, with reducing separations between the atoms is illustrated in Fig. 6.4.

- The width of a band is a function of (i) the strength of the interaction and (ii) the overlap between the neighbouring atoms.

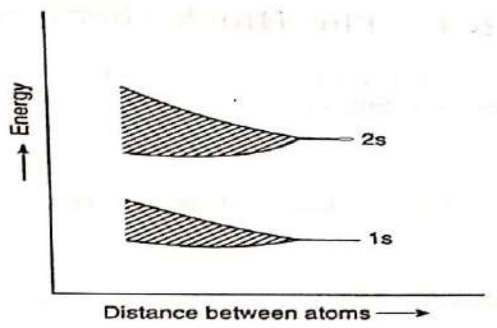


Fig. 6.4 Formation of bands for 1s and 2s states

6.3 Periodic potential in a crystal

The potential energy (P.E.) of an electron in the vicinity of an atomic nucleus of charge Ze is given by

$$V = -\frac{Ze^2}{4\pi\varepsilon_0 r} \tag{6.3.1}$$

where r is the electron-nucleus separation and ε_0 the permittivity of free space.

The variation of V with r for an isolated atom is illustrated in Fig. 6.5. When a number of such nuclei are brought close together to form a crystal, the P.E. of an electron is the sum of the potential energies due to the individual nuclei. The potential energy as a function of distance for an infinite one-dimensional crystal would appear as depicted in Fig. 6.6 i.e, the variation of potential energy is a periodic function of the distance, with equi-spaced nuclei.

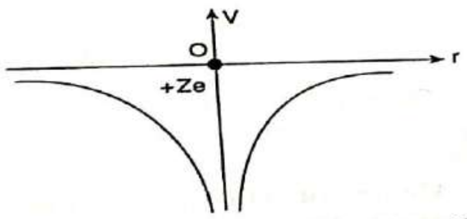


Fig. 6.5 Variation of potential energy with distance for an isolated atom

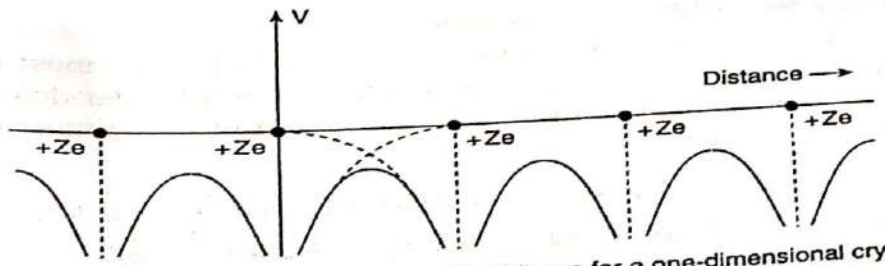


Fig. 6.6 Variation of potential energy with distance for a one-dimensional crystal