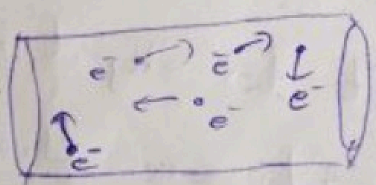
EC-204
Assignment

J.Abhinav
9201150

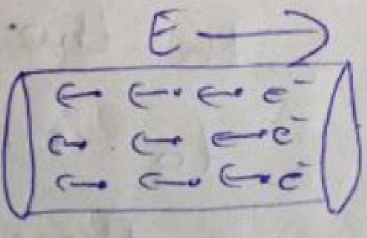
① In a conductor when temperature is increased resistivity increases.
A conductor contains a large number of loosely bound electrons called as free electrons, also the positive part of the atom i.e nucleus is fixed in its position, this is called lattice. So, in absence of electric field, electrons move freely in all directions. The number of electrons moving from left to right is equal to right to left, so there is no current flow. Sometimes the electron can collide with the positive lattice and come to rest. The path of electron will thus be uncertain. But when electric field is applied, electrons move opposite

to that of electric field, at this time they may be accelerated because of externally applied electric field. At the same time, they can also collide with positive ions i.e lattice and halt and agin move because of electric field. Thus the electron moves with a drift velocity. It is the average velocity of all the electrons



net $I = 0$

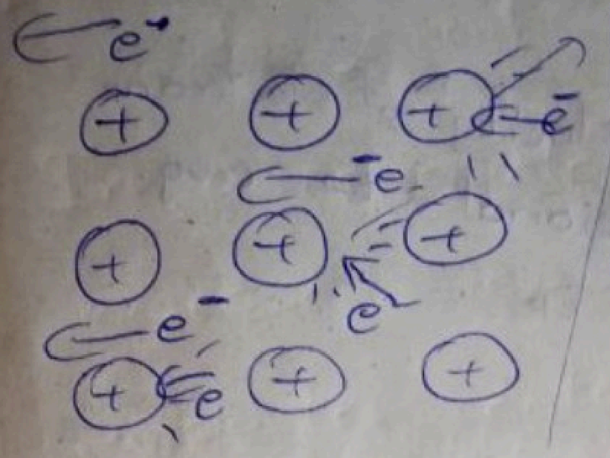
Electrons move in random directions because of thermal energy.



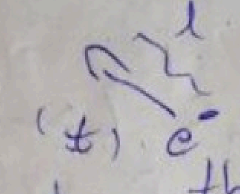

$I \neq 0$

In presence of electric field, they move in ordered motion.

Electrons keep drifting, they halt when they strike lattice and again regain energy becoz of electric field,



The electrons collide frequenty with lattice.




Let 'l' be the drift distance travelled by an electron in time 't'.

Then drift velocity

$$V_d = \frac{l}{t}$$

Let the avaroge time that an electron takes between successive collisions be 'T', then we know.

$(\because s = ut + \frac{1}{2}at^2;\ u = 0)$

$$l = \frac{1}{2} a_e (T)^2 \qquad m = m_e = \text{mass of } e^-$$

$$F_e = m_e a_e \qquad a_e = \frac{Eq}{m}$$

$$qE = m_e a_e \Rightarrow$$

$$l = \frac{1}{2} \frac{Eq}{m} (T)^2$$

$$V_d = \frac{l}{T} = \frac{1}{2} \frac{Eq\,(T)^{\cancel{2}}}{m\cancel{T}} = \frac{1}{2}\left(\frac{Eq}{m}\right) T$$

$$\boxed{V_d \propto \tau}$$

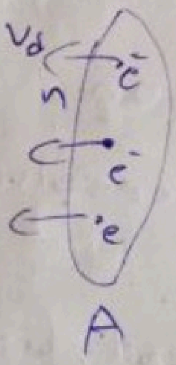
Hence, the drift velocity of electrons is directly proportional to avg. collision time.

we know,

$J \Rightarrow$ Current density

$J = \frac{I}{A} = \sigma E$ ($\because$ Ohm's law $J = \sigma E$)

we also, $J = \frac{I}{A} = \underline{neV_d}$




Let 'n' no. of electrons move through a cross-sectional area 'A', each having charge 'q', crossing in time $\Delta t$, with drift velocity '$V_d$'. Then net charge ($\Delta Q$)

$$\Delta Q = n V_d A \Delta t q$$

$$I = \frac{\Delta Q}{\Delta t} = \frac{n V_d A \cancel{\Delta t} q}{\cancel{\Delta t}} = n V_d A q$$

$$J = \frac{I}{A} = \frac{n V_d \cancel{A} q}{\cancel{A}}$$

$$\boxed{J = n V_d q}$$

From Ohm's law

$J = \sigma E$

$\sigma = \frac{1}{\rho}$ $\rho \to$ resistivity

$\sigma \to$ conductivity.

$n V_d q = \sigma E$

$n V_d q = \frac{E}{\rho}$

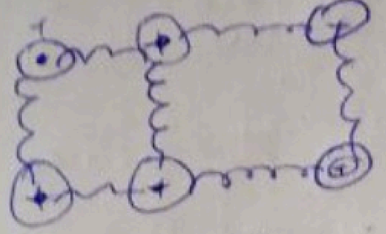
$\rho = \frac{E}{n V_d q} = \frac{E}{n\left(\frac{1}{2}\right)\frac{E q}{m}\tau q}$

$\rho = \left(\frac{2 E m}{n E q^2}\right)\tau$

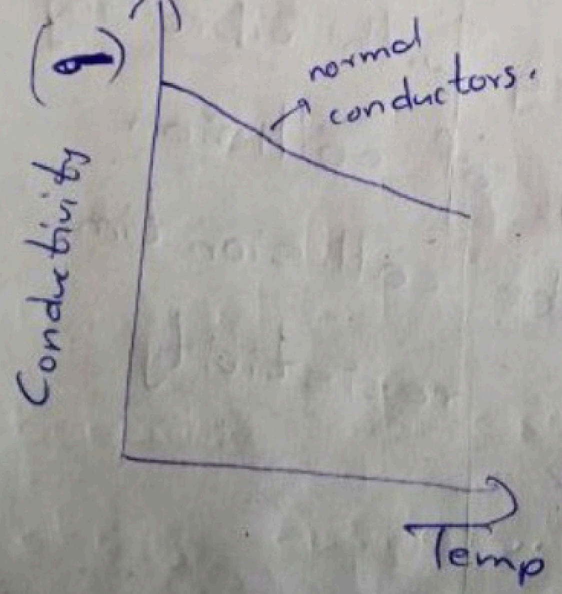
$\boxed{\rho \propto \frac{1}{\tau}}$

As, temperature increases, atoms in a conductor start vibrating as they absorb energy. As, now there is more of an electron colliding with vibrating lattice. So, frequency of collision increases $\left(f = \frac{1}{\tau}\right)$, so, the collision time decreases. As $\rho \propto \frac{1}{\tau \downarrow}$, resistivity increases.

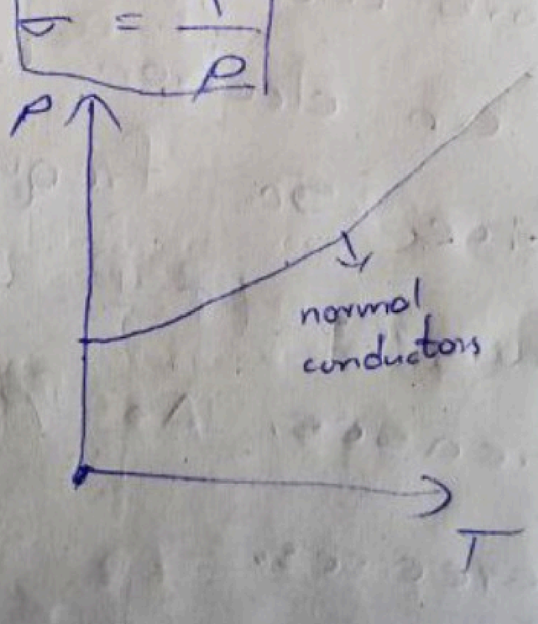
The positive ions keep vibrating about their positions. Like springs are connected between



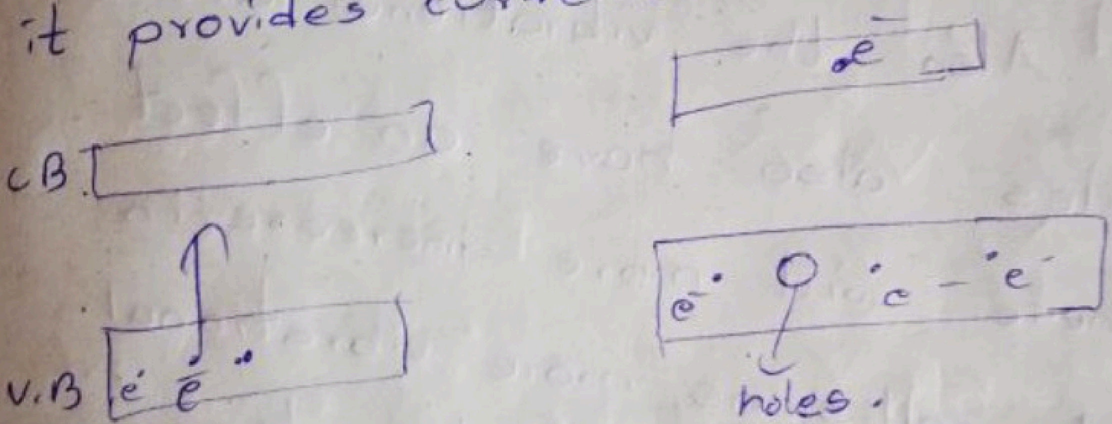
them. More is the temperature, more is the vibrational frequency. Hence lesser the average collision time (or) relaxation time ($\tau$). More is the resistivity as electrons collide more often at higher temperature. This is the case in conductors but in Semiconductors (S.C) there is a ~~cho~~ reverse.




$$\boxed{\sigma = \frac{1}{\rho}}$$



In semiconductor solid, there is an energy band. One, is the valence band where electrons are bounded to nuclei and do not help in conducting electricity or current.
But if electron is in conduction band, that $e^-$ is free electron & it provides current.




The removal of electron from V.B by supply of heat e.t.c creates a positive charge carrier called holes. Both these electrons & holes are responsible for conductivity in a semi conductor.

If temperature is increased, the avg. energy of electron and positive lattice is also increased. Electrons gain energy and break bonds in V.B and move to conduction band. Similarly holes will also increase. Overall as charge carriers are increased, conductivity increases.

Also, the vibrational lattice molecules also have an effect as there will more increase in thermal collisions, more vibrational frequency, lesser relaxation time

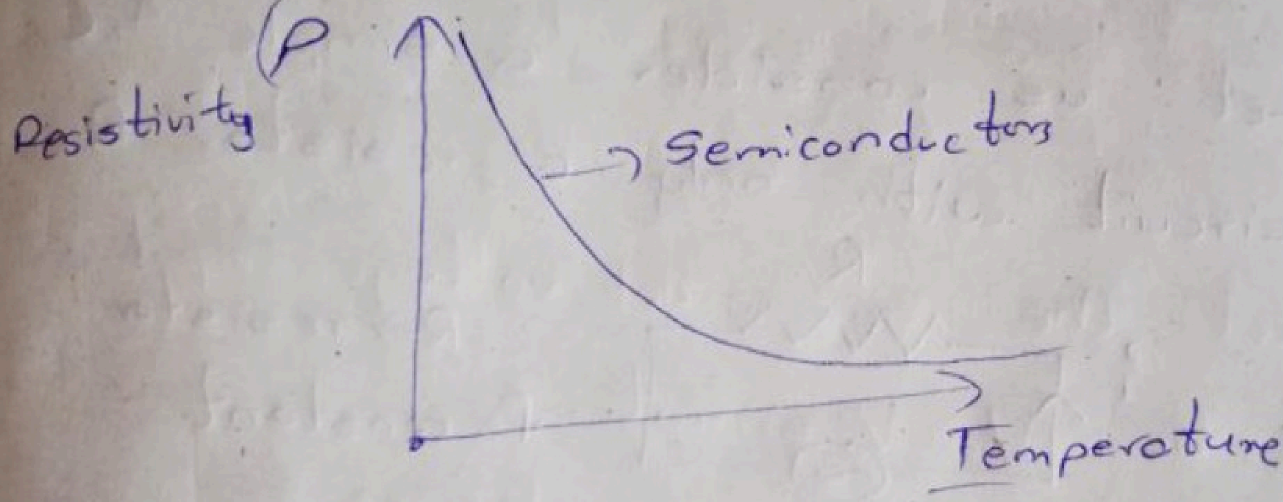
$$\sigma \propto \frac{1}{\rho}$$

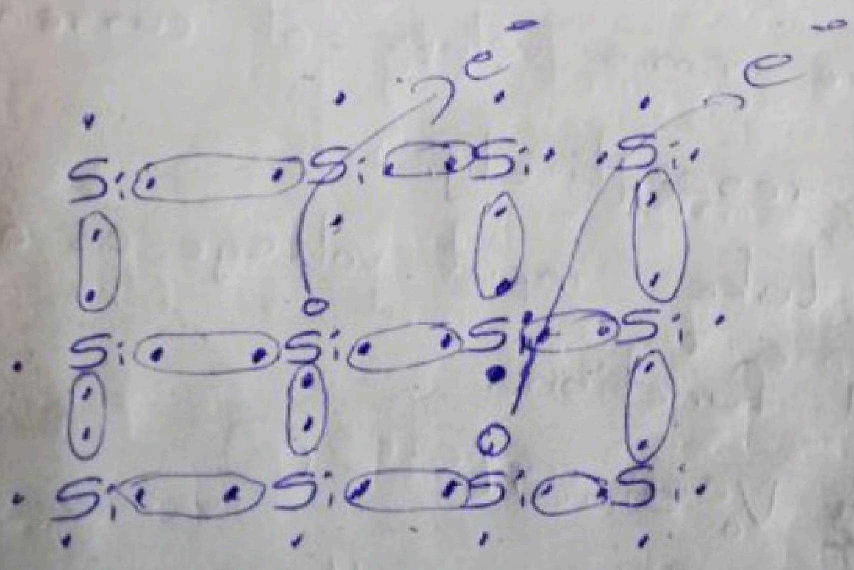
$$\boxed{\rho \propto \frac{1}{\tau}}$$

$\Downarrow$

This effect is negligible in S.C, because of excessive formation of charge carriers.

Thus, for Semiconductors with increasing temperatures, resistivity decreases (or) conductivity increases. It is exactly opposite of what we saw in metals.



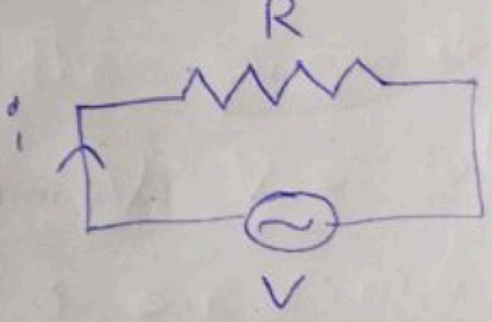



J.Abhinav 9201150

(2) Phase difference ~~is~~ between A.C current & voltage is '0' for resistor & 90° for capacitor (current leads) & -90° for inductor (current lags).

For Resistor:

Let us consider a simple A.C circuit with only a resistor 'R'.




R → resistor

f = constant

$i_{rms}$ & $V_{rms}$ are r.m.s values of current & voltage respectively.

Let us take input voltage as a sinusoidal function.

$$V_{rms} = V_0 \sin\omega t \quad \text{— (1)}$$

$V_0$ → instantaneous voltage

$\omega$ → frequency

For A.C we know

sinusoidal → $V = \frac{V_0}{\sqrt{2}}$ & $i = \frac{i_0}{\sqrt{2}}$

From Ohm's law we can write

$V_{rms} = I_{rms} R$ $\quad I_{rms} = i$

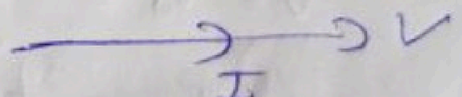
$V_0 \sin\omega t = I_{rms} R$

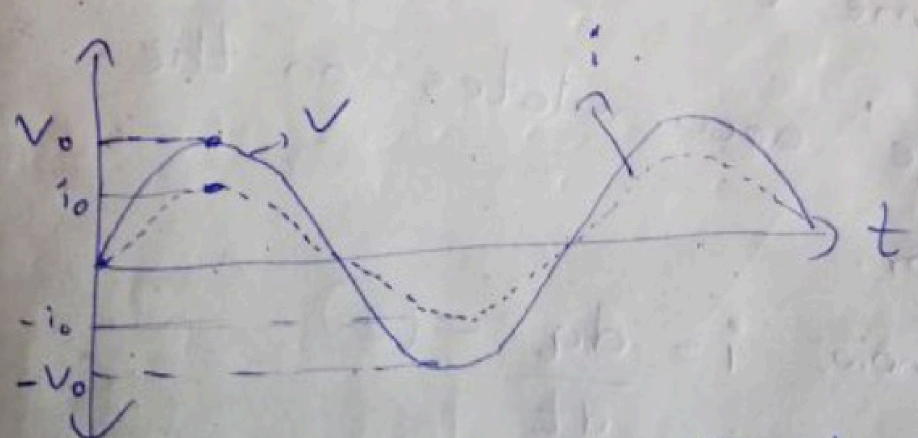
$i = \frac{V_0}{R} \sin\omega t$

$i_{rms} = i_0 \sin\omega t$ — (2)

Comparing (1) & (2) we see that V & i are having same phase.

As, they are in same phase the phase difference between current & voltage is '0' for a resistor.



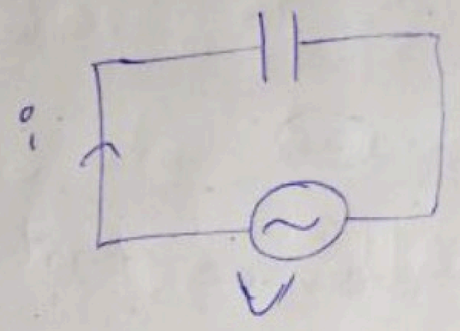




V & i signals with function of time, assuming 'ω' as constant.

For a Capacitor:

Considering a purely capacitor A.C circuit having sinosoidal voltage source with constant frequency,

C



Let the sinosoidal voltage input be $V = V_0 \sin\omega t$

V & i are r.m.s voltages & current respectively

$V = V_0 \sin\omega t$ — ①

At a time 't' current 'i' flows, where 'q' charge accumulates on the capacitor.

we know, $i = \frac{dq}{dt}$ — ②

Rate of flow of charge is current.

we know, $C = \frac{Q}{V}$ — (3)

C → Capatience.

V → Voltage

Q → charge

$C = \frac{q}{V}$

$CV = q$

$q = C V_0 \sin\omega t$

Diff. w.r.t 'time'

$\frac{dq}{dt} = C V_0 \frac{d}{dt}(\sin\omega t)$ from eq^n (2)

$i = \omega C V_0 \cos\omega t$

$i = C V_0 \omega \cos\omega t$

let, $C V_0 \omega = i_0$

$V_0 = \frac{i_0}{\omega C}$ comparing with $V = IR$

The resistance component will be $\left(\frac{1}{\omega C}\right)$.

Here we call it as reactance $(X_c)$

$X_c = \frac{1}{\omega C}$

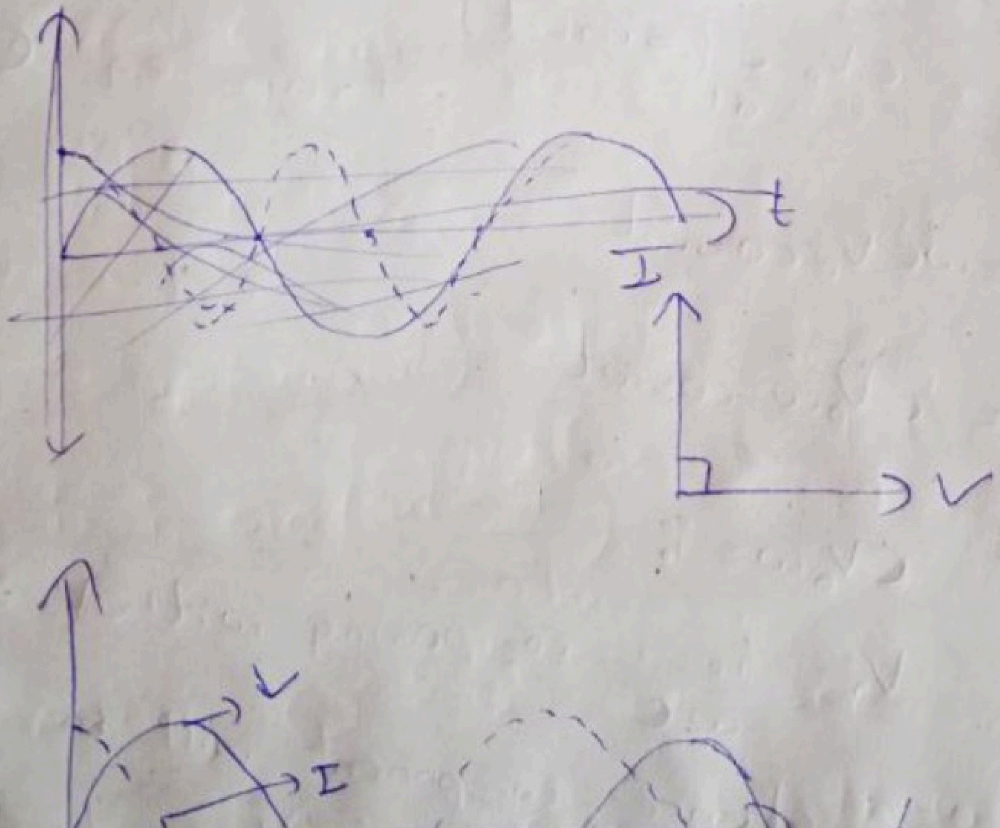
$i = i_0 \cos\omega t$

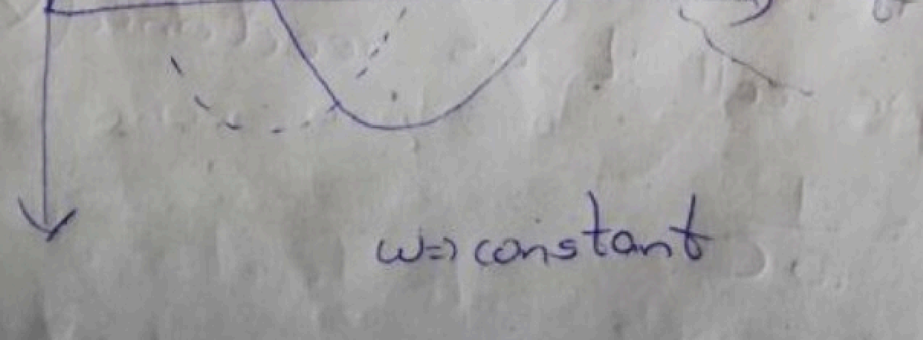
$i = i_0 \sin\left(\omega t + \frac{\pi}{2}\right)$ — (4)

Comparing $V$ & $i$ re (1) & (4)

we see $i$ leads voltage by a phase of $\left(\frac{\pi}{2}\right)$ (or) $90°$

Thus, for a capacitor current leads the voltage by $90°$ (or) $\frac{\pi}{2}$.



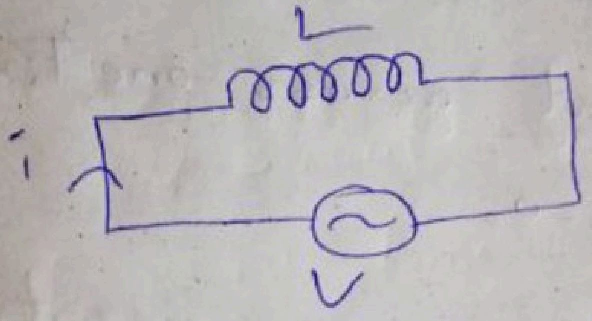




$\omega \Rightarrow$ constant

For an Inductor :

Consider a purely inductive 'AC' circuit. voltage & is sinosoidal, with constant frequency.

$V$ & $i$ are r.m.s voltages & current.



now, $V = V_0 \sin\omega t$ — ①

we know for an inductor voltage across 'L' is $V_L = L\frac{di}{dt}$

By Kirchoff's Loop law, we get

$$V - V_L = 0$$

$$V_0 \sin\omega t - L\frac{di}{dt} = 0$$

$$V_0 \sin\omega t = L\frac{di}{dt}$$

$$\frac{di}{dt} = \frac{V_0}{L}\sin\omega t$$

Integrating we get,

$$\int \frac{di}{dt} = \int \frac{\epsilon_0}{L} \sin \omega t$$

$$i = -\frac{\epsilon_0}{\omega L} \cos \omega t + c$$

c is a constant, now as we see avg. of cos ωt across one Time period is 0. c = 0.

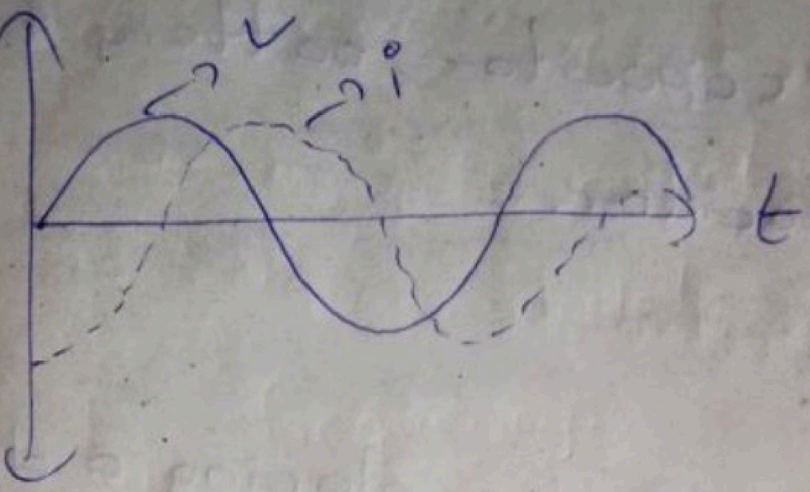
$$i = -\frac{\epsilon_0}{\omega L} \cos \omega t$$

let $\frac{\epsilon_0}{\omega L} = i_0$

$$i = i_0 (-\cos \omega t)$$

$$i = i_0 \sin\left(\omega t - \frac{\pi}{2}\right) \quad -(2)$$

Comparing (1) & (2) we see that current "i" lags with voltage by a phase angle of $-\frac{\pi}{2}$ (or) $-90°$.



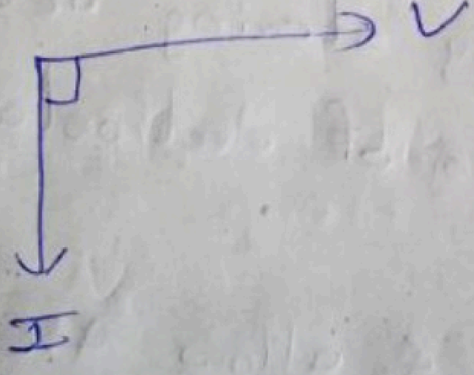

V & i variation with time

$\omega \Rightarrow$ constant

So, for an inductor, current lags the voltage by $90°$,

(or)

Voltage leads the current by $90°$.



J. Abhinav 9201150

(3) Diff. b/w capacitor, battery & Supercapacitor.

Capacitor:

→ It is made by placing a dielectric material between the metal plates.

→ They charge and discharge almost instantaneously.

→ It is a passive component.

→ Its range is very small i.e μF to mF.

→ It is a energy storing device and stores in form of electrostatic energy.

→ They block D.C & allow A.C signals.

→ It is widely used as motor starters in domestic appliances.

→ It is almost present in every electronic device.

Battery:-

⇒ It also stores energy in the form of chemical energy.

→ It is an active component.

⇒ Used in D.C circuits only

⇒ It charges & discharges slowly

⇒ It releases energy slowly where as capacitor releases bulk energy in a very short time

⇒ There are battery of various ranges.

⇒ Unit to measure battery power is Ampere per hour. (Ah).

→ Lifetime is less.

Supercapacitor:

⇒ It is a double layered capacitor with an electrolyte in place of dielectric.

⇒ It has higher capatience in range of 1F & 10F.

⇒ It releases much energy in smaller time.

⇒ Energy storage capacity is lower than of batters but higher than than capacitors.

⇒ Used in flash lights, laptops e.t.c.

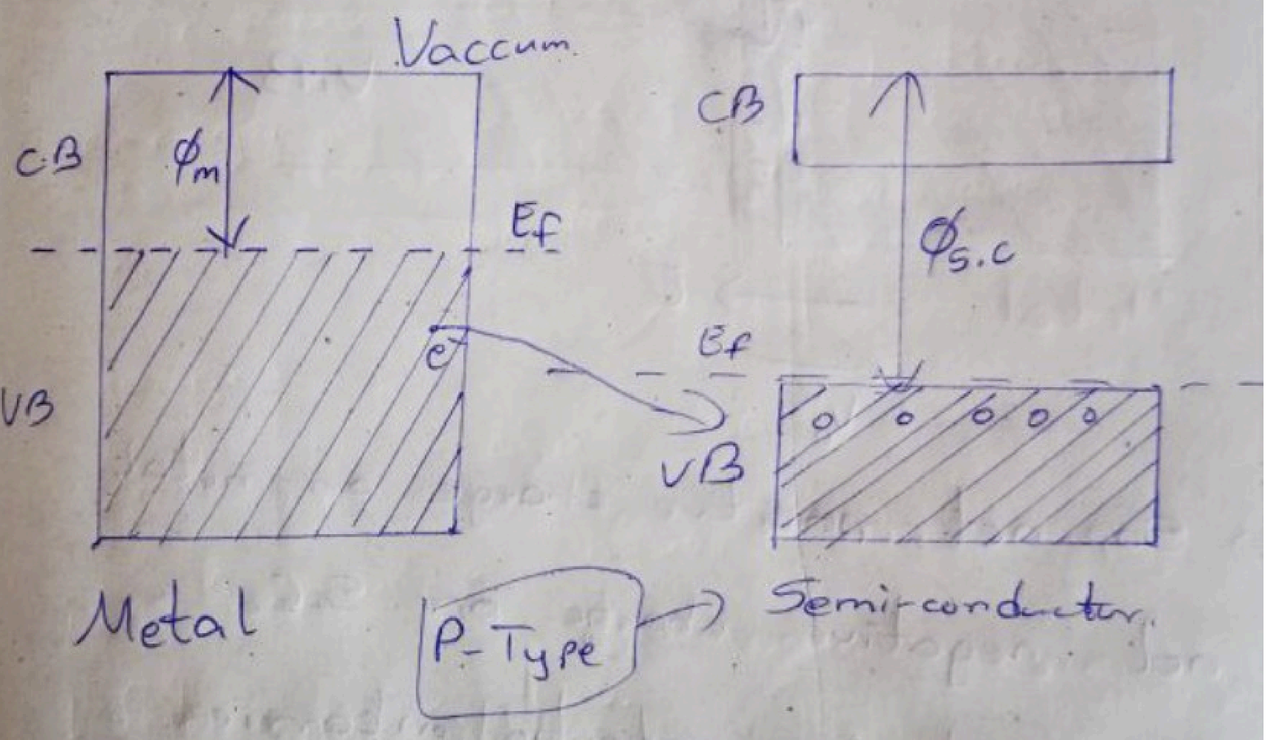
J. Abhinav 9201150

④ Energy band bending diagram for P-type metal-semiconductor.

Schottkey Junction :

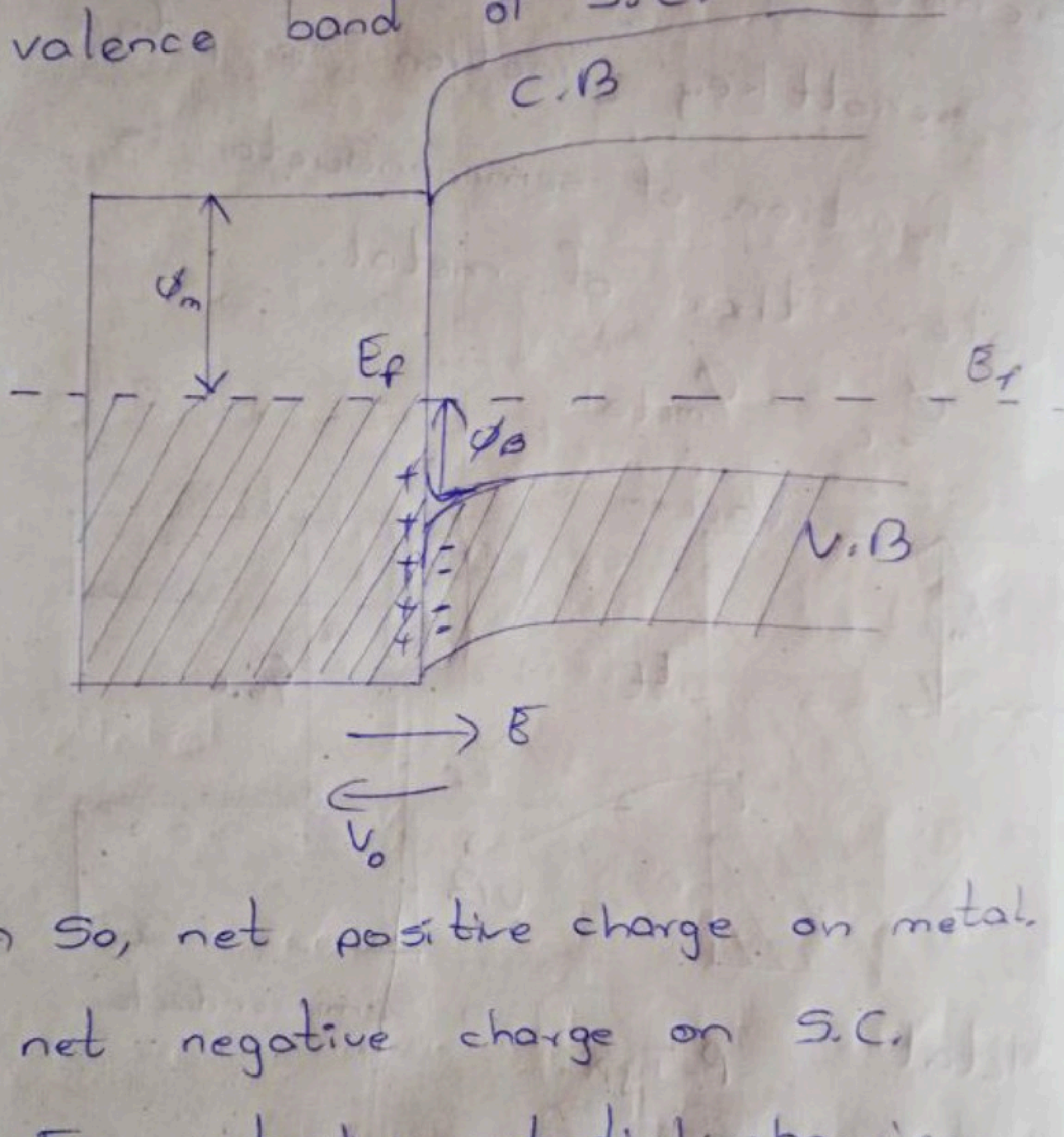
→ In schottkey junction for p-type work function of semiconductor is greater than of metal.

$\phi_{s.c} > \phi_{metal}$




→ At junction formation both fermi levels line up at thermal equilibrium. Here, barrier will form.

→ As work function of metal is low w.r.t S.C, electrons from metal move & fill up the holes in valence band of S.C.




→ So, net positive charge on metal. net negative charge on S.C.

→ ~~For~~ retarding potential (or) barrier potential of holes is $\phi_B$, which must be overcomed in order for current to flow. Hence, current flows only in one direction.

# Ohmic Contact

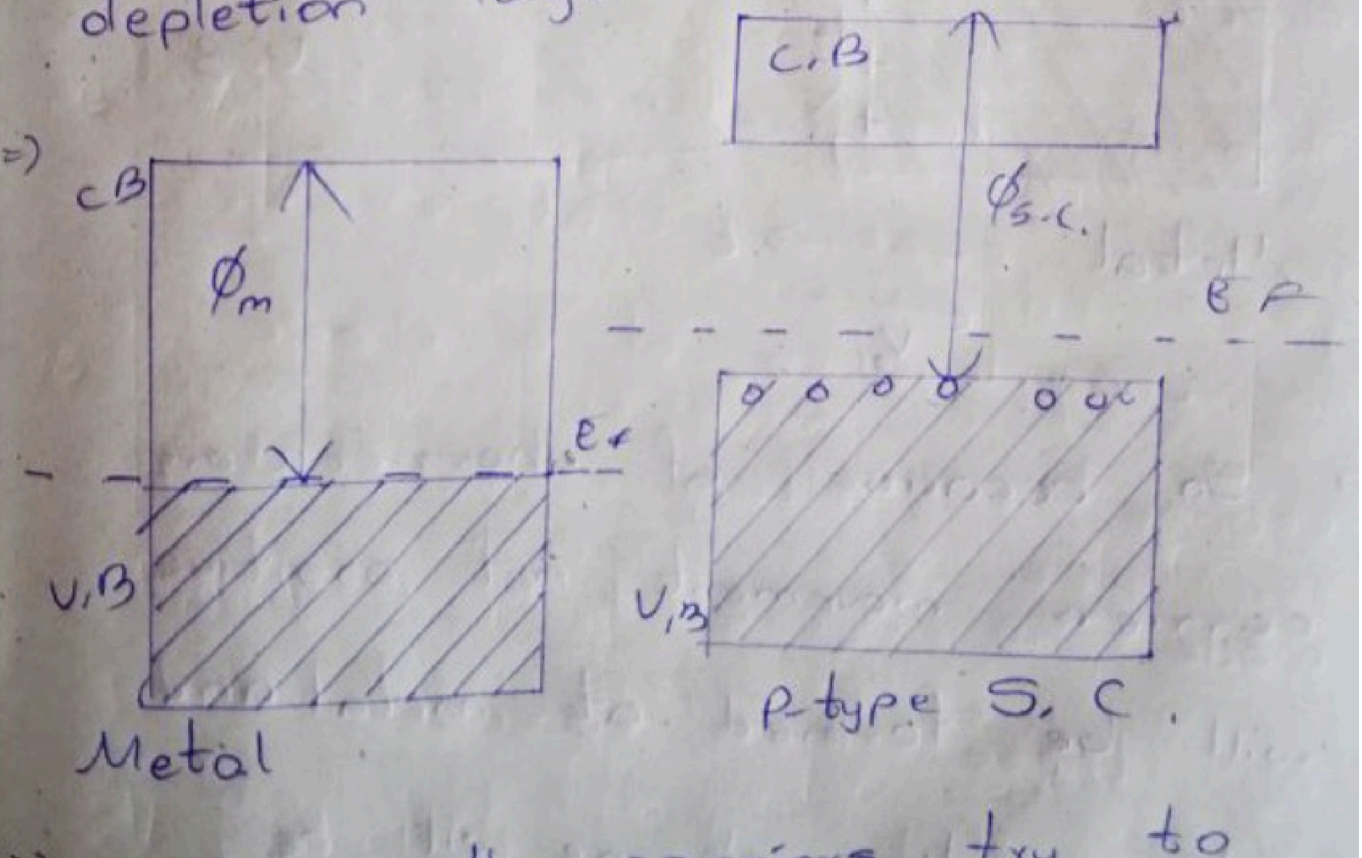
Energy band bending diagrm of p-type.

⇒ In ohmic contact, the work function of metals ($\phi_m$) is greater than of semiconductor ($\phi_{sm}$)

$$\phi_m > \phi_{sm}$$

⇒ Unlike Schottkey junction no depletion layer forms here.

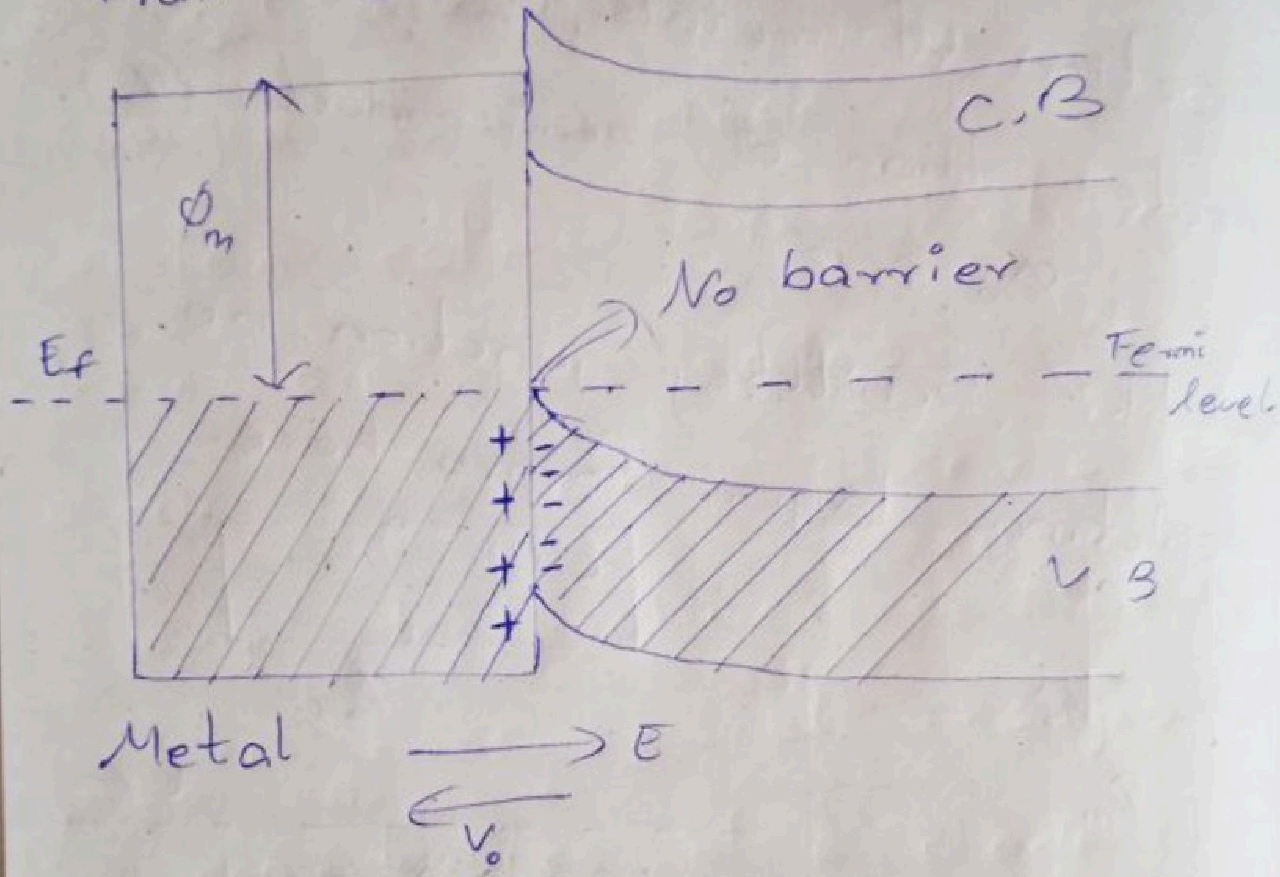
⇒




⇒ So, here the carriers try to move from along the junction

⇒ Hole movement takes place from S.C to metal.

⇒ Electron movement takes place from metal to S.C.




⇒ So, because of ~~charrier~~ charge carriers movement, net positive will be formed at metal and

⇒ net negative charge will be formed at non-metal.

⇒ As, here there are no barriers charges can flow easily.

⇒ So, in both modirections movement of carriers takes place. Thus, in ohmic junction current flows in both ways.

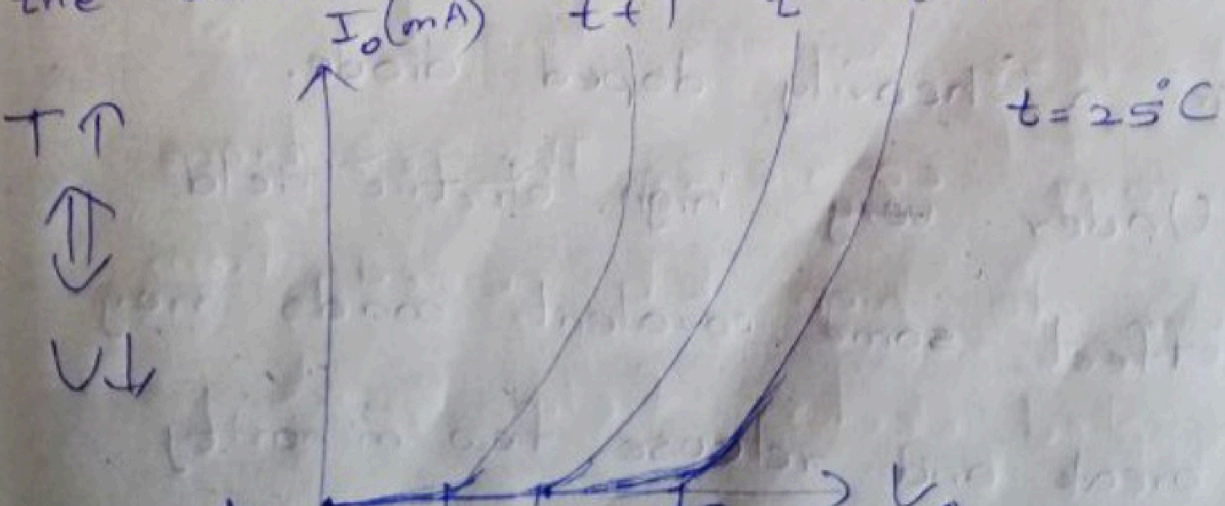
J-Abhinav
Q201150

(5) Temperature Coefficient

tells us about the change we will get when temperature is changed. In a diode we normally maintain optimum temperature. There are two cases in a diode i) Forward & 2) Reverse Bias. Through temperature coefficient we can observe what changes in charecteristics of a diode like change in Voltage when the diode is operated in any one of those two cases.

Normally, when temperature is increased, covalent bonds break because of excess energy and form more charge carriers. So, more charges drift through the barrier, that current is called drift current. As drift current increases, the width of depletion layers decreases, as charges get energy to move through the barrier and more charges will be formed near depletion layer. This is the observation under forward bias.

As temperature increases, Lesser the width of depletion layer, lesser the barrier potential.




→ A ~~positive~~ negative temp coefficient in F.B., In a forward bias p-n junction diode, the voltage drop decreases with -1.8 mV per C' in Silicon & -2.02 mV per C' in Ge.

Rise in temperature increases e & hole pairs and thus increases conductivity. As a result current(I) through p-n junction also increases. As a result reverse saturation current ($I_o$) formed due to minority carriers also increases.

Forward Bias $\Rightarrow$ $I \uparrow$ as $T \uparrow$

Reverse Bias $\Rightarrow$ $I_o \uparrow$ as $T \uparrow$

We also have diode equation $I = I_o\left(e^{\frac{qV}{KT}} - 1\right)$ shows how diode current changes with temperature.

5) In reverse bias we observe two cases, they are based on doping concentration and other factors. At break down condition in reverse bias we observe two cases

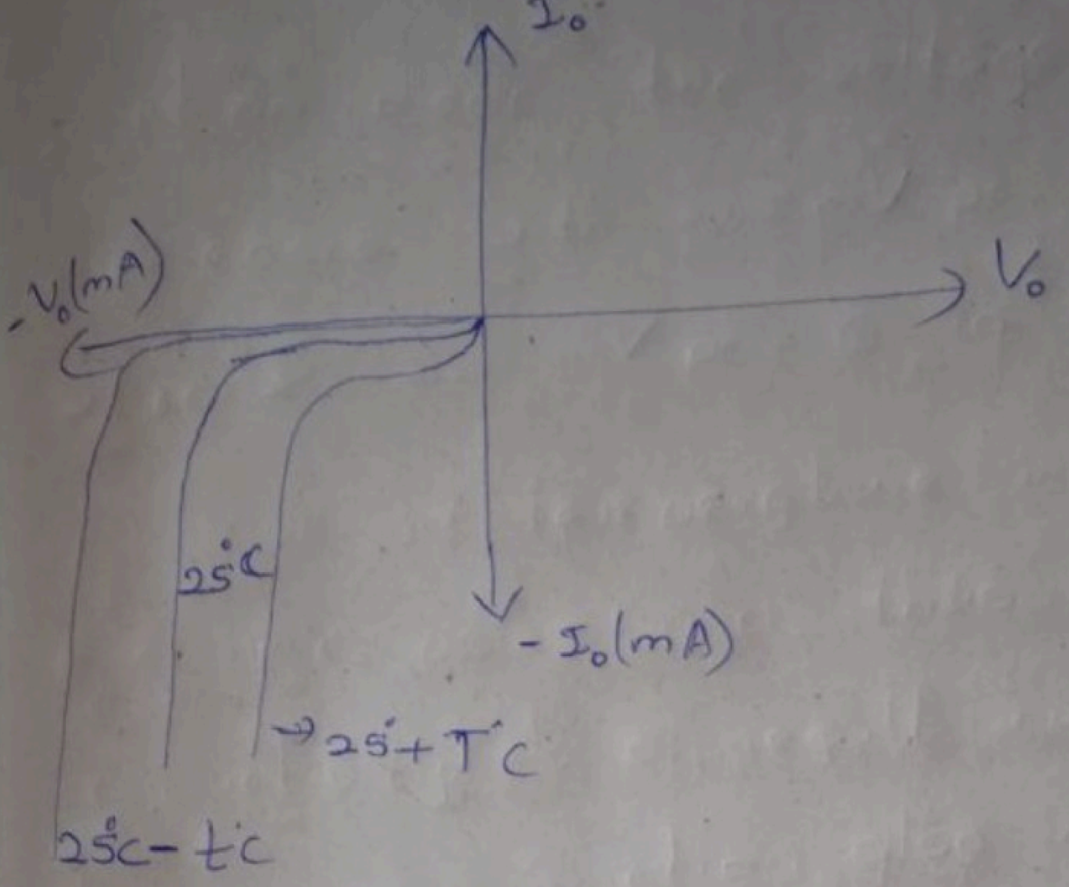
1) Zener break down
2) Avalanche breakdown.

In Zener breakdown condition a negative temperature coefficient is observed. With increase in temperature, break down voltage decreases. Zener Breakdown occurs in a heavily doped diode.

Under ~~very high~~ electric field effect, some covalent bonds may break and release few minority charge carriers. Because of high doping, high barrier voltage will be there so high electric field, these few minority carriers under this electric field ~~dis~~ will eventually form large number of minority charge carriers. This results in increase of current in reverse bias. So, as temperature increases more minority charge carriers will form at low electric field than original. So, breakdown voltage will be low for at high temperatures. So, a negative temperature coefficient is observed in reverse bias.

In a lightly doped diode we see avalanche breakdown. There will be some minority charge carriers in a diode under reverse bias. When ~~hi~~ sufficiently high reverse voltage is applied, a sufficiently high electric field generates much kinetic energy to those minority charge carriers, that they disrupt the covalent bond resulting in ~~t~~ excess number formation of charge carriers. The electrons due to high K.E gained from applied electric field break the covalent bonds of the semiconductor. As temperature is increased, the charge carriers will form more, but at the same time, higher external field is required ~~is~~ to energise the charge carriers (or) $e^-$s so that they can break the covalent bonds. So, here a positive temperature coefficient is observed. With increase in temperature, external electrical field must be increased orelse the break down voltage is increased if field is constant.

In Zener diode.




In Avalanche case