

UNIT - I

Electronic Materials

- free Electron Theory.
- Density of States + Energy band diag.
- Kronig-Penny model (to introduce origin of band gap)
- Energy bands in solids
- E-K diagram
- Direct + Indirect bandgaps
- Types of Electronic materials: metals, semiconductors + Insulators
- Density of states
- Occupation Probability
- Fermi level
- Effective mass
- Phonons

(by)

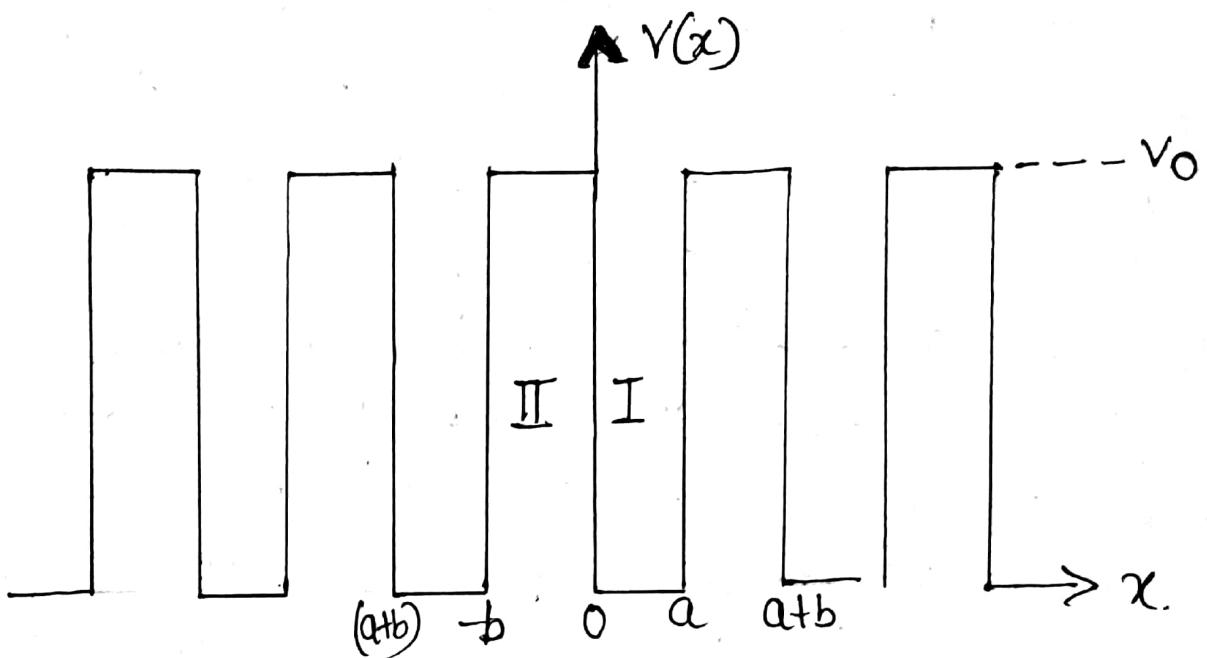
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Free Electron theory :- free electron theory of metals assumed that a conduction electron in metal moves in a region of constant potential so, it is completely free to move about in a crystal restricted only by the metal boundaries. This theory successfully explained heat capacity, electrical conductivity, thermal conductivity etc. But the theory fails to explain other physical properties of solids like classification of solids into metals, insulators & semiconductors. Hence free electron theory is modified by considering interactions of electrons with positive ions in the solids. The interaction of electron with positive ion core give rise to energy gaps. This energy gap has a great significance in determining whether a solid is insulator, conductor or semiconductor.

Kronig - Penny Model

This model introduce the origin of forbidden gap. According to this model electron moves in periodically varying potential. He assumed that the potential energy of

electron has the form of periodic array of square wells separated by distance i.e. potential energy is zero when x lies $b/\omega \rightarrow a$ & potential energy is V_0 when x lies $b/\omega \rightarrow -b \rightarrow 0$ as shown in fig below.



From fig

Region I, $V(x) = 0$ when $0 < x < a$ called Potential well

Region II, $V(x) = V_0$ $-b < x < 0$ called Potential barrier.

In region I ($0 < x < a$), potential Energy $V(x) = 0$

∴ Schrodinger Equation is

$$\frac{d^2\psi_1}{dx^2} + \frac{2m}{\hbar^2}(E - V)\psi_1 = 0$$

as in region I $V(x) = 0$ (2)

so; above Eq^y becomes

$$\frac{d^2\psi_1}{dx^2} + \frac{2m}{\hbar^2} E \psi_1 = 0$$

$$\frac{d^2\psi_1}{dx^2} + \alpha^2 \psi_1 = 0 \quad (1)$$

$$\text{where } \alpha^2 = \frac{2mE}{\hbar^2} \quad f(\alpha)$$

In region II ($-b < x < 0$) Potential Energy $V(x) = V_0$; so Schrodinger Eq^y becomes

$$\frac{d^2\psi_2}{dx^2} + \frac{2m}{\hbar^2} (E - V_0) \psi_2 = 0$$

$$\frac{d^2\psi_2}{dx^2} - \beta^2 \psi_2 = 0 \quad (2)$$

$$\text{where } \beta^2 = \frac{2m(V_0 - E)}{\hbar^2} \quad (\star)$$

Now; general solution of Eq^y (1) + (2) is

$$\psi_1 = A e^{i\alpha x} + B e^{-i\alpha x} \quad (3)$$

$$\psi_2 = C e^{\beta x} + D e^{-\beta x} \quad (4)$$

where A, B, C, D are constant, whose values can be determined on applying boundary conditions.

The Constant A, B, C, D are chosen so that $\psi_1, \psi_2, \frac{d\psi_1}{dx} + \frac{d\psi_2}{dx}$ are continuous at $x=0$

& $x=a$ i.e.

$$\Psi_1(0) = \Psi_2(0) + \left| \frac{d\Psi_1}{dx} \right|_{x=0} = \left| \frac{d\Psi_2}{dx} \right|_{x=0}$$

On applying boundary condition at $x=0$
in Eq (3) & (4)

$$A+B = C+D \quad (5)$$

& boundary condition $\left| \frac{d\Psi_1}{dx} \right|_{x=0} = \left| \frac{d\Psi_2}{dx} \right|_{x=0}$

$$\frac{d\Psi_1}{dx} = i\alpha A e^{i\alpha x} - i\alpha B e^{-i\alpha x} \quad (6)$$

$$\frac{d\Psi_2}{dx} = \beta C e^{\beta x} - \beta D e^{-\beta x}. \quad (7)$$

Now; $\left| \frac{d\Psi_1}{dx} \right|_{x=0} = \left| \frac{d\Psi_2}{dx} \right|_{x=0}$

$$i\alpha A - i\alpha B = \beta C - \beta D$$

$$i\alpha(A-B) = \beta(C-D) \quad (8)$$

In periodic potential wave function must
be in Bloch form

$$\Psi_k(x+a+b) = e^{ik(a+b)} \Psi_k(x)$$

So; $\Psi_k(x) = e^{-ik(a+b)} \Psi_k(x+a+b) \quad (9)$

for maintaining periodicity of wave function
at $x=-b$ & $x=a$, we obtained boundary
condition due to periodicity of potential as

(3)

for $x = -b$

$$\psi_2(-b) = e^{-ik(a+b)} \psi_1(a) \quad (10)$$

$$f \left| \frac{d\psi_2}{dx} \right|_{x=-b} = e^{-ik(a+b)} \left| \frac{d\psi_1}{dx} \right|_{x=a} \quad (11)$$

Now; applying Condition Eq(10) in Eq(3) & Eq(4)

$$(C e^{\beta b} + D e^{\beta b}) = e^{-ik(a+b)} [A e^{i\alpha a} + B e^{-i\alpha a}] \quad (12)$$

also applying Condition Eq(11) in Eq(6) & (7)

$$\beta(C e^{\beta b} - D e^{\beta b}) = e^{-ik(a+b)} i\alpha [A e^{i\alpha a} - B e^{-i\alpha a}] \quad (13)$$

Eq(5), (8), (12), (13) involve four unknown Constant A, B, C, D . These Equations have Solution if determinant of coefficients A, B, C, D vanishes

i.e.

$$\begin{vmatrix} 1 & 1 & -1 & -1 \\ i\alpha & -i\alpha & -\beta & \beta \\ e^{-ik(a+b)} e^{i\alpha a} & e^{-ik(a+b)} e^{i\alpha a} & -e^{\beta b} & -e^{\beta b} \\ i\alpha e^{-ik(a+b)} e^{i\alpha a} & -e^{-ik(a+b)} i\alpha e^{-i\alpha a} & -\beta e^{\beta b} & \beta e^{\beta b} \end{vmatrix} = 0$$

On Solving above determinant we get

$$\frac{\beta^2 - \alpha^2}{2\alpha\beta} \sinh(\beta b) \sin\alpha a + \cosh(\beta b) \cos(\alpha a) = \cos k(a+b) \quad (14)$$

for more convenient equation Kronig-Penney
 Consider the potential i.e. $V_0 \rightarrow \infty$ when $b \rightarrow 0$
 but bV_0 remains finite (barrier width)

So; when $V_0 \rightarrow \infty$ $\beta^2 \gg \alpha^2$

then

$$\frac{\beta^2 - \alpha^2}{2\alpha\beta} = \frac{\beta^2}{2\alpha\beta} = \frac{\beta}{2\alpha}$$

Also when $b \rightarrow 0$; $\sinh(\beta b) \rightarrow \beta b$
 $\cosh(\beta b) \rightarrow 1$

$$\text{So; } \frac{\beta^2 - \alpha^2}{2\alpha\beta} \sinh(\beta b) = \frac{\beta}{2\alpha} \times \beta b = \frac{\beta^2 b}{2\alpha} = \frac{b}{\hbar^2} \left[\frac{2m}{\hbar^2} (V_0 - E) \right]$$

using Eq (\star)

$$\frac{\beta^2 - \alpha^2}{2\alpha\beta} \sinh(\beta b) = \frac{bm}{\alpha\hbar^2} (V_0 - E) \quad \text{as } V_0 \gg E$$

$$\text{So; } \frac{\beta^2 - \alpha^2}{2\alpha\beta} \sinh(\beta b) = \frac{mbV_0}{\hbar^2\alpha}$$

Hence Eq (14) becomes

$$\frac{mV_0b}{\hbar^2\alpha} \sin(\alpha a) + \cos\alpha a = \cos ka \quad \text{(as } b \rightarrow 0\text{)} \quad (15)$$

Now, multiply num & denominator by a .

$$\frac{mV_0ba}{\hbar^2\alpha a} \sin(\alpha a) + \cos\alpha a = \cos ka$$

$$p \frac{\sin(\alpha a)}{\alpha a} + \cos\alpha a = \cos ka \quad (17)$$

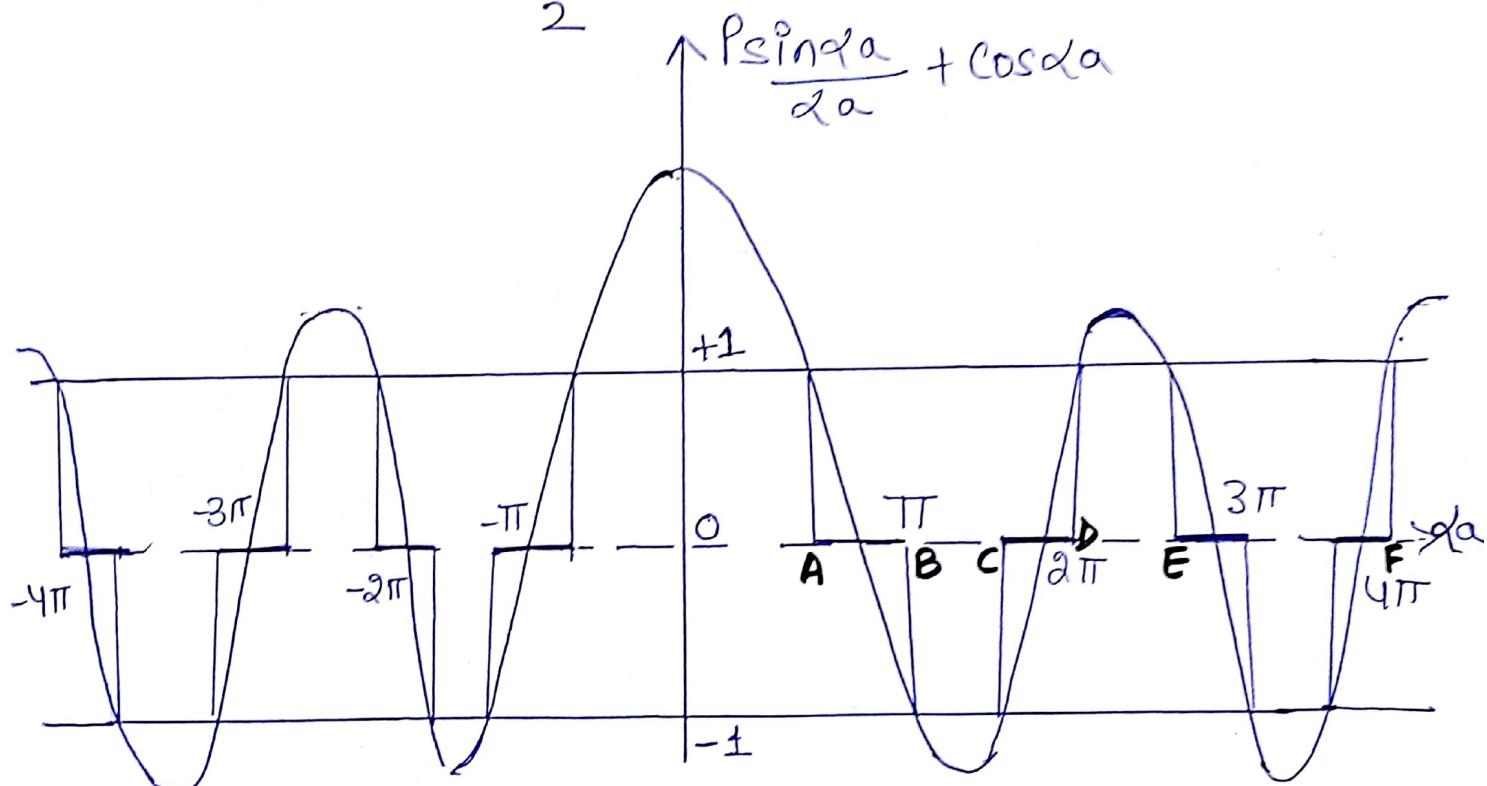
(4)

Here, $P = \frac{mv_0 ab}{\hbar^2}$ is measure for area,

bv_0 of potential barrier (width=b & height= v_0)

Physically, it means binding of a given electron more strongly to a particular potential well.

Now, plot of Eq(17) $\frac{P \sin(\alpha a)}{\alpha a} + \cos(\alpha a)$ Versus αa for $P = \frac{3\pi}{2}$



Important Conclusions from KP Model

1. Energy spectrum of electrons consist of no. of allowed energy bands separated by forbidden gap (like BC, DE)
2. width of allowed bands increases with increase of αa as $\frac{P}{\alpha a} \sin(\alpha a)$ decreases with increase of αa , it means curve becomes

more & more flat as αa increases

\Rightarrow width of allowed band decreases with increase in P i.e. with more binding energy of electrons

If $P \rightarrow \infty$ than Energy spectrum become, line spectrum

Also if $P \rightarrow \infty$ left side of Eq(17) has to stay within ± 1

So, $\frac{\sin \alpha a}{\alpha a} \rightarrow 0$ i.e. $\sin \alpha a \rightarrow 0$

$$\alpha a = \pm n\pi$$

$$\alpha^2 = \frac{n^2 \pi^2}{a^2} \text{ Now}$$

Compare the value of α^2 with Eq 1(a)
we get

$$\frac{n^2 \pi^2}{a^2} = \frac{2mE}{\hbar^2}$$

$$E = \frac{n^2 \pi^2 \hbar^2}{2ma^2}$$

\Rightarrow which shows Energy of particle is discrete

4 Effect of P

When $P \rightarrow 0$ then Eq(17) becomes

$$\cos \alpha a = \cos ka$$

$$\alpha = k$$

$$\alpha^2 = k^2$$

$$\alpha^2 = k^2 = \frac{2mE}{\hbar^2} \quad \text{using Eq } f(a)$$

$$E = \frac{\hbar^2 k^2}{2m}$$

⇒ This is appropriate for completely free particle

E-K Diagram or Energy(E) Versus Wavenumber(k) Diag.

In Kronig-Penney model, it was observed that electron moving in periodic potential have energy values only b/w allowed energy bands. The discontinuities in energy values arise at a point $= \pm \frac{n\pi}{a}$

The allowed eigen values are.

$$E = \frac{\hbar^2 k^2}{2m}$$

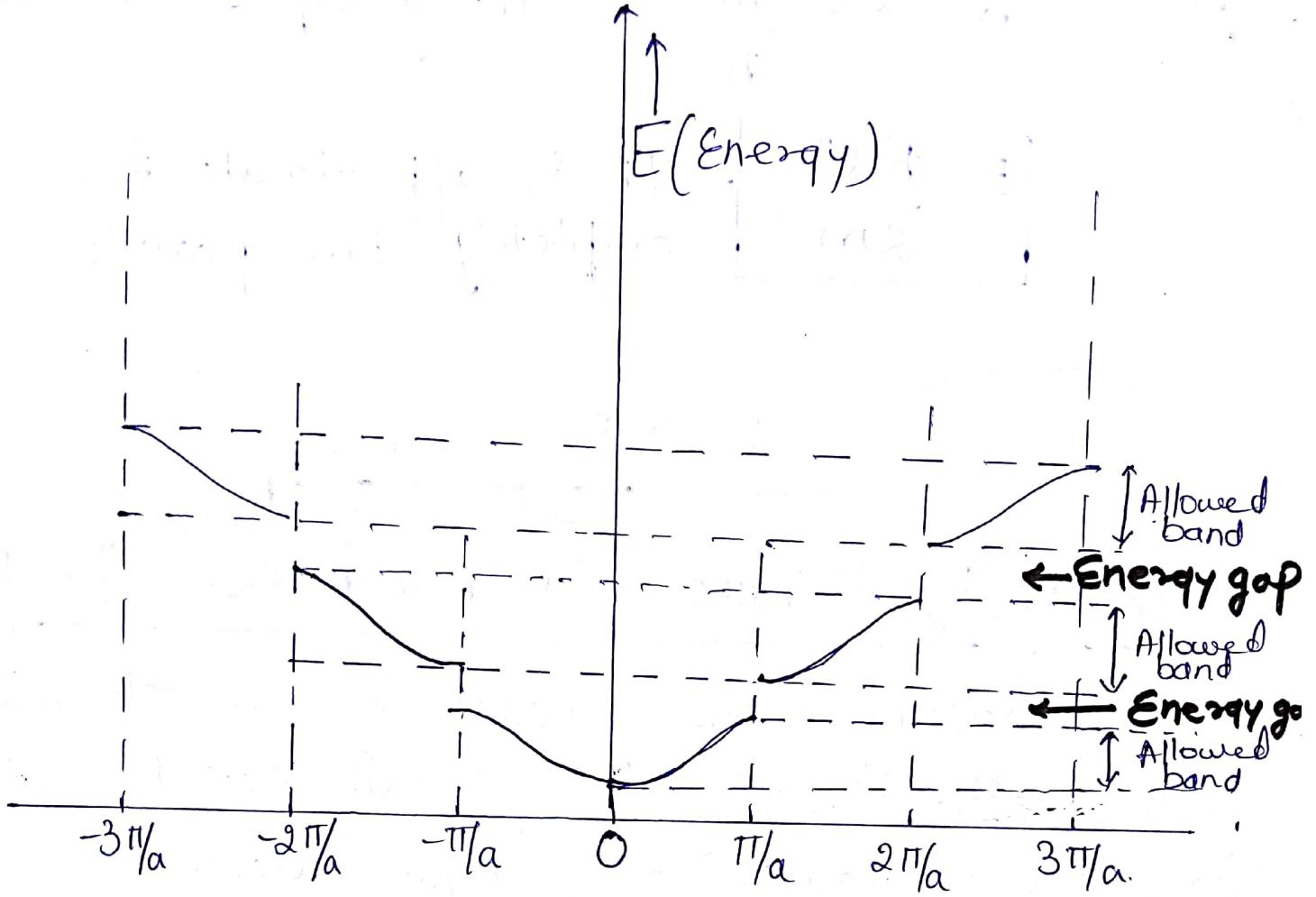
————— (±)

where k = wavenumber ($k = \pm \frac{n\pi}{a}$)

n = values ($n = \pm 1, \pm 2, \pm 3, \dots$)

a = Atomic periodicity.

Eq (1) gives E-k Curve. Due to discontinuities in Energy values (Energy Gaps), the parabola is discontinuous



from fig. Electron has allowed Energy band from $k = +\pi/a$ to $-\pi/a$ (called first Brillouin zone) similarly in second zone consist of two parts one extending from π/a to $2\pi/a$ & another is from $-\pi/a$ to $-2\pi/a$. These zone boundaries represent maximum energy of electron without discontinuity. In Between these allowed energy bands there will be finite gap called forbidden gap or band gap

Energy bands in Solids:-

We know electrons of atoms rotates around their nuclei in certain permitted energy levels. The electrons present in the inner shells are strongly bounded to their nuclei while electrons present on outer shells are not strongly bounded to their nuclei. The electrons present in the outermost shells are called valence electrons.

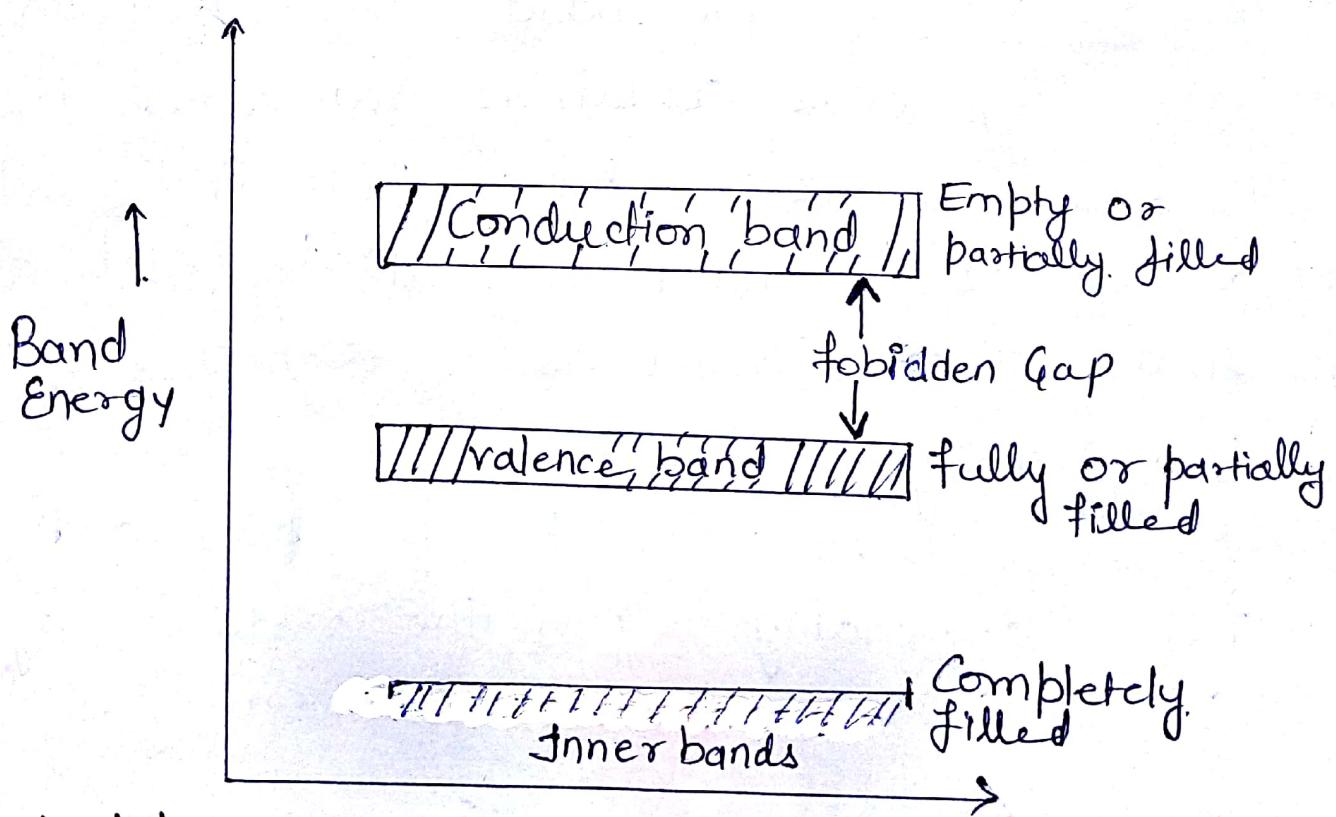
Valence band The band formed by series of energy levels containing valence electrons is known as valence band. Thus valence band defined as "a band formed by valence electrons or a band having highest occupied band energy."

→ Valence band may be partially or completely filled depending upon the nature of crystal. This band never be empty.

Conduction Band:- Some valence electrons are loosely attached to the nucleus. Even at ordinary temperature some of valence electrons left the valence

band. These are called free electrons. Free electrons are responsible for conduction of current in conductor hence also called conduction electrons. Thus Conduction band is "lowest unfilled energy band".

- ⇒ This band may be empty or partially filled. In Conduction band electrons can move freely.
- ⇒ Insulators have empty Conduction band.



forbidden Gap The separation between Conduction band & Valence band is known as forbidden Gap. There is no allowed

energy state in this gap. Hence, no electron can stay within forbidden energy gap.

- ⇒ Greater is the forbidden Energy Gap, more tightly the valence electrons bound to the nucleus.
- ⇒ In Order to push the electron from Valence band to Conduction band, External energy is required which is equal to forbidden Gap energy.

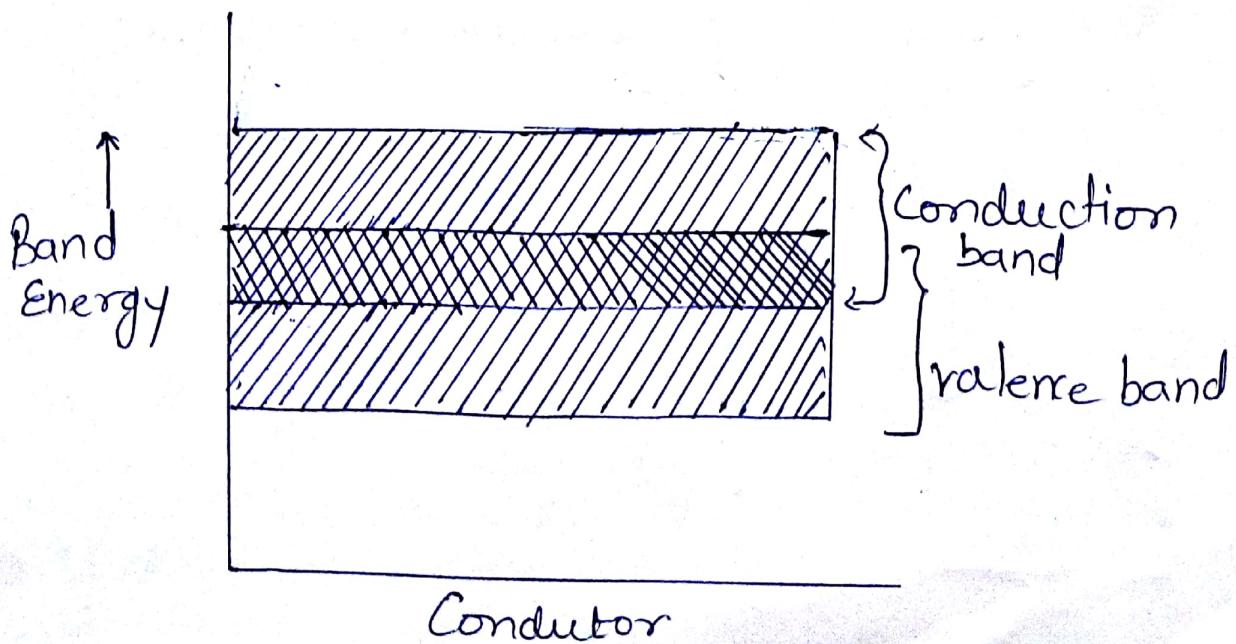
Types of Electronic materials:-

metal, semiconductor & insulator

In case of Conductors, there is no forbidden gap between Valence band & Conduction band (as shown in fig) Hence large no. of free electrons are available for conduction.

characteristic features of conductors:-

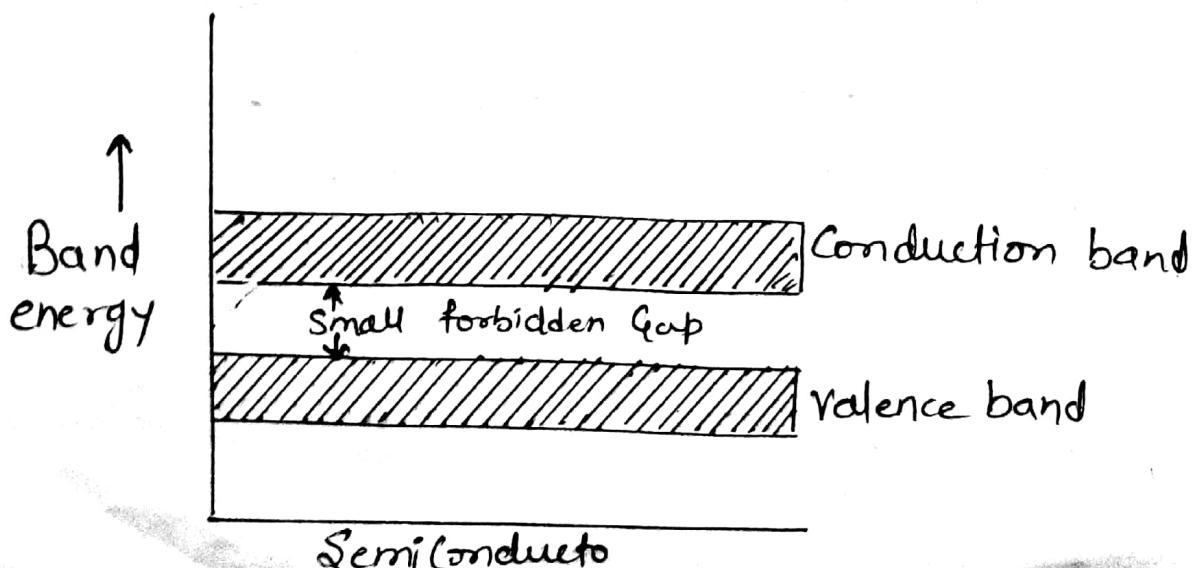
- ⇒ Large number of free electrons are available for conduction
- ⇒ There is no forbidden gap b/w Valence band & Conduction band
- ⇒ There is no structure to establish holes.
- ⇒ Total Current in Conductor is due to flow of Electrons



Semiconductors:- Semiconductor is one whose conductivity lies between insulators & conductors. At 0 Kelvin valence band is completely filled while conduction band is empty. So there is no conductivity at 0 K. But when small energy is supplied electron can easily jump from valence band to conduction band. Hence, conductivity increases as temp. increases.

Characteristic features of Semiconductors:-

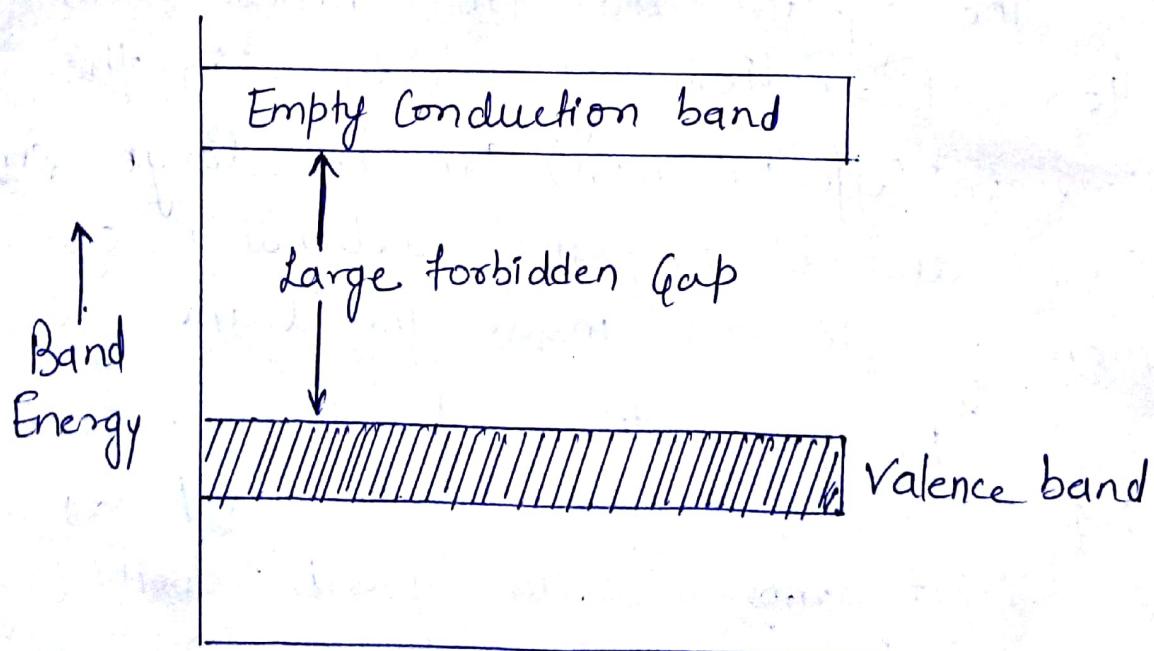
- ⇒ There is small forbidden gap. The forbidden gap for Ge = 0.7 eV & Si = 1.1 eV.
- ⇒ At 0K it behaves like insulators but as the temp increases, conductivity of semiconductors also increases.
- ⇒ Resistivity varies from 10^{14} to 10^{-7} ohm metre.
- ⇒ Their electrical properties lies b/w Conductors & insulators.



Insulators :- In insulators forbidden gap is very wide, (as shown in fig.). Due to this fact electrons can't jump from valence band to conduction band for e.g. glass, wood etc.

Characteristic features of Insulators :-

- ⇒ Insulators have filled valence band
- ⇒ They have empty conduction band
- ⇒ forbidden gap is very wide (≈ 5 to 10 ev)
- ⇒ Resistivity is very high
- ⇒ Under the influence of electric field their conductivity is zero



Concept of Effective mass

or

Effective Mass

When motion of electron is Considered to be in periodically varying potential, then the mass of electron changes. Under the application of Electric field at some portion electron will accelerate with electric field strength while at some portion it de-accelerate.

The mass of electron under periodically varying electric field is known as "effective mass of electron". represented by (m^*)

The effective mass (m^*) varies with direction of motion of electron in the lattice. m^* (effective mass) can be large, small even can also be negative depending on position of electron inside the lattice.

According to de-broglie electron moving with velocity is considered as a wave packet moving with group velocity (v_g)

$$v_g = \frac{dw}{dk} \quad \text{--- (1)}$$

we know $E = h\nu$

$$E = \frac{h}{2\pi} 2\pi\nu \quad (10)$$

(Multiply num. &
Deno. by 2π)

$$E = \frac{h}{2\pi} \omega \quad (\text{as } \omega = 2\pi\nu)$$

Now,

$$dE = \frac{h}{2\pi} d\omega \quad (\text{on differentiation})$$

$$d\omega = \frac{2\pi}{h} dE$$

Now, put the value of $d\omega$ in Eq (1)

$$V_g = \left(\frac{2\pi}{h}\right) \frac{dE}{dk} \quad (2)$$

Now, acceleration of electron is

$$a = \frac{2\pi}{h} \frac{dE}{dt} \left(\frac{dE}{dk}\right)$$

$$a = \frac{2\pi}{h} \frac{d^2E}{dk^2} \left(\frac{dk}{dt}\right) \quad (3)$$

Now; the quantity $\frac{d^2E}{dk^2}$ can be calculated from E-K Curve

Now, we have to find out value of $\left(\frac{dk}{dt}\right)$

So, let us consider an electron is subjected to electric field of strength (E) for time dt . If velocity of electron is v_g .

Now, work done (dE) is

$$dE = eE \nu_g dt$$

$$dE = eE \left[\frac{2\pi}{h} \left(\frac{dE}{dk} \right) dt \right] \text{ using Eq(1)}$$

Now,

$$\frac{dE}{dt} \times \frac{dk}{dE} \times \frac{1}{dt} = \left(\frac{2\pi}{h} \right) eE$$

$$\frac{dk}{dt} = \left(\frac{2\pi}{h} \right) eE$$

Now, put the value of $\frac{dk}{dt}$ from above Eq in Eq(3).

$$a = \left(\frac{2\pi}{h} \right) \frac{d^2E}{dk^2} \left[\frac{2\pi}{h} eE \right]$$

$$a = \left(\frac{4\pi^2}{h^2} \right) eE \frac{d^2E}{dk^2}$$

or

$$a = \frac{eE}{\left(h^2/4\pi^2 \right) \left(\frac{d^2E}{dk^2} \right)^{-1}} \quad (4)$$

In free classical particle

$$m \frac{dr}{dt} = eE$$

$$(\because F=ma) \\ (eE=m \frac{dr}{dt})$$

$$\frac{dr}{dt} = \frac{eE}{m} = a \quad (5)$$

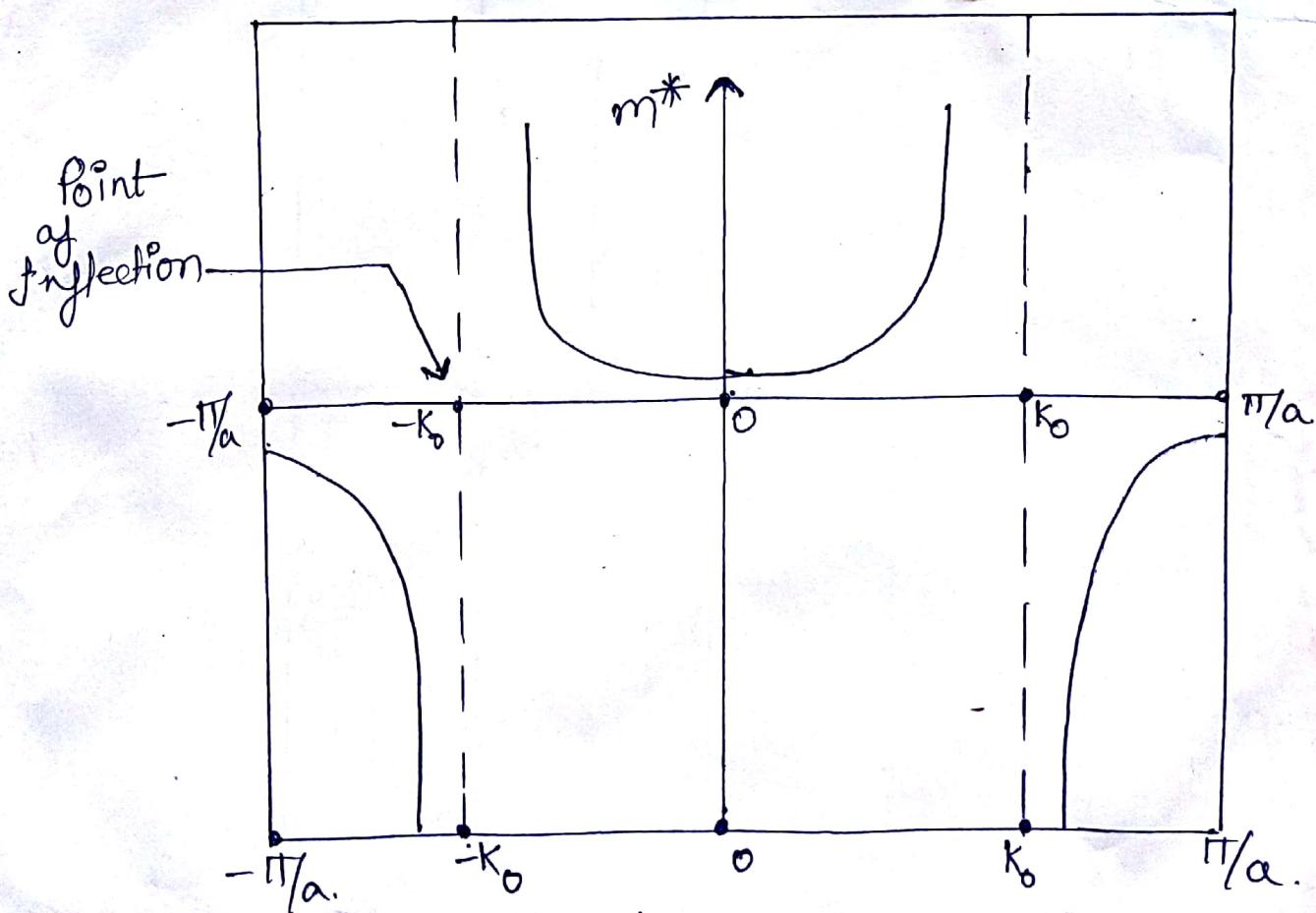
On comparing Eq (4) & (5)

$$m^* = \left(\frac{h^2}{4\pi^2} \right) \left(\frac{d^2 E}{dk^2} \right)^{-1}$$

$$m^* = \frac{\hbar^2}{d^2 E / dk^2}$$

$$\because \hbar = \frac{h}{2\pi}$$

So, effective mass is not constant but depends on the value of $d^2 E / dk^2$ (shape of E-k curve). fig shows variation of effective mass as a function of k.



Variation of m^* with k .

from Graph

- (1) Near $k=0$; effective mass approaches to m
- (2) As the value of k increases, effective mass m^* increases, and reaches its maximum value at point of inflection, m^* is
- (3) Above the point of inflection, m^* is negative and as $k \rightarrow \pi/a$, it decreases to small negative value.
So, effective mass m^* may be greater, smaller or even negative than mass (m) of electron.
-

Occupation Probability.

OR

Fermi-Dirac Distribution function

Fermi-Dirac distribution function which express the probability distribution of electrons among various energy levels of a material under thermal equilibrium condition. If is represented by $f(E)$, is given by

$$f(E) = \frac{1}{e^{(E-E_F)/k_B T} + 1}$$

where E_F = Fermi Energy

k_B = Boltzmann constant

T = Temp

Case-1

when $T=0$ & $E < E_F$ then

$$f(E) = \frac{1}{e^{-\infty} + 1} = \frac{1}{0+1} = 1$$

It means at $T=0$, all the levels below Fermi level are occupied.

Case - 2

When $T=0$ & $E > E_F$ then,

$$f(E) = \frac{\frac{1}{2}}{e^{\infty} + \frac{1}{2}} = \frac{\frac{1}{2}}{\infty} = 0$$

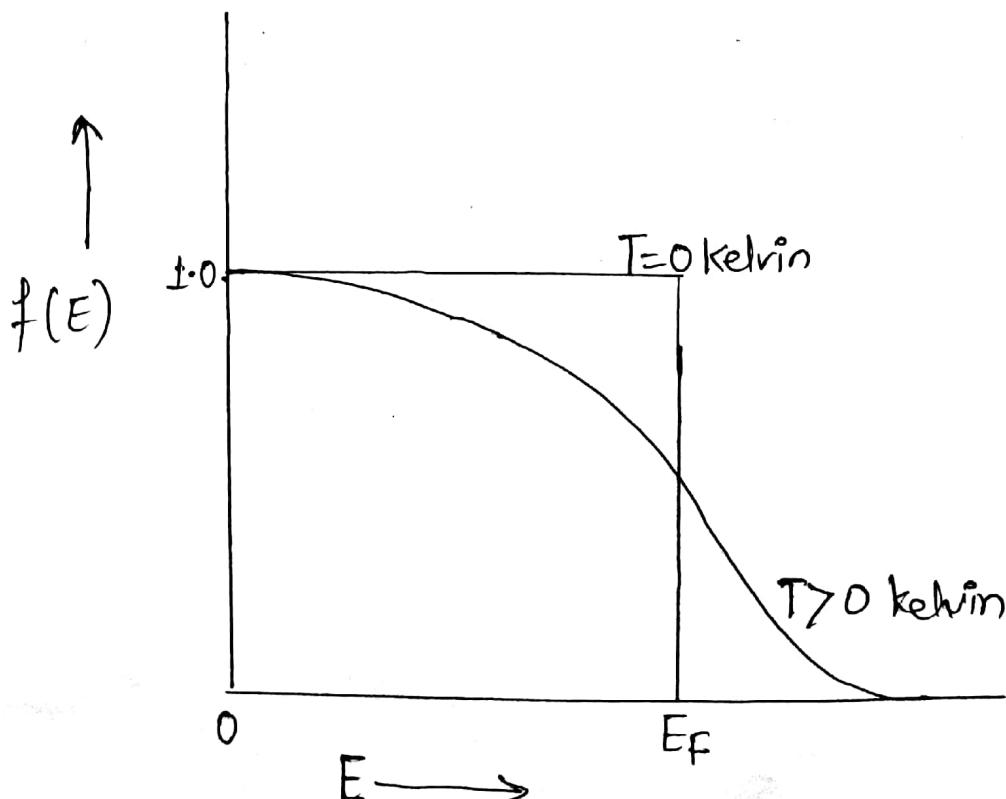
So, at $T=0$, all the energy levels above fermi level are vacant

Case - 3

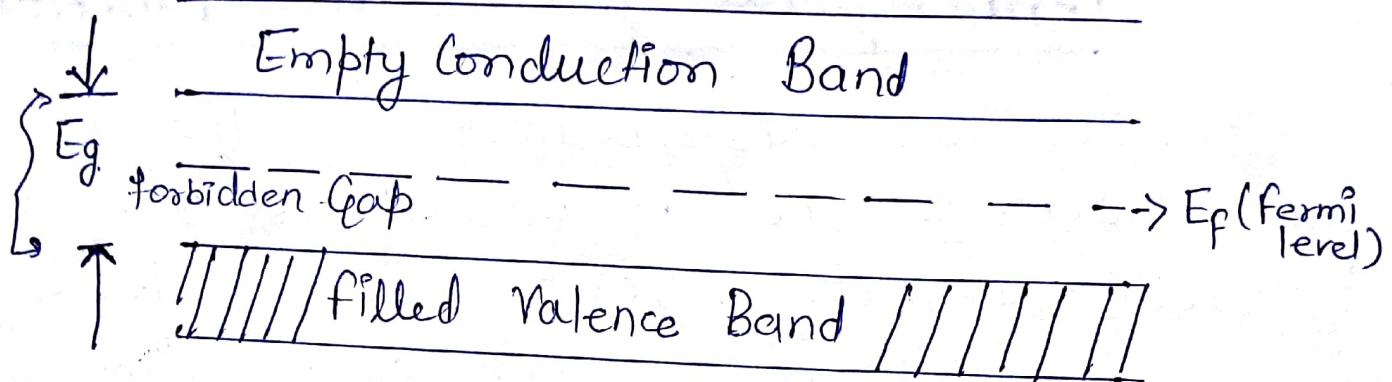
when $E=E_F$ & $T=0$ then

$$f(E) = \frac{\frac{1}{2}}{e^0 + \frac{1}{2}} = \frac{\frac{1}{2}}{1 + \frac{1}{2}} = \frac{\frac{1}{2}}{\frac{3}{2}} = \frac{1}{3}$$

So, fermi level is the state at which probability of electron occupation is $\frac{1}{2}$ at any temp. above 0 Kelvin & also it is the level of maximum energy of filled state at 0 Kelvin.



Fermi Level



Fermi level :- It refers to a characteristic energy of material. The level which divides the filled & empty level is called fermi level at absolute zero & corresponding energy is called fermi energy denoted by (E_F)

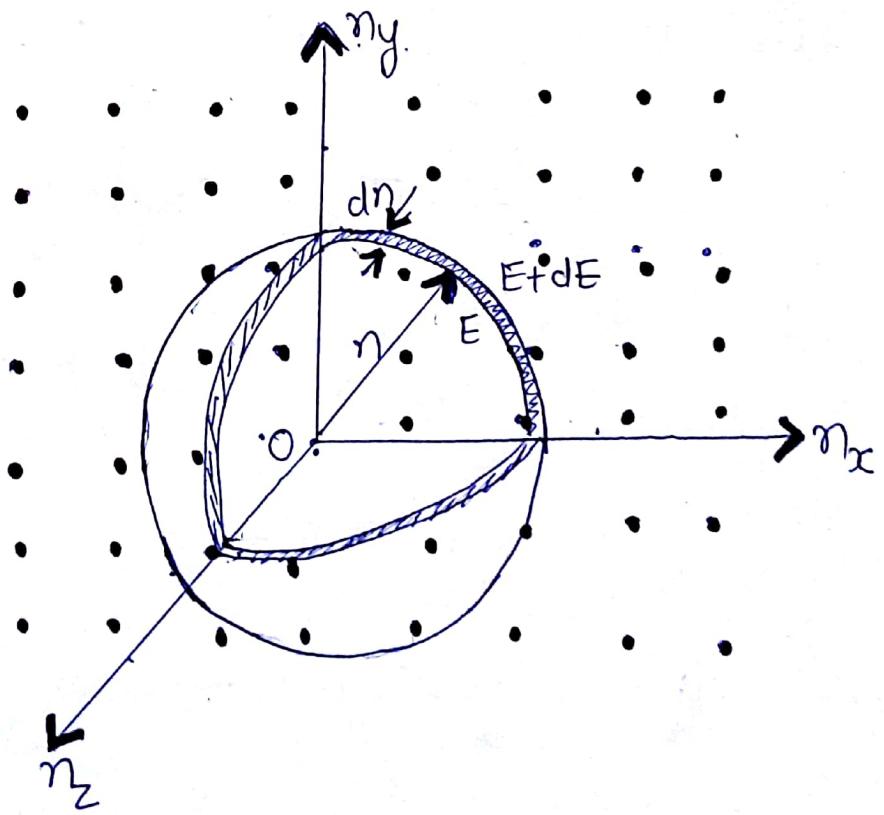
In case of intrinsic semiconductor concentration of e^- decreases above the bottom of conduction band similarly, concentration of holes decreases below the top of valence band. Thus centre of gravity of e^- & holes lie at middle of forbidden gap.

In Intrinsic Semiconductors fermi level is lie in the middle between top of valence band & bottom of conduction Band.

Density of States

Density of States means Total number of electronic states per unit energy range i.e. E.

for this let us consider space of points n_x, n_y, n_z (quantum numbers). Here each point represent energy states. Now a radius vector n is drawn from origin to points n_x, n_y, n_z . All points in sphere with have same energy.



$$\text{Volume of sphere} = \frac{4}{3}\pi n^3$$

as n_x, n_y, n_z are positive so all the energy

States Octant of sphere (i.e.) $(\frac{1}{8})$ volume
of sphere.

$$\text{So, number of states within sphere} = \frac{1}{8} \left(\frac{4}{3} \pi n^3 \right) \quad (1)$$

Similarly,

$$\text{Number of states with sphere of radius } (n+dn) \text{ is} = \frac{1}{8} \left[\frac{4}{3} \pi (n+dn)^3 \right] \quad (2)$$

Now, number of energy states b/w E & $E+dE$
is given by (Subtracting Eq (1) + (2))

$$\begin{aligned} Z(E) dE &= \frac{1}{8} \left[\frac{4}{3} \pi (n+dn)^3 \right] - \frac{1}{8} \left[\frac{4}{3} \pi n^3 \right] \\ &= \frac{1}{8} \frac{4}{3} \pi [(n+dn)^3 - n^3] \\ &= \frac{\pi}{6} [n^3 + dn^3 + 3n^2dn + 3ndn^2 - n^3] \\ &= \frac{\pi}{6} [dn^3] \quad (\because dn \text{ is very small}) \\ Z(E) dE &= \frac{\pi}{6} n^2 dn \quad (3) \end{aligned}$$

$$\text{We know energy } E = \frac{n^2 h^2}{8\pi L^2}$$

$$n^2 = \frac{8\pi L^2 E}{h^2} \quad (4)$$

$$n = \left(\frac{8mL^2}{h^2} \right)^{1/2} E^{1/2} \quad (5)$$

Now, differentiating Eq (4)
we get

$$2n \, dn = \left(\frac{8mL^2}{h^2} \right) dE$$

$$dn = \frac{1}{2n} \left(\frac{8mL^2}{h^2} \right) dE \quad (6)$$

Now put Eq (5) & (6) in Eq (3)

$$Z(E) \, dE = \frac{\pi}{2} n (ndn)$$

$$= \frac{\pi}{2} \left(\frac{8mL^2}{h^2} \right)^{1/2} E^{1/2} \left[n \frac{1}{2n} \left(\frac{8mL^2}{h^2} \right) dE \right]$$

$$Z(E) \, dE = \frac{\pi}{4} \left(\frac{8mL^2}{h^2} \right)^{3/2} E^{1/2} dE$$

We know, pauli's exclusion principle permit
two electrons in each state,

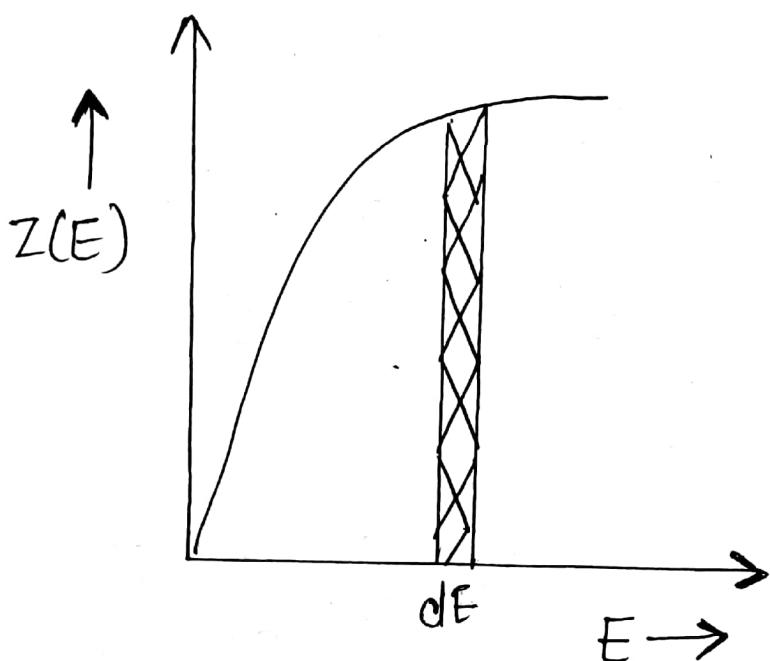
So number of energy levels actually available are.

$$Z(E) \, dE = 2 \times \frac{\pi}{4} \left(\frac{8mL^2}{h^2} \right)^{3/2} E^{1/2} dE$$

$$Z(E) \, dE = \frac{\pi}{2} \left(\frac{8mL^2}{h^2} \right)^{3/2} E^{1/2} dE$$

This expression shows $Z(E)$ is parabolic function of E as shown below

from fig. $\therefore \underline{Z(E) \text{ increases with}} \\ \underline{\text{increase in crystal volume.}}$



Graph b/w density of states versus energy

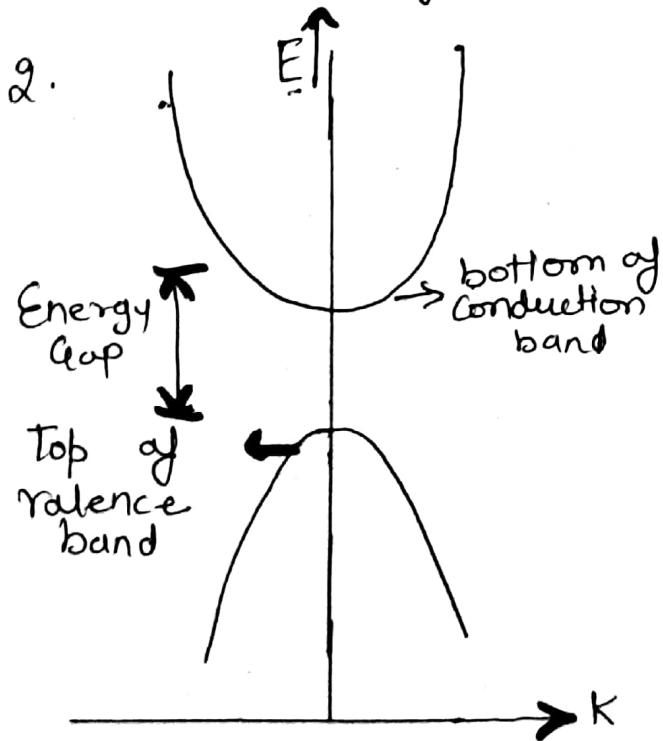
If $V = L^3 = 1$ (for simple cubic)

$$Z(E) dE = \frac{\pi}{2} \left(\frac{8m}{h^2} \right)^{3/2} E^{1/2} dE$$

Direct & Indirect band Gap

Direct Band Gap

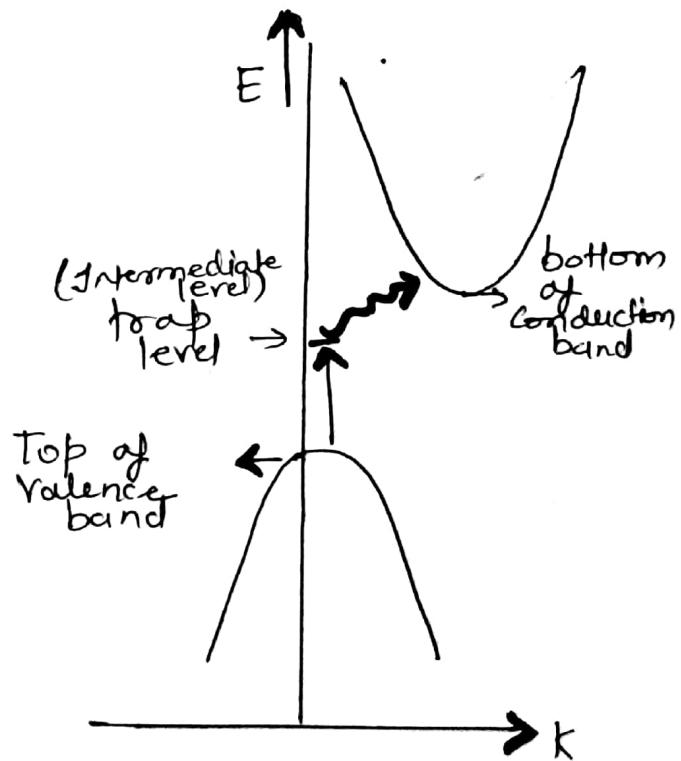
1. Direct band Gap
Semiconductor have top of valence band & bottom of conduction band lies at the same value of k



2. Direct band Gap
Semiconductor e^- excite from valence band to conduction band directly. There is no involvement of intermediate state

Indirect band gap

1. In-Direct band Gap
In semiconductor the top of valence band & bottom of conduction band lies at different values of k .



2. Indirect Semiconductor.
 e^- can't directly excite from valence band to conduction band while, if firstly excited to trap (intermediate level) & then to conduction band

3. Probability of radiative recombination is high

4. Efficiency of direct band Semiconductor is higher. Thus direct band Semiconductors are always preferred over indirect band gap Semiconductors for making optical sources.

5. Example :- Gallium Arsenide (GaAs), Cadmium Sulphide (cds) etc.

3. Probability of radiative recombination is low.

The efficiency of indirect band Gap Semiconductor is lower

Example :- Silicon, Germanium etc.

Phonon

Phonon comes from Greek word "Phone", which means sound or voice because long wavelength phonon give rise to sound.

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A phonon is quantum mechanical description of vibrational motion in which a lattice of atoms or molecules uniformly oscillates at a single frequency. They follow Bose-Einstein statistics. Phonon also follow both particle & wave nature. but doesn't carry physical momentum, but if interact with other particles & fields then resultant momentum is called crystal momentum.

Difference b/w Photon & Phonon

Photon

1. It is quanta of energy in electromagnetic wave
2. It travel with velocity of light
3. Photon do not require any medium for propagation i.e. they can travel in vacuum.
4. Transition between different Energy level of electron emit photon.

Phonon

1. It is quanta of energy of elastic wave.
2. It travel with velocity of sound in solids
3. Phonons required medium to propagate as they can't travel in vacuum.
4. Vibration of atoms & molecules produce phonon.

5. Photons do not interact with each other if they have different wavelength.

5. Phonons at different frequencies can mix together & generate superimposed wavelength.