INTRODUCTION TO THE SUBJECT

Electronics: Branch of Science deals with the motion of electrons in gases, liquids and solids under differ operating Conditions.

Electronics deals with the study, design and the utilization of electron devices.

AREA OF APPLICATION:

i) Entertainment and Communication
ii) Control and Instrumentation
iii) Medicine Science
iv) Defence

Electronic Components:

a) Active Components: Capable of processing or amplifying an electrical Signal
Example — Semiconductor devices, Tube devices.

b) Passive Components: not capable of processing or amplifying, but without their aid active components are not able to amplify or process.

i) Resistor: Control the flow of electric current
- Provide desired amount of voltage in a electronic Circuit

$$V = IR$$

ii) Capacitor: Opposes change in voltage in the Circuit by means of Charge storage

$$Q = CV$$

- It block dc Current

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Inductor: Opposes change in current by means of energy Storage in the form of Magnetic field

$$e = L\frac{dI}{dt}$$

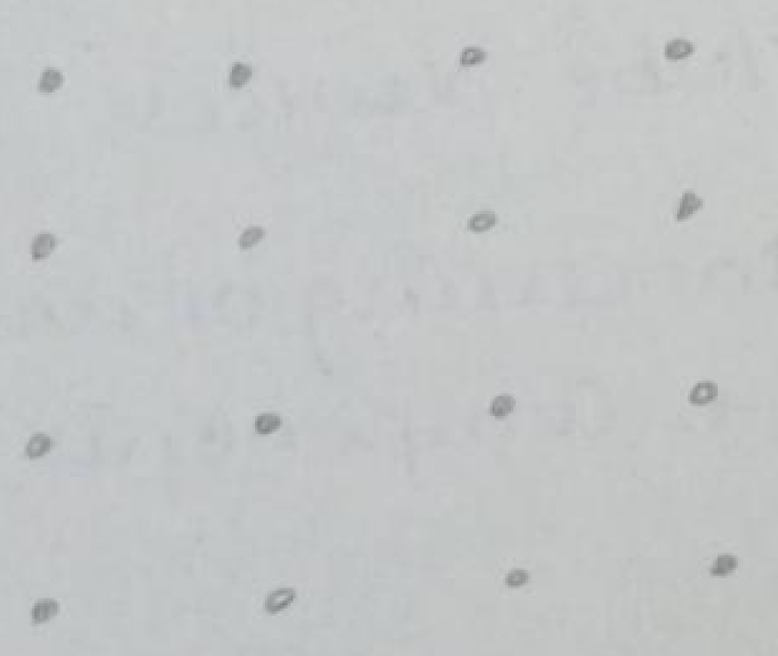
- It block ac current

Operation of electronic devices depends upon the motion of charged particles within them, which in turn depends on the Structure and arrangement of atoms in Solids.

STRUCTURE OF SOLIDS:

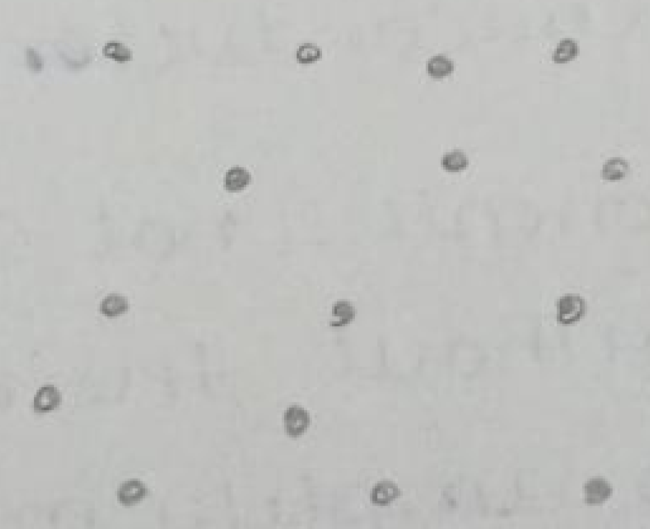
) Crystalline: Solid consist of atoms or molecules arranged in a periodic manner which is repeated throughout the entire Solid Material.

) Amorphous: do not have crystalline Structure



Crystalline

Example: All metals
- Semiconductors



Amorphous

Example: Insulator
- Wood, plastic, paper etc

CLASSIFICATION OF SOLID MATERIALS

a) Conductor : Good Conductor of electricity as they have large no. of mobile charge carriers or free electrons

Resistivity: $10^{-8}\ \Omega\text{-}m$ and increases with increase in temperature

b) Insulator: Bad Conductor of electricity, no charge carriers or free electrons.

Resistivity: $10^{12}\ \Omega\text{-}m$, Constant upto limit after which it suddenly fall.

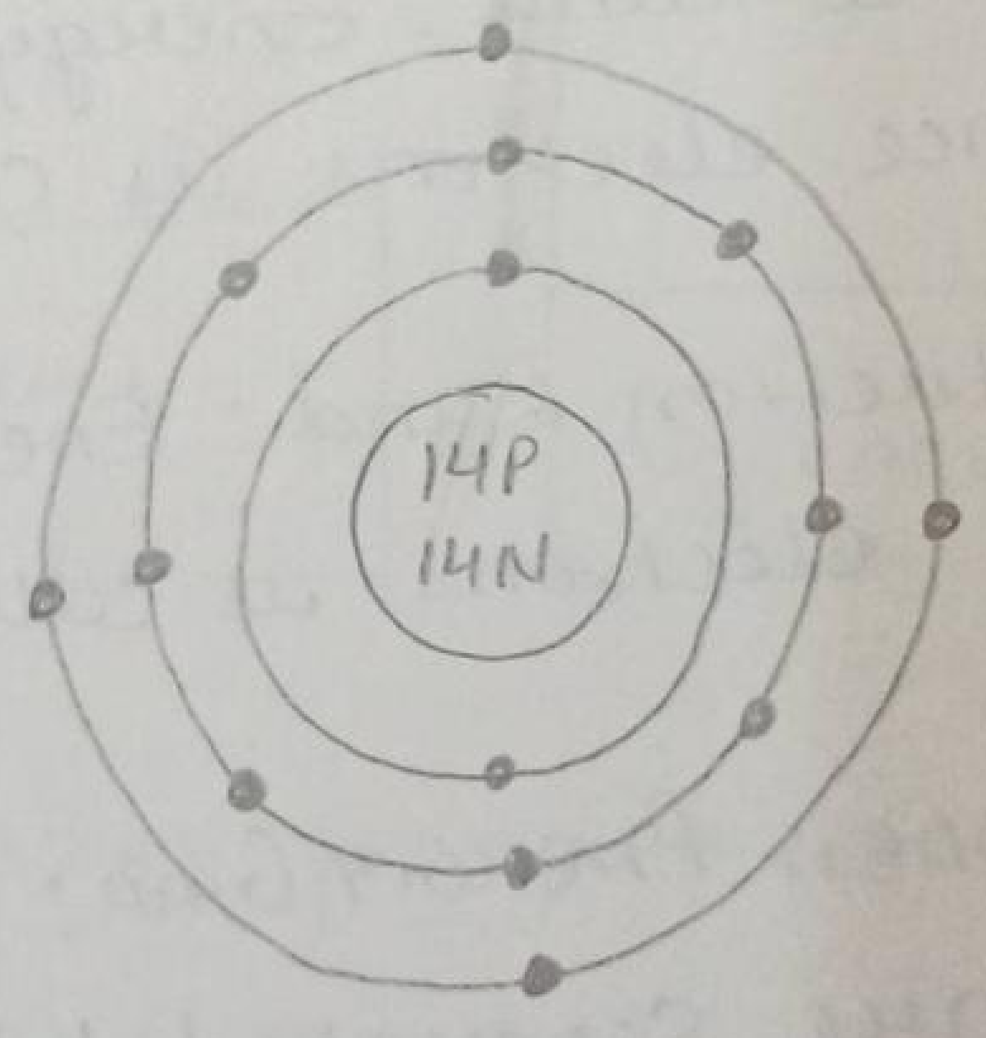
c) Semiconductor : Conductivity lie between those of Conductor and insulator.

Resistivity : 10^{-4} to $0.5\ \Omega\text{-}m$, decreases with increase in temperature.

STRUCTURE OF AN ATOM : Nucleus (Protons + Neutrons) + electrons

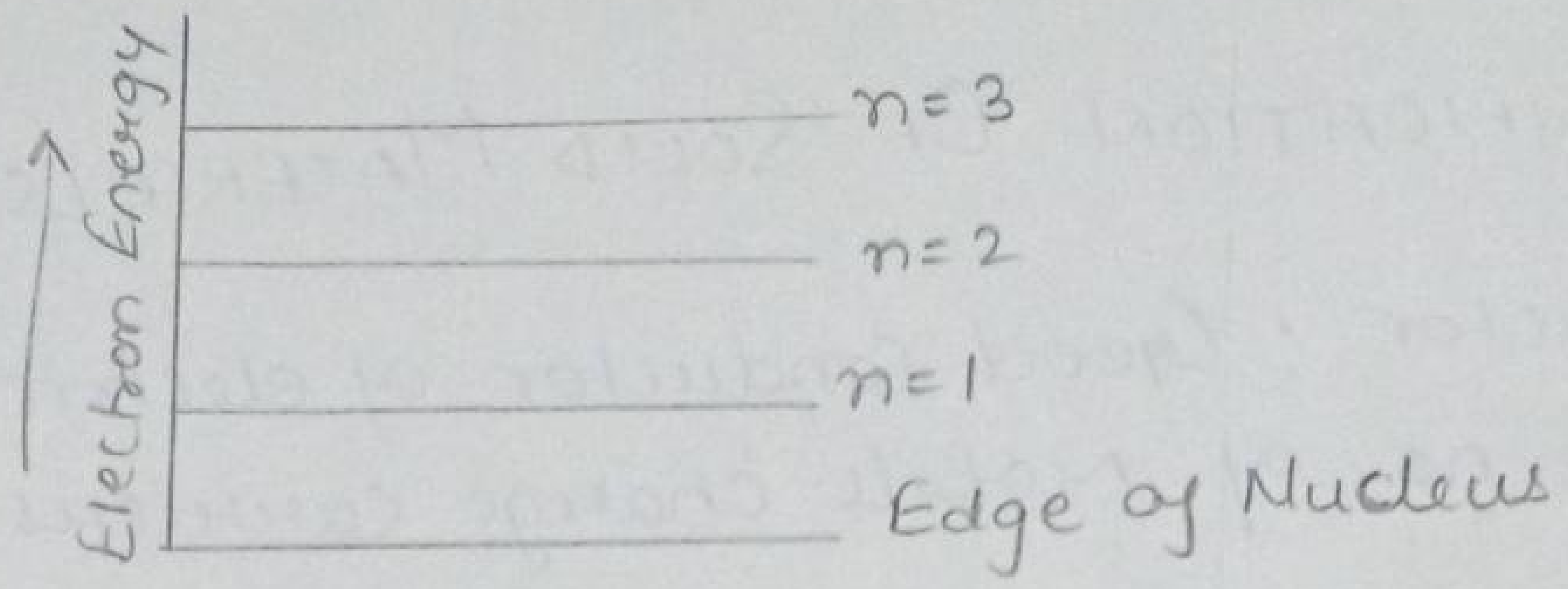
An orbit or shell can contain max^m $2n^2$ electrons, except last shell which can only hold upto 8 electrons.

$n \rightarrow$ no. of orbit



Silicon atom (14 e^-)

Each isolated atom can have only a certain no. of orbit, each orbit has fixed amount of energy associated with it and electron moving in particular orbit posses the energy of that orbit.



Energy Bands in Solids: In isolated atom, electrons revolving in any shell possess a certain amount of energy, But when atoms form a solid, the orbit of an electron is affected not only by the charges of its own atom but by neucleus and electrons of each atom in solid.

Because of this, electrons in the same orbit have a range of energies called energy band

∴ "Range of energies possessed by electrons of the same orbit in a solid is called energy band"

Bands of Major Consideration are:

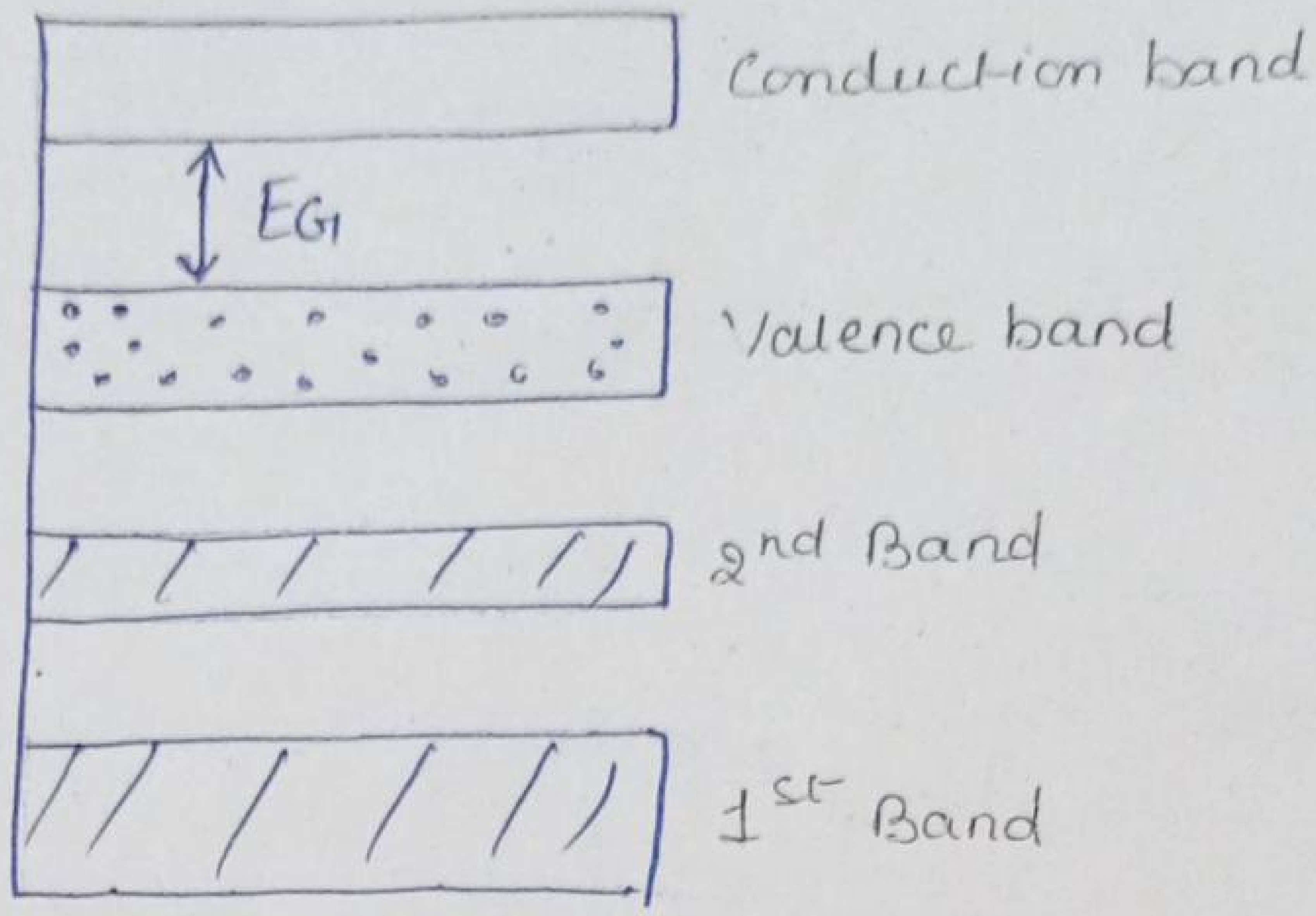
i) Valence Band: Energy band which possesses the valence electrons is called valence band.

ii) Conduction Band: Energy band which possesses free electrons is called Conduction band

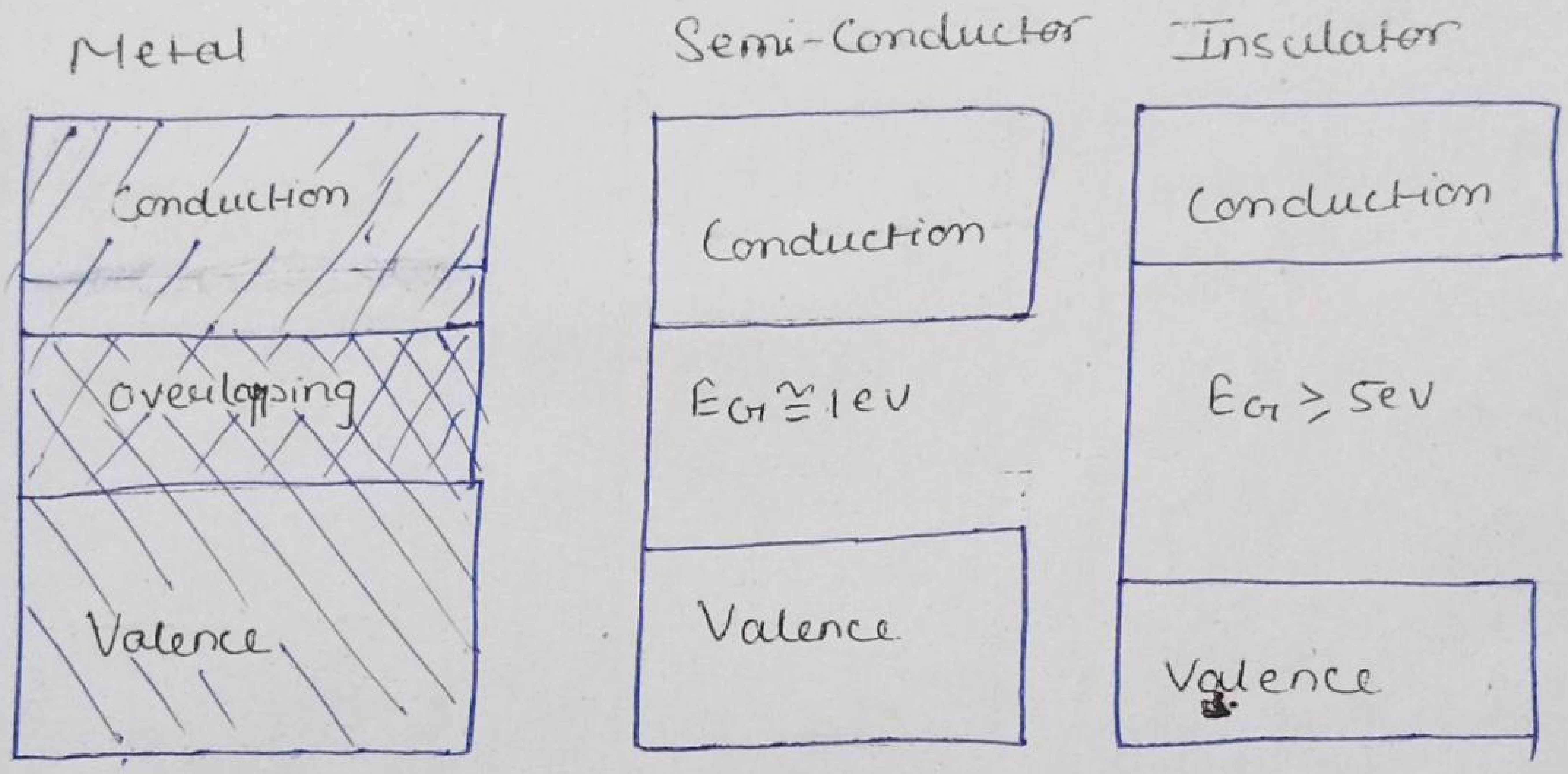
FORBIDDEN ENERGY GAP: Valence band and Conduction band are seperated by an energy gap in no electron can normally exist.

To make valence electron free, some external energy through heat or light equal to E_G should be supplied.

Energy Band Diagram (silicon)



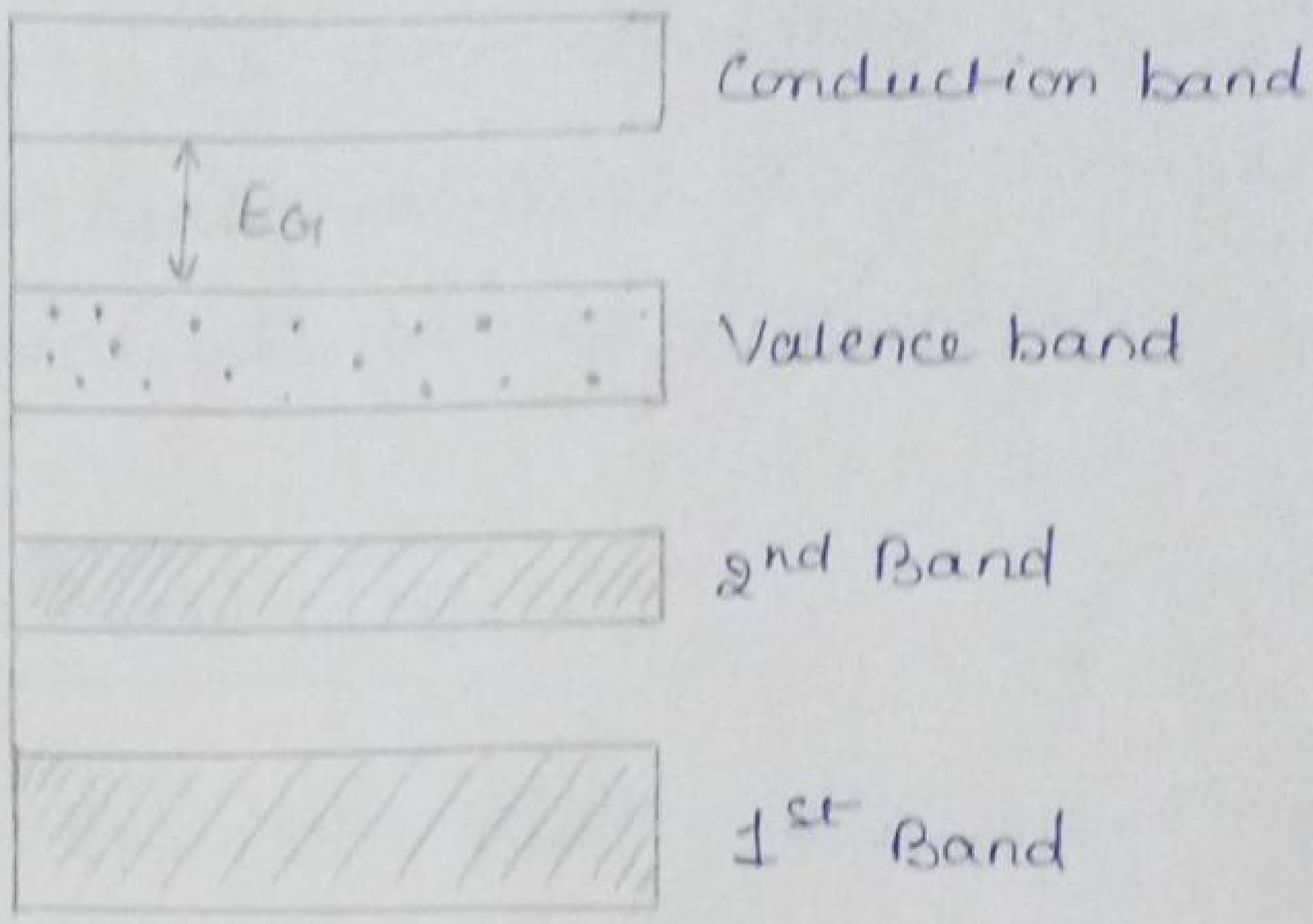
Energy Band Diagram



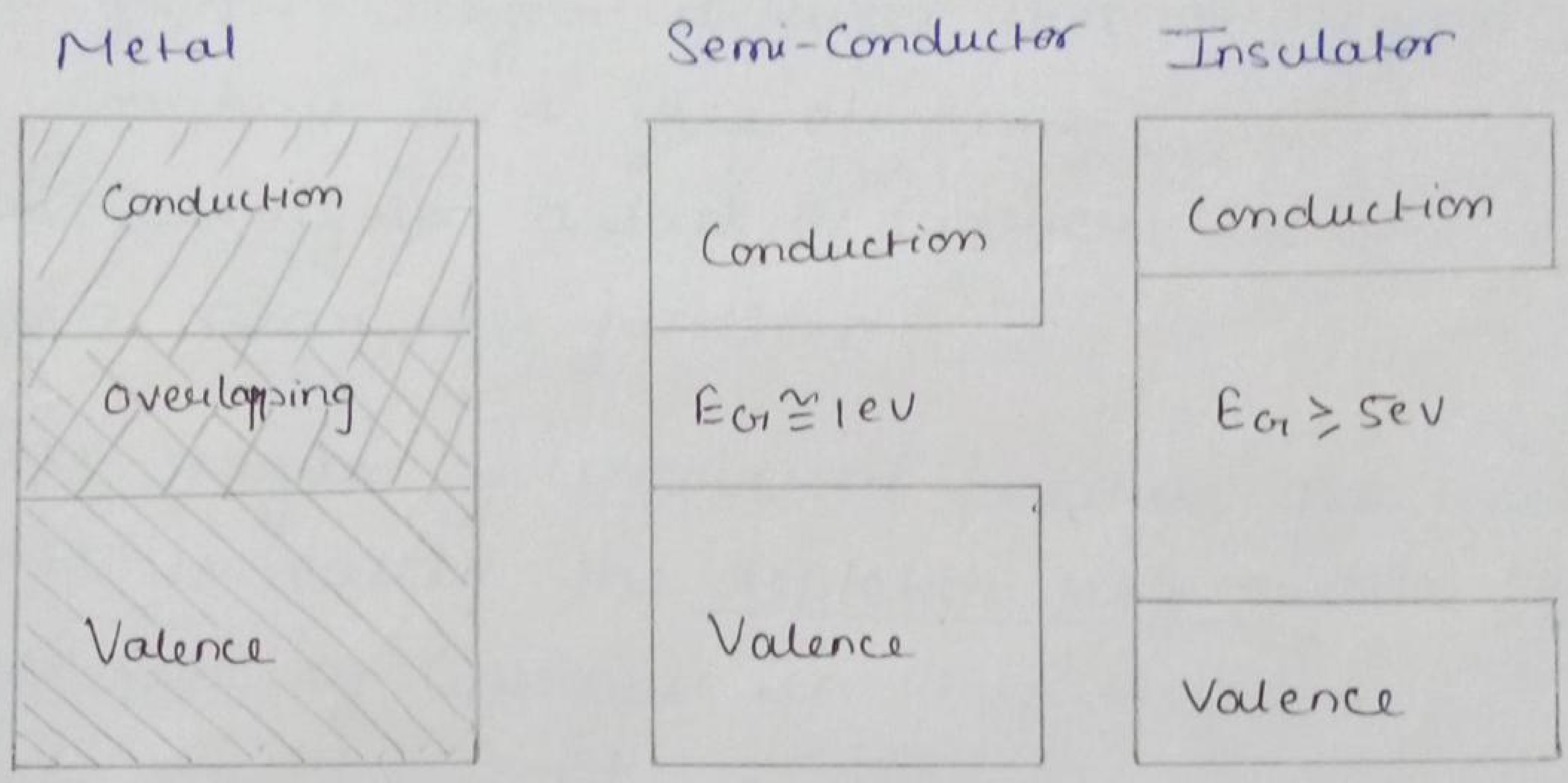
$E_G = 0.72 eV$ for germanium

$E_G = 1.12 eV$ for Silicon

Energy Band Diagram (silicon)



Energy Band Diagram



$E_G = 0.72\,eV$ for germanium

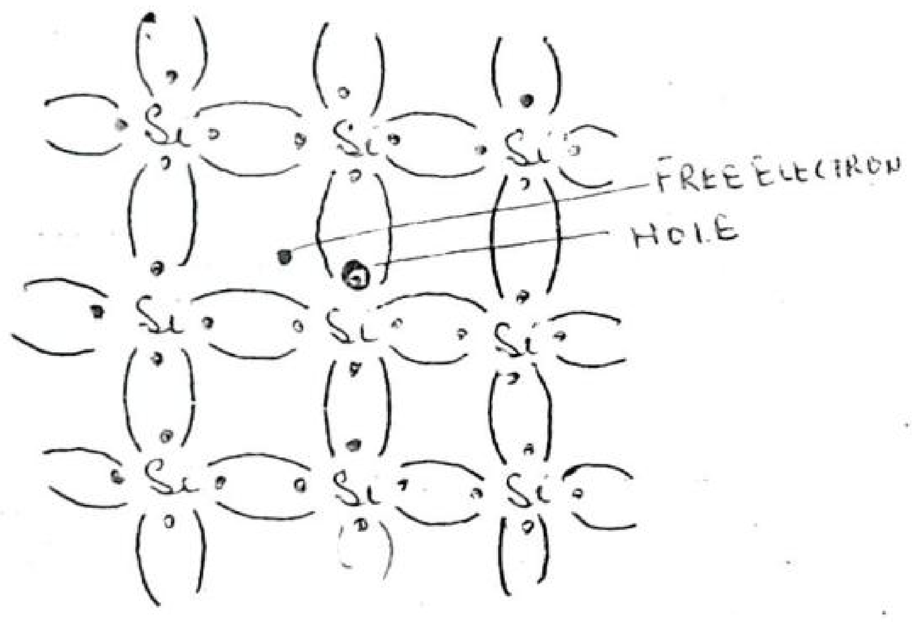
$E_G = 1.12\,eV$ for Silicon

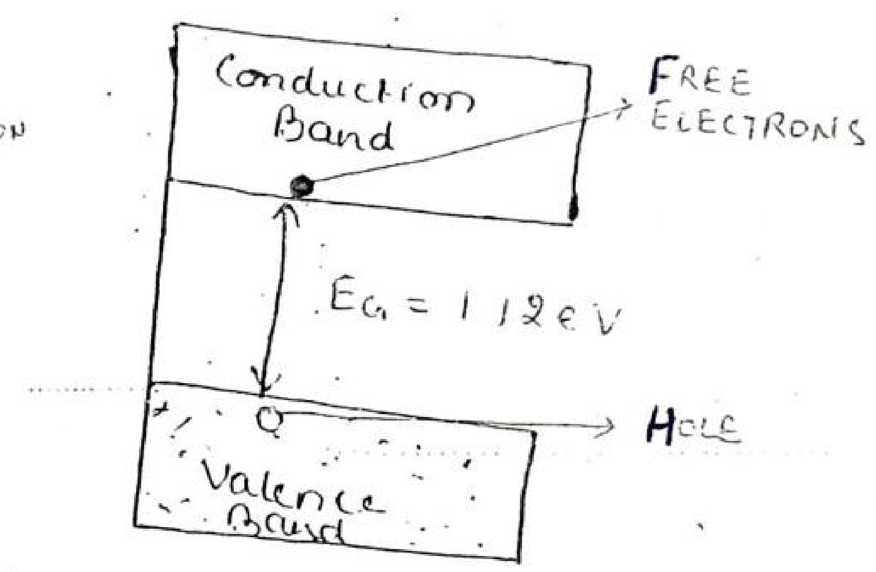
Semiconductors : Germanium (Ge-32), Silicon (Si-14), Selenium, etc

Intrinsic Semiconductor : Semiconductor in extremely pure form impurity content is less than 1 part impurity in 100 million parts. There are four electrons in the outermost orbit, each valence electron form covalent bond with neighbouring atom at 0K (−273.15°C) no free electron is available.

Generation of Electron hole pair (at 300K) : at room temp some covalent bonds break and electrons becomes free to move through the crystal and a vacancy is produced known as Hole. ie, electrons and holes are produced in pairs.

This type of simultaneous generation of electrons and holes due to temperature is called Thermal generation.





Electrons and holes are free charge carriers.
$E_G = 0.72eV$ for Ge
$E_G = 1.12eV$ for Si

Recombination : Thermally generated electron ~~hole~~ and holes move freely throughout the crystal. Due to this there is a possibility of collision between electrons and holes.

Whenever there is a collision, an electron takes the position of hole and both of them disappear. This process is called recombination.

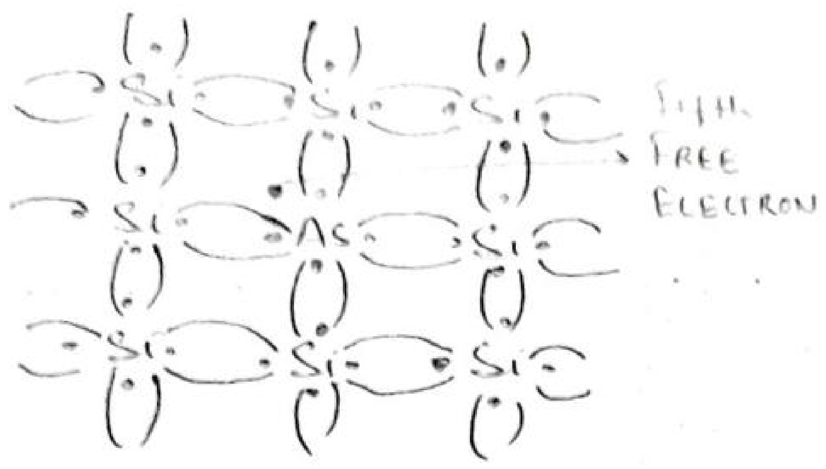
The average time of existence of an electron or hole is called mean lifetime. ~~too~~ 1μs to 10^3 μs

Extrinsic Semiconductor : By adding some amount of impurity atoms to a pure or intrinsic semiconductor we can change its conductivity or characteristics.

This process of adding impurity to a pure semiconductor is called Doping, and A dopped semiconductor is called Extrinsic semiconductor.

N-type Semiconductor : if Pentavalent impurity atoms are added to intrinsic Semiconductor, N-type Semiconductor is obtained

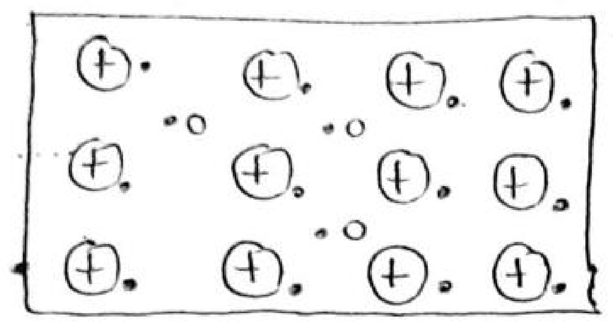
Example: Arsenic (As), Phosphorus (P), Antimony (Sb)



fifth electron is loosely bound to the parent atom a very little amount of energy is required to ~~dett~~ deattach this electron

$E = 0.05 eV$ for silicon

$= 0.01 eV$ for germanium.



The pentavalent impurity atom donates one electron and becomes a positively charge ion called donor ion

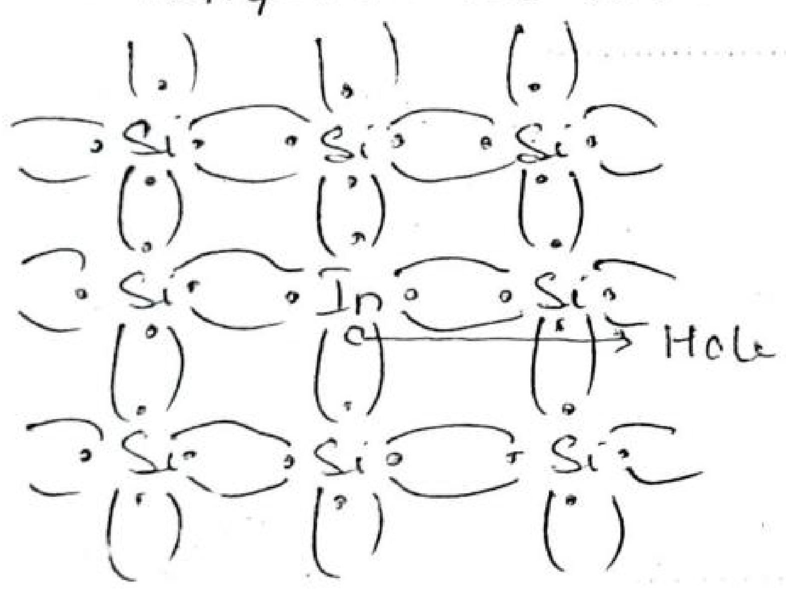
• → Free electron Majority Charge Carriers)

o → Holes (Minority Charge Carriers)

⊕ → Immobile positive ion (Donor ion)

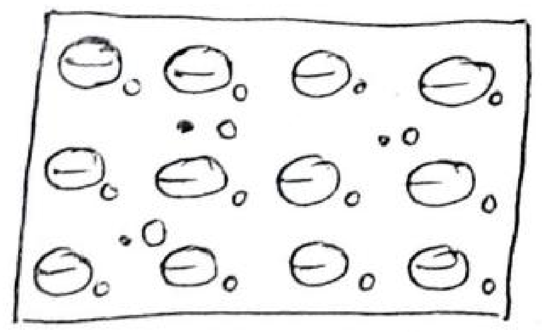
P-type Semiconductor : If trivalent impurity atoms are added to intrinsic Semiconductor p-type Semiconductor is obtained.

Example: Aluminium (Al), Indium (In), gallium.



The fourth Silicon atom cannot make a covalent bond with Indium atom as it has three valence electrons.

Hence, the ~~fouth~~ fourth covalent bond is incomplete, A vacancy that exist in the incomplete covalent bond constitute a hole.



This vacancy or hole have a tendency to complete the covalent bond from the neighbouring atoms to complete the covalent bond.

Since indium atom accepts one electron it is also called accepter ion

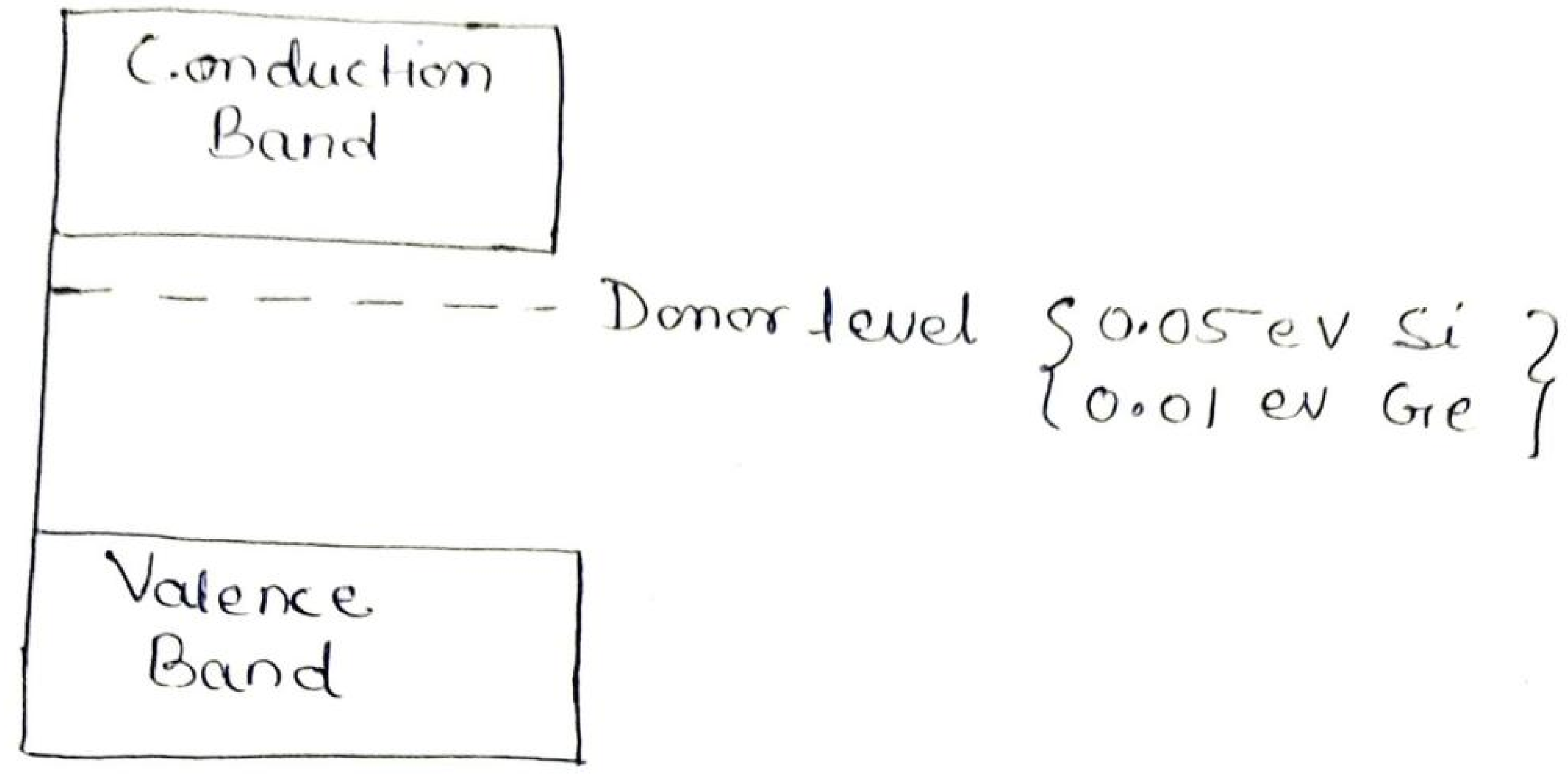
o → Hole Majority Charge Carriers

• → electron Minority Charge Carriers

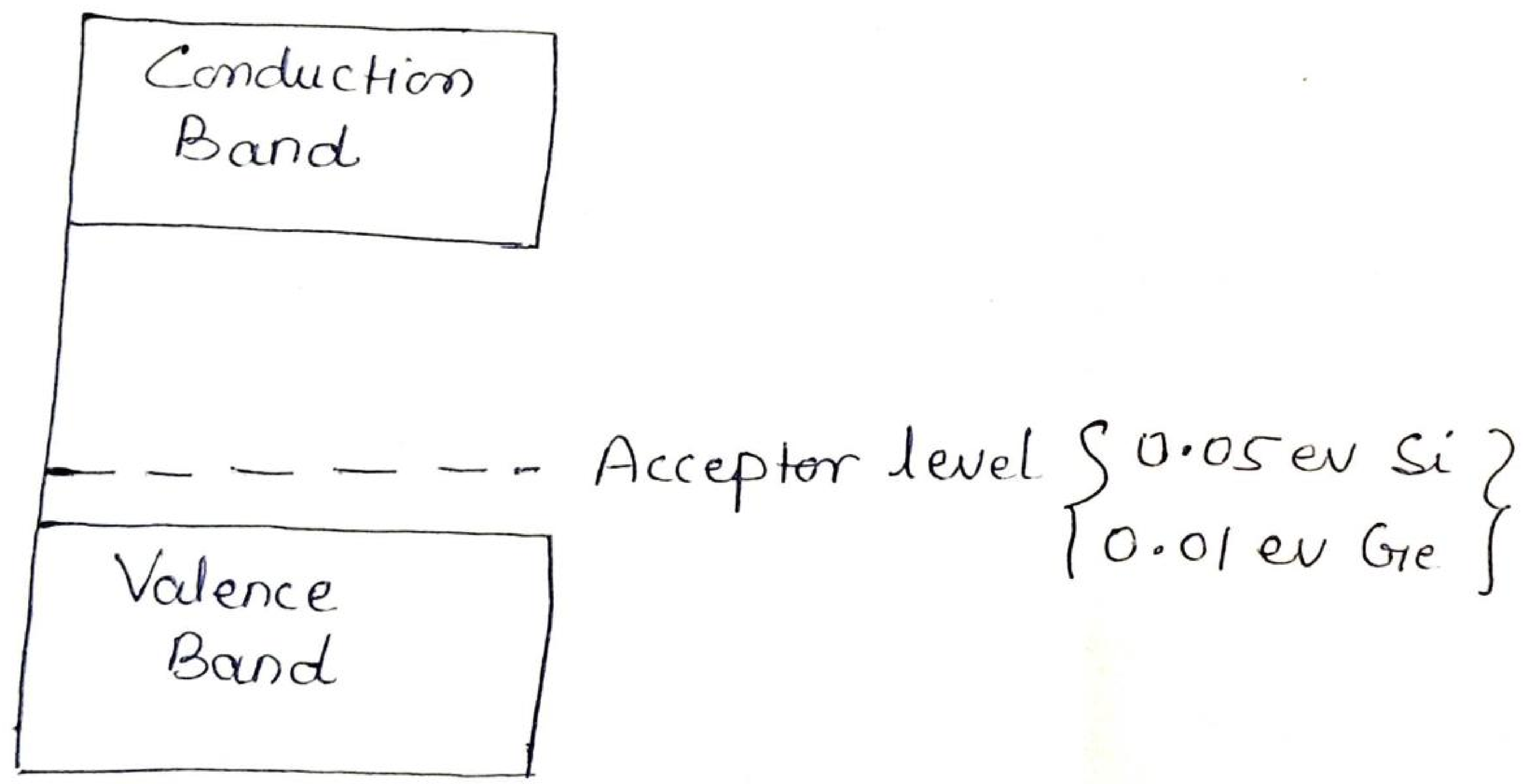
⊖ → Acceptor ion

Energy Band Diagram for Extrinsic Semiconductor

n-type Semiconductor



p-type Semiconductor



SEMICONDUCTOR DIODE : (P-n Diode)

P-n junction is formed when a wafer of the semiconductor material Such as Silicon is doped So that one region is N-type and other is p-type

⇒ Depletion Region formation :

At the instant the two materials are "joined"

→ Electrons from n-region diffuses into p-region and Combine with holes.

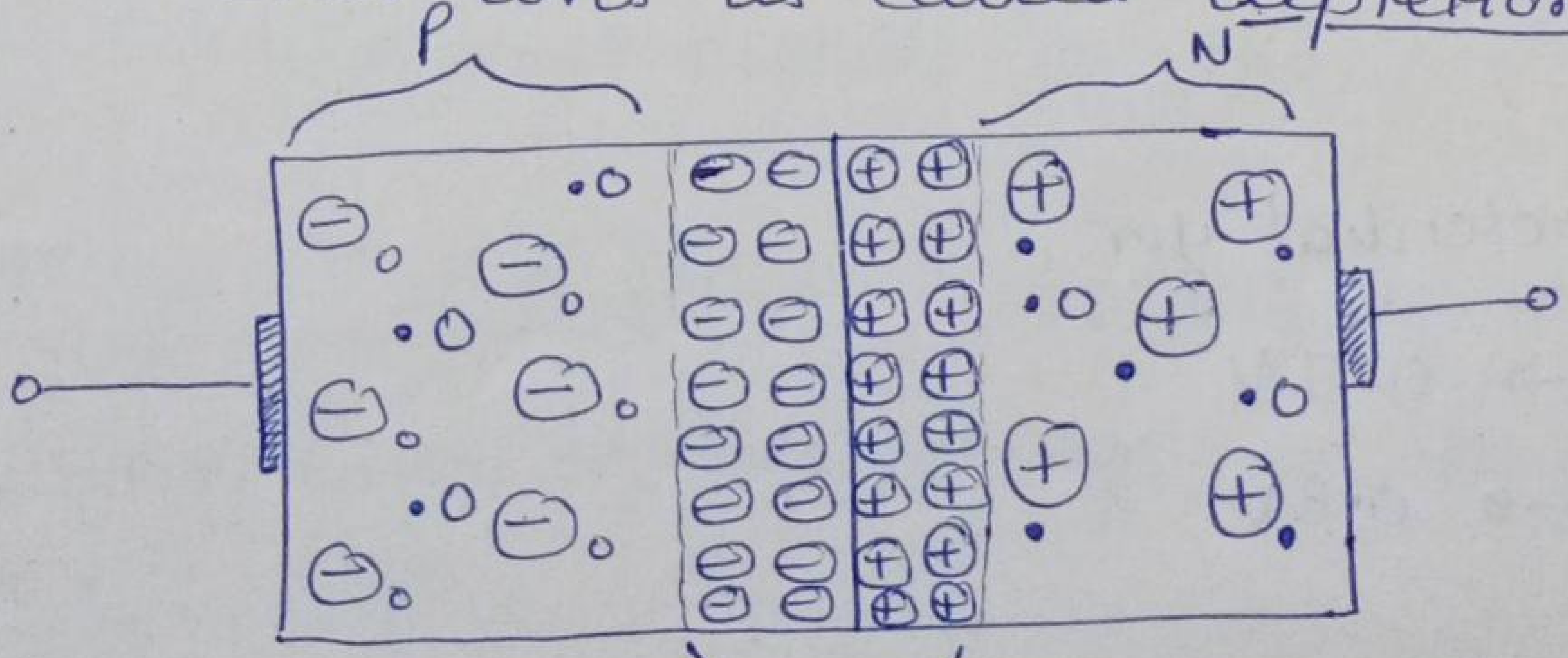
→ Holes from p-region diffuses into n-region and Combine with free electrons.

Resulting in a lack of Carriers in the region near the junction.

"This region of uncovered positive and negative ions is called the depletion region due to the depletion of Carriers in this region."

OR

"The region having the uncompensated acceptor and donor ions is called depletion region".



Depletion Region

As, Depletion region contains immobile or fixed ions which are electrically ~~car~~ charged it is also called Space charge region

Barrier Potential : Due to presence of immobile positive and negative ions on opposite sides of the junction, an electric field is created across the junction know as barrier potential or junction potential or cut in voltage.

because it acts as a barrier to oppose the flow of electrons and holes across the junction. It represents height of barrier that is to be overcome for the commencement of flow of electrons and holes.

Factors Deciding the barrier potential value

→ Semiconductor material used (Si or Ge)

→ Intrinsic concentration of Si and Ge

→ Level of doping on P and N side

→ Temperature.

Barrier potential for

Si → 0.7 V

Ge → 0.3 V

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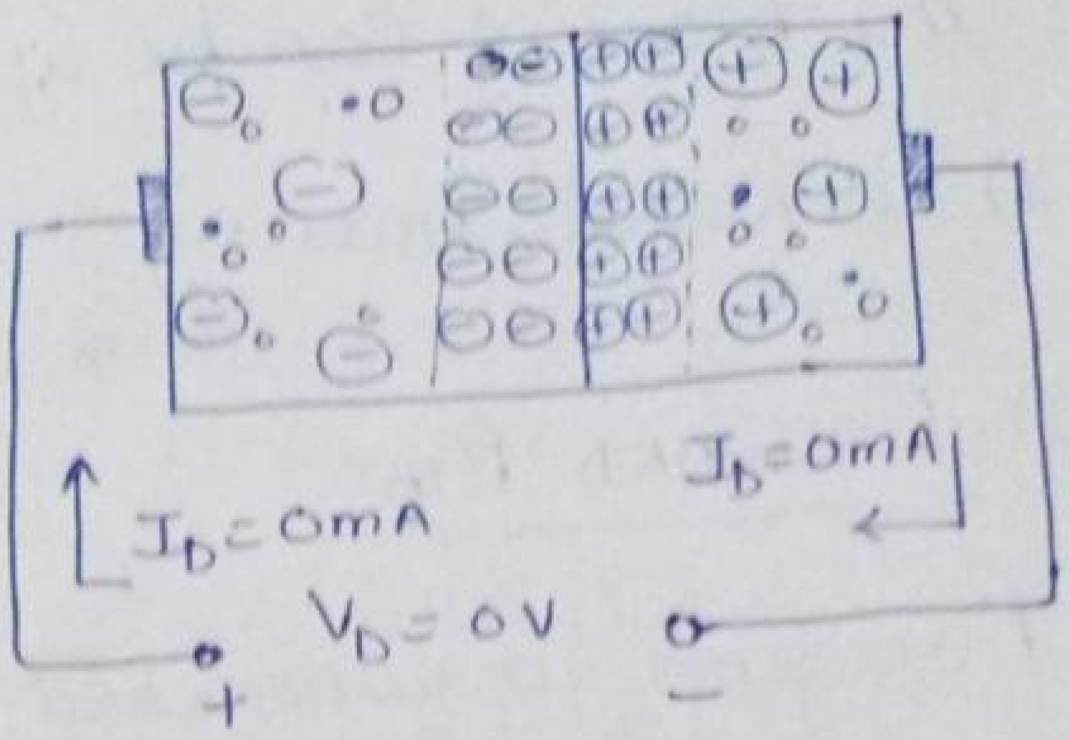
UNDER NO-BIAS CONDITION :



Even after depletion region is established, few majority carriers have sufficiently high kinetic energy to balance the barrier potential and cross the junction and a small current flows which is called Majority Carrier Current

Minority carrier flow

e ⟶ ⟵ h

Majority carrier flow

h ⟶ ⟵ e

Since, there are some minority carriers in both regions, they are accelerated across the junction by ~~both regions~~ the barrier potential called Minority Carrier Current.

As both current flows in opposite direction

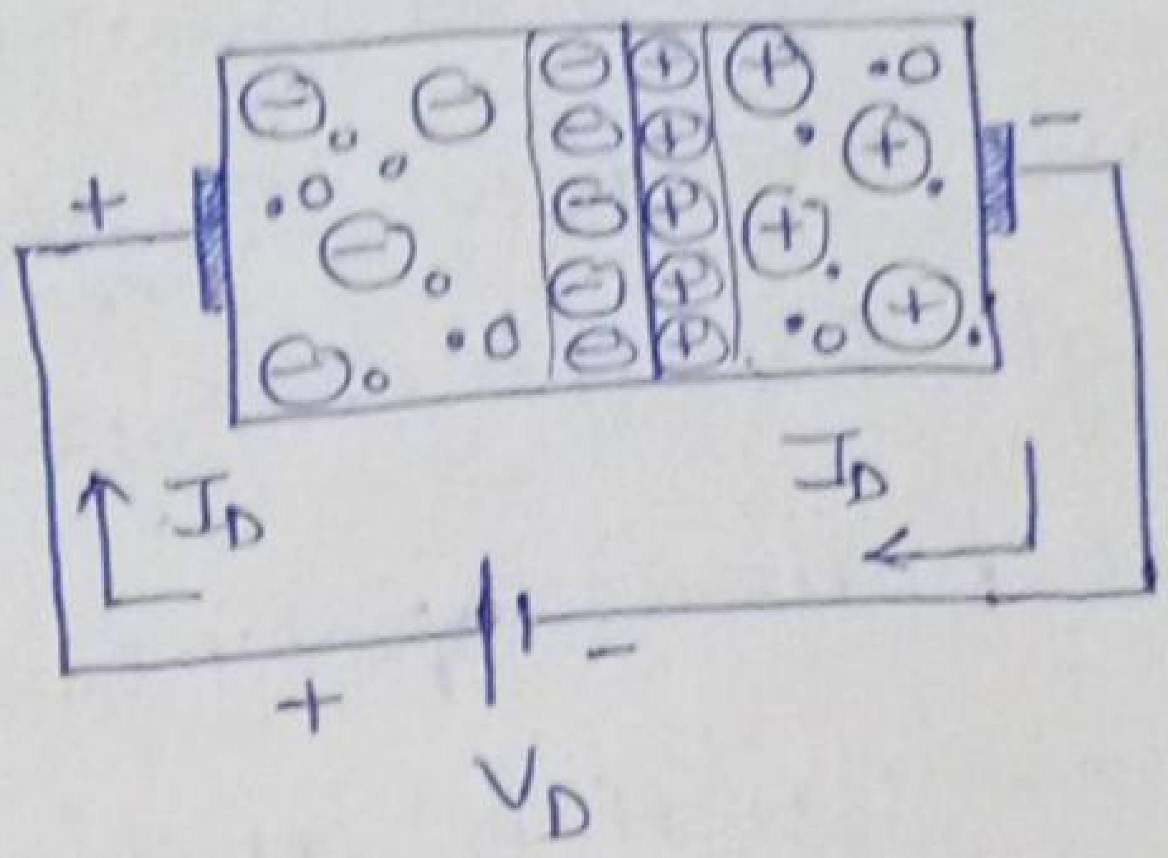
" In the absence of an applied bias voltage, the net flow of charge in any one direction ~~of~~ for a semiconductor diode is zero."

BIASING OF P-N DIODE : Biasing is the process of applying external DC Voltage to the semiconductor diode.

The biasing can be of two types

1) forward biasing   2) Reverse biasing.

1) FORWARD BIAS



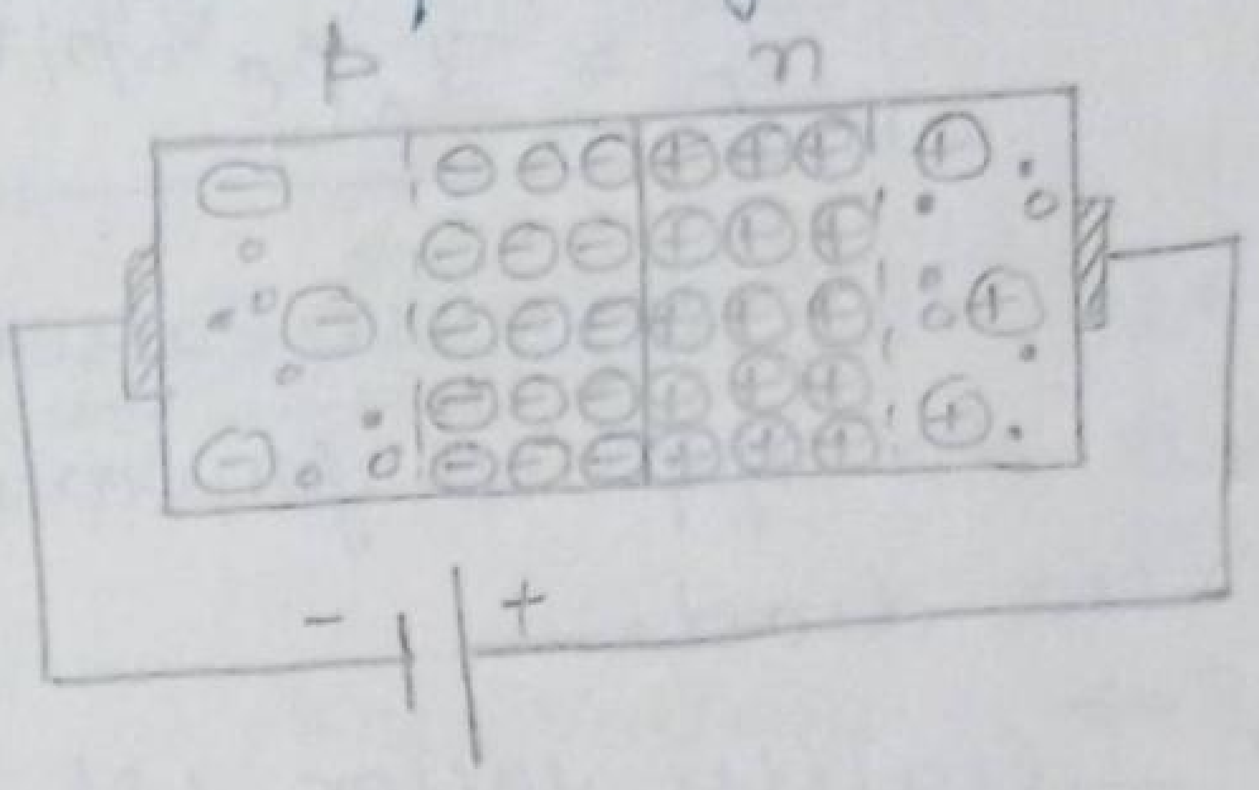
P-region is connected to the positive terminal and n-region is connected to the negative terminal of the DC Source.

The application of a forward-bias voltage V_D will pressure electrons in the n-region and holes in the p-region to recombine with ions near the boundary and reduce the width of the depletion region.

As the applied bias increases in magnitude the depletion region will continue to decrease in width untill a flood of electrons can pass through the junction resulting in an exponential rise in current

Reverse - Bias Condition :

⇒ Positive terminal of the battery is connected to the N-region and negative terminal of the battery is connected to the p-region.



Holes in the P region are attracted towards the negative terminal of the battery whereas electrons are attracted towards the positive of the battery.

Due to this depletion region becomes wide and it increases the potential barrier. So, Majority carriers are not able to cross the junction

Hence, in Reverse bias there is no current due to majority charge carriers.

⇒ But there are few thermally generated minority carries in both the regions. Increase Barrier potential enhances the flow of minority carriers across the junction. So, a very small amount of current flows through the p-n junction.

"The current that exists under reverse-bias condition (due to flow of minority charge carriers) is called Reverse Saturation Current and is represented by I_s or I_o

DIODE CURRENT EQUATION:

The general characteristics of a semiconductor diode can be defined by the following equation, referred to as Shockley's equation

$$\boxed{I_D = I_0 \left(e^{V_D/\eta V_T} - 1\right)} \text{ Amp}$$

$I_s \rightarrow$ is the reverse saturation current

$V_D \rightarrow$ is the applied forward-bias voltage across the diode

$\eta \rightarrow$ Ideality factor, which is a function of the operating conditions and physical construction.

$$\eta = 1 \text{ for Ge} \quad , \quad \eta = 2 \text{ for Silicon}$$

$V_T \rightarrow$ thermal voltage

$$\boxed{V_T = \frac{kT}{q}}$$

k is Boltzmann's constant $= 1.38 \times 10^{-23}$ J/K

$T \rightarrow$ absolute temperature in Kelvins

$q \rightarrow$ Magnitude of electronic charge $= 1.6 \times 10^{-19}$ C

at room temperature

$$V_T = \frac{T}{11600} \quad \text{or} \quad V_T = 25.875 \text{ mV}$$

$$\boxed{V_T \cong 26 \text{ mV}} \text{ at room temperature}$$

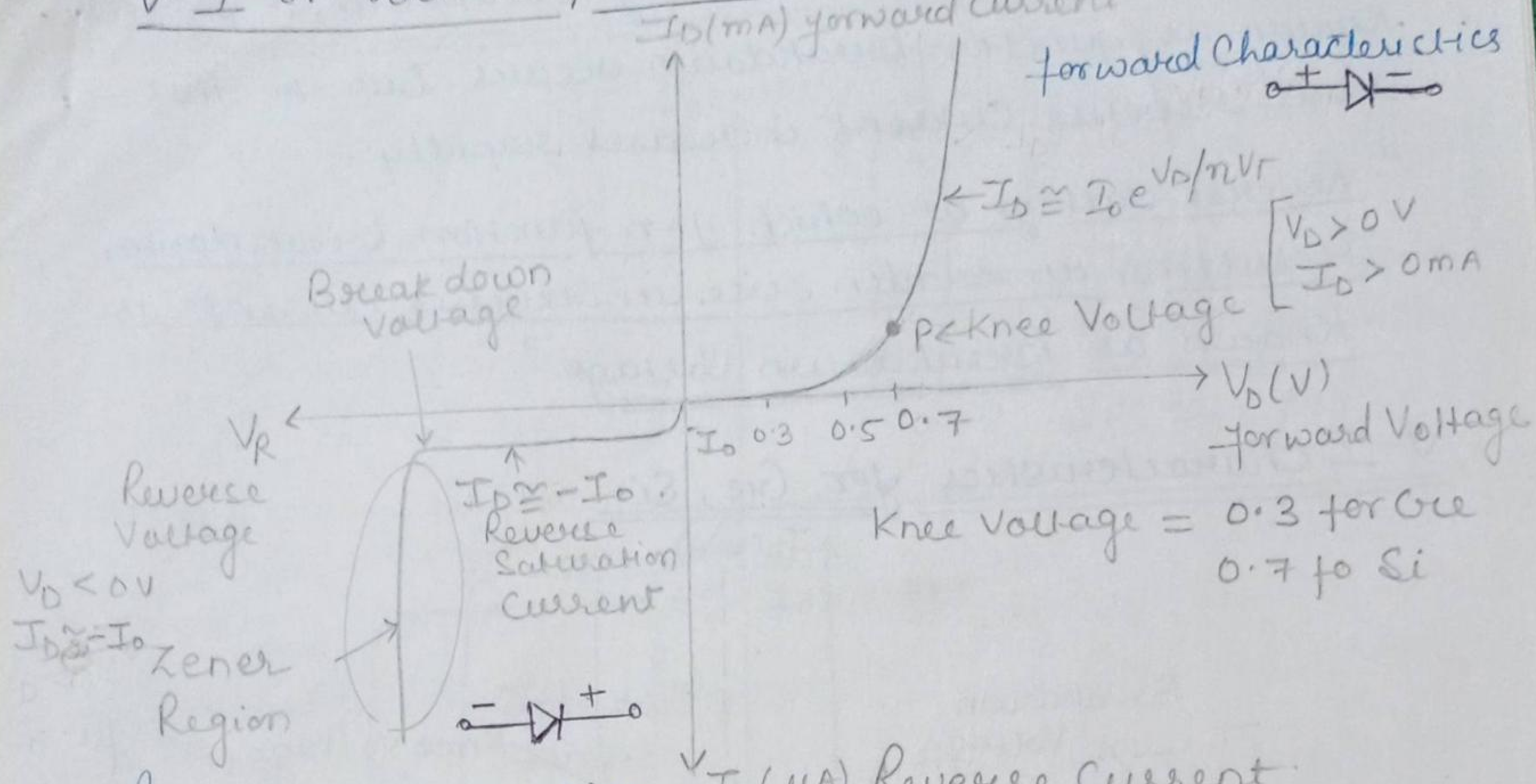
for V_D positive

$$\boxed{I_D \cong I_0 e^{V_D/\eta V_T}} \qquad \because e^{V_D/\eta V_T} >>> 1$$

for V_D Negative

$$\boxed{I_D \cong -I_0} \qquad \because e^{V_D/\eta V_T} <<< 1$$

V–I or Volt-ampere Characteristics of Diode



<u>Forward Characteristics</u>: Upto point P, diode current is very small, as applied voltage has to overcome the barrier potential and diode conduct poorly

Once the applied voltage is slightly greater than barrier potential, the diode current increases exponentially and diode conducts heavily.

" <u>The forward voltage at which current start increasing is called Knee voltage</u> "

<u>Reverse Characteristics</u>: Below breakdown voltage the diode current is very small and remains almost constant This current is due to the movement of minority carriers and known as Reverse Saturation current I_o or I_s

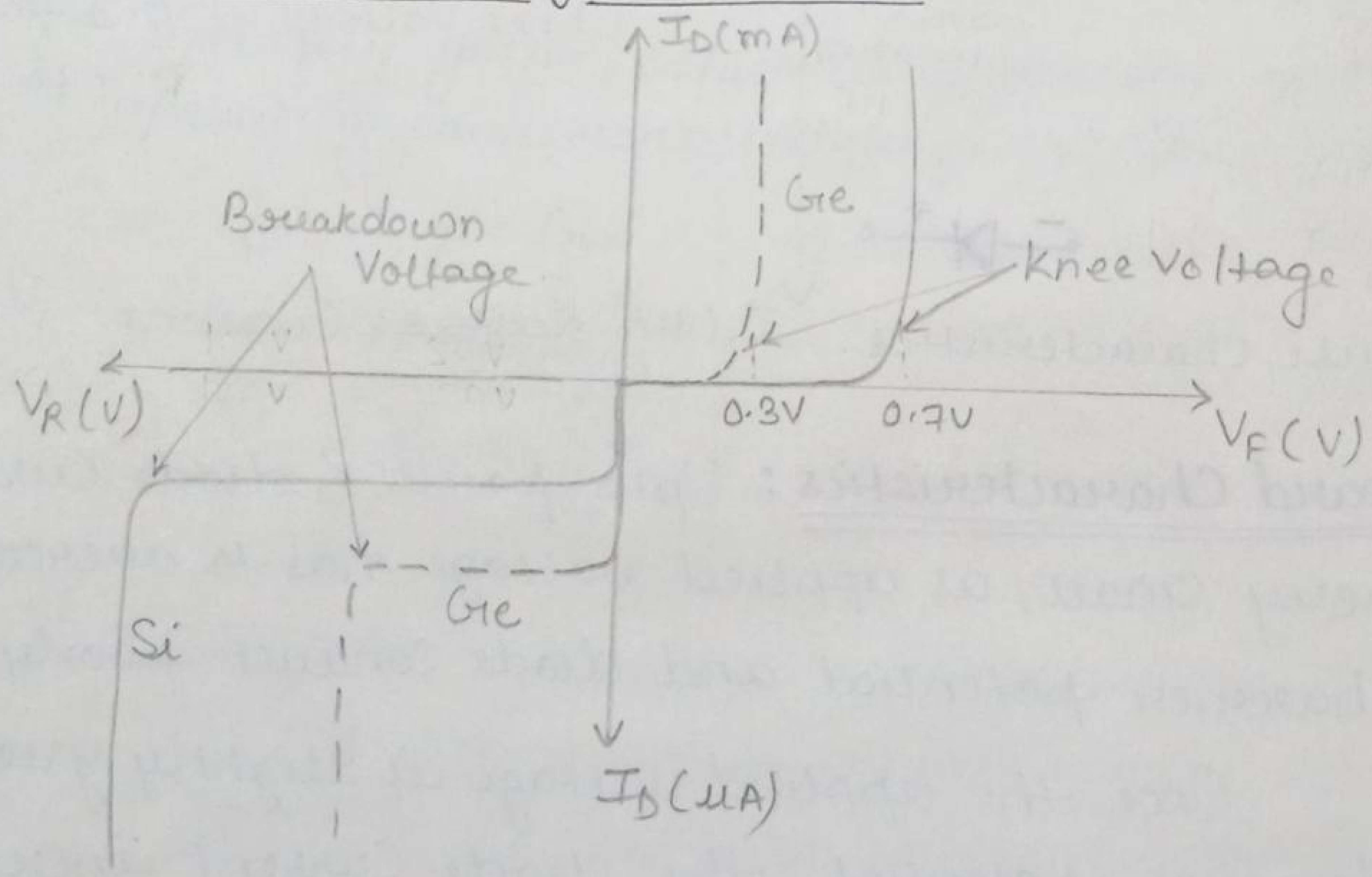
$I_o \rightarrow \mu A$ for Ge

$I_o \rightarrow nA$ for Si

If a large Reverse bias voltage is applied, a process known as junction breakdown occurs. Due to this diode reverse current increases rapidly.

"Reverse voltage at which p-n junction break down, resulting in sudden rise in reverse current is known as Breakdown Voltage"

V-I characteristics for Ge, Si

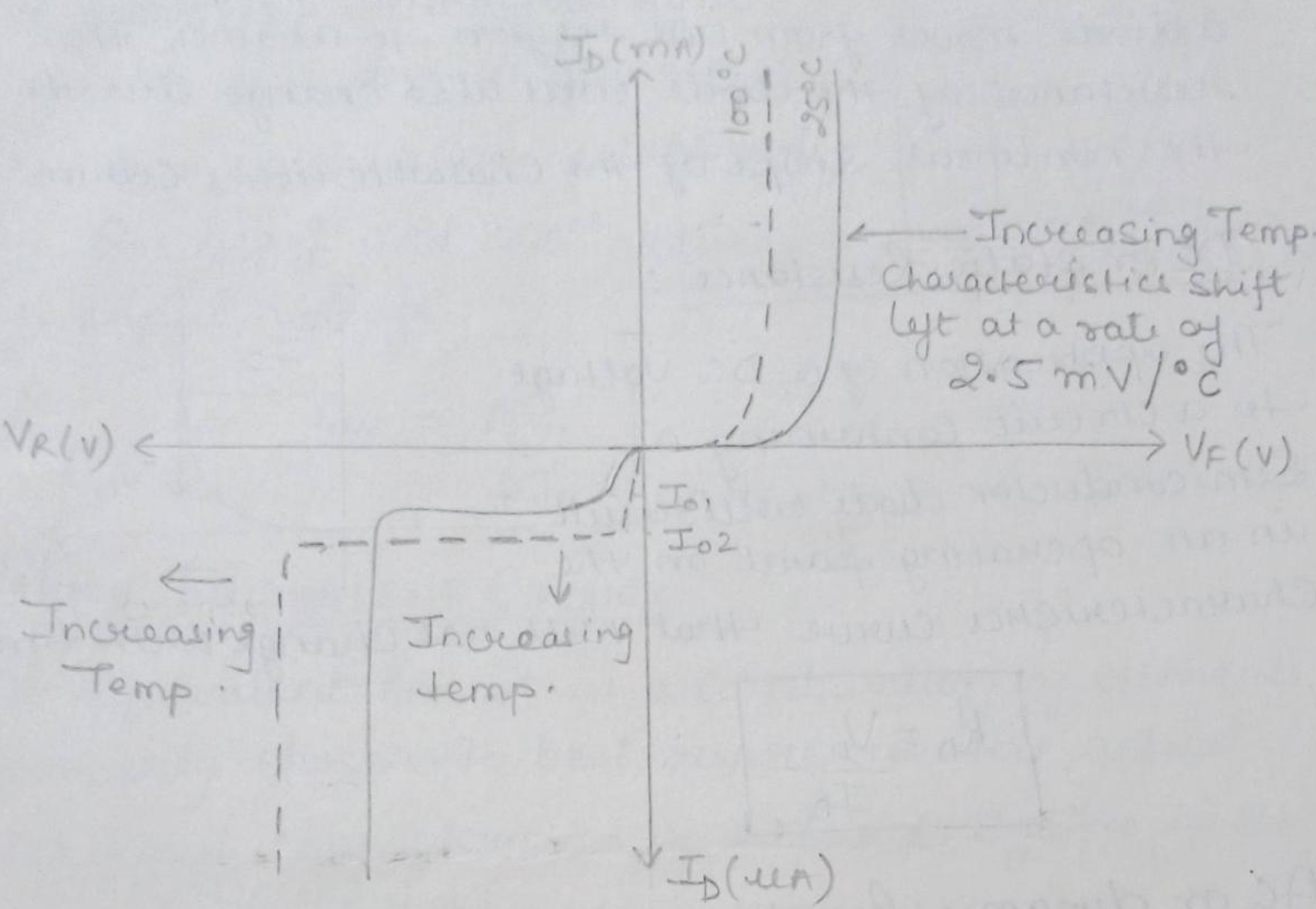


⇒ Knee Voltage for Si is 0.7V and for Ge is 0.3V

⇒ Breakdown voltage for Si diode is higher than that of the Ge diode. i.e Si diode can withstand higher reverse voltage.

⇒ The reverse Saturation current I_o for Ge diode is few μA whereas for a Si diode is nA at room temperature.

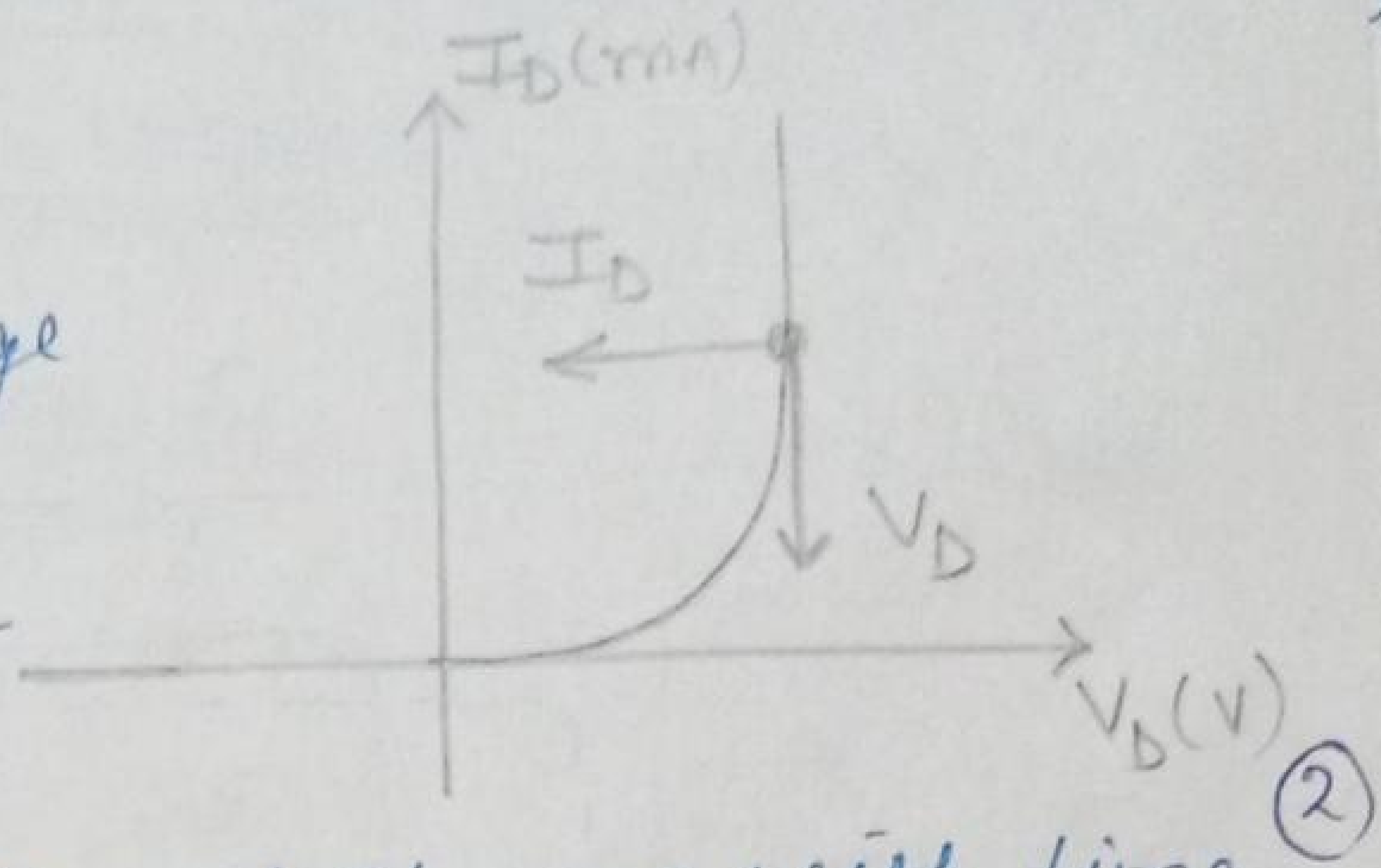
7. EFFECT OF TEMPERATURE ON V-I CHARACTERISTICS



- In the forward bias region the characteristics of a silicon diode shifts to the left at a rate of 2.5 mV per °C increase in temperature.
- In reverse-bias region the reverse saturation current of a silicon diode doubles for every 10°C rise in temperature.
- The reverse breakdown voltage of a semiconductor diode will increase or decrease with temperature depending on the zener potential

Diode Resistance :- As the operating point of a diode moves from one region to another the resistance of the diode will also change due to the non linear shape of the characteristics curve.

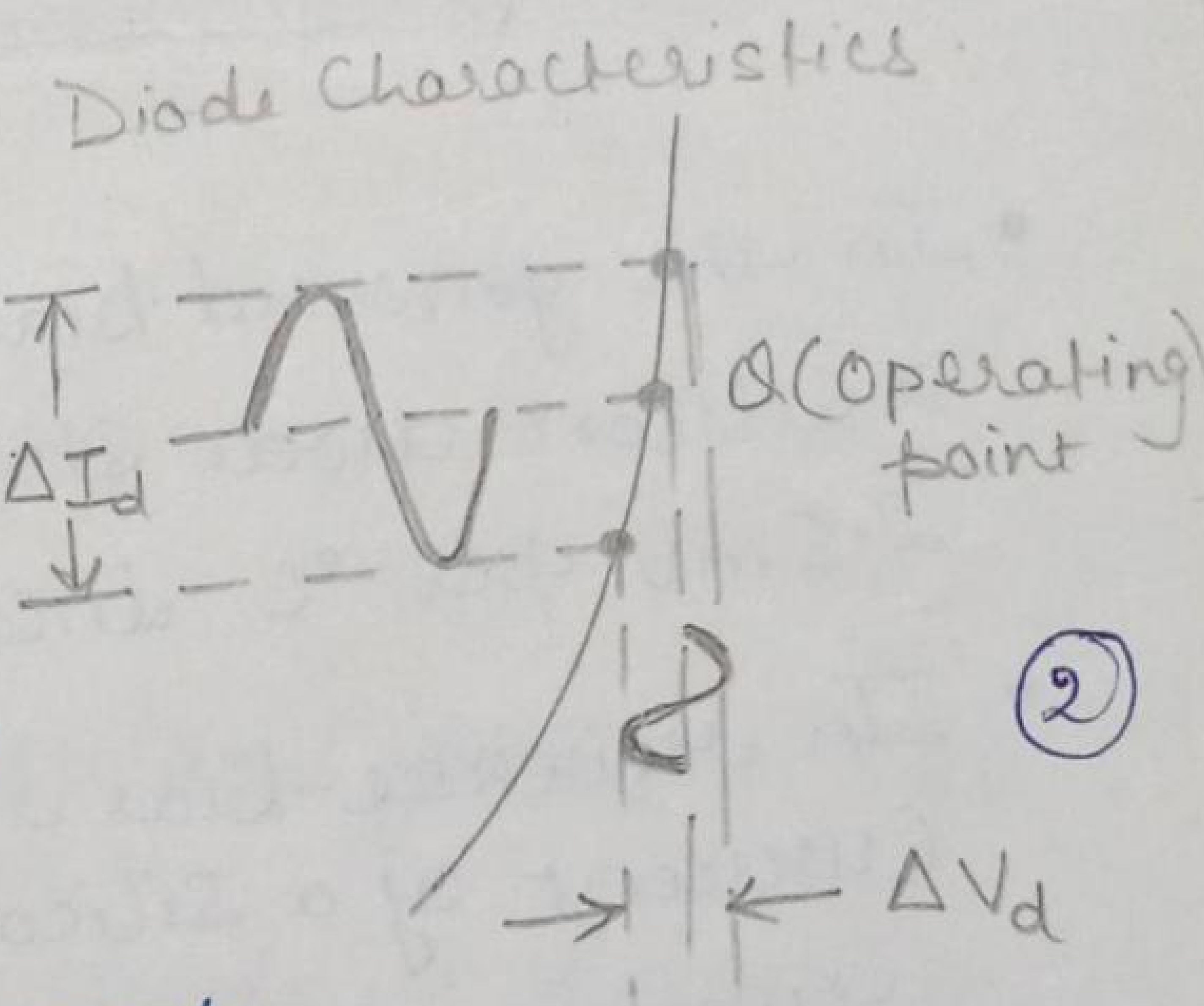
DC or static Resistance :



The application of a DC voltage to a circuit containing a semiconductor diode will result in an operating point on the characteristics curve that will not change with time.

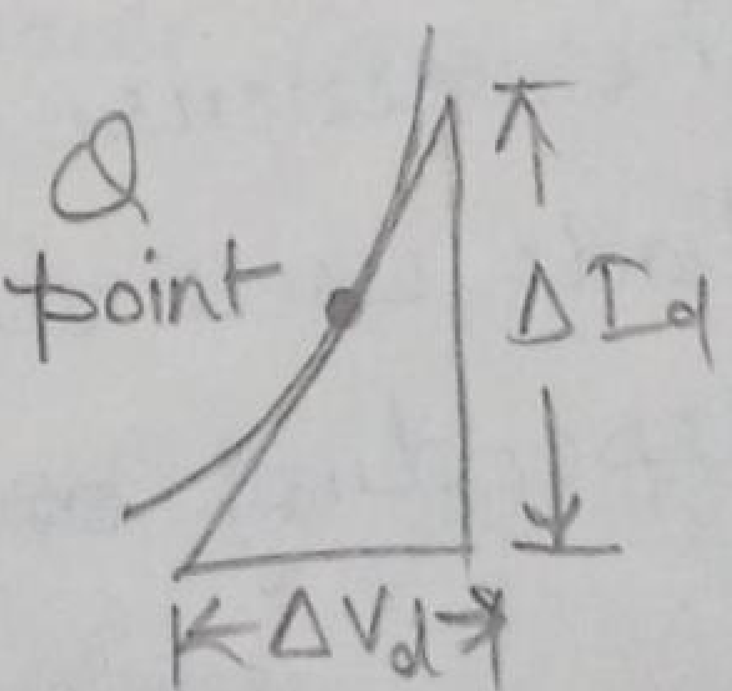
$$\boxed{R_D = \frac{V_D}{I_D}}$$

AC or dynamic Resistance :



If a sinusoidal input is applied, The varying input will move the instantaneous operating point up and down a region of characteristics.

A straight line drawn tangent to the curve through the Q point will define a particular change in the voltage and current that can be used to determine the ac or dynamic resistance.



$$\boxed{r_d = \frac{\Delta V_d}{\Delta I_d}}$$

$$r_{ac} = r_f = \frac{\eta V_T}{I}$$

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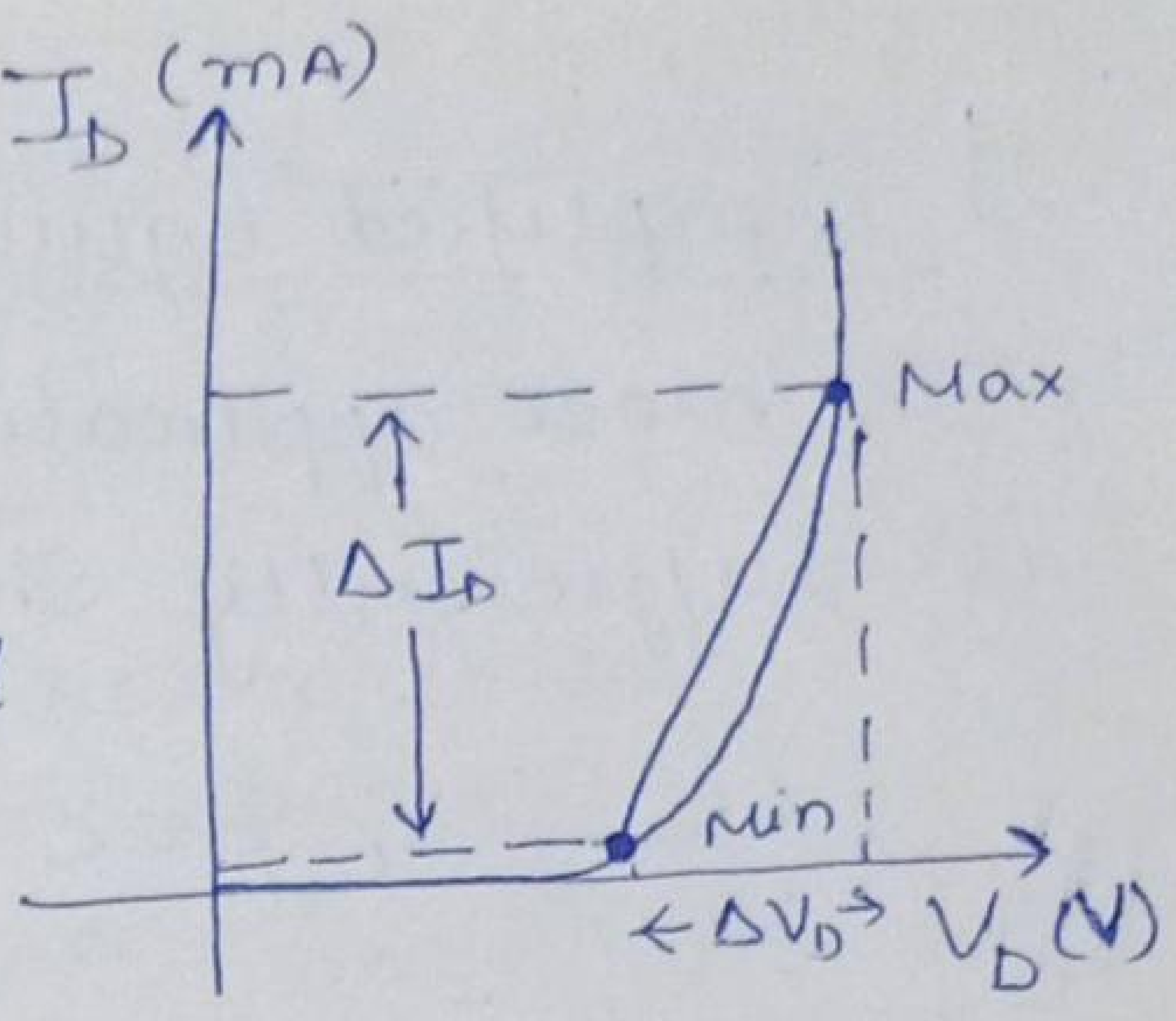
Average AC Resistance

The resistance determined by a straight line drawn between the two intersections establised by the max^m and min^M values of input voltage



$$r_{av} = \left.\frac{\Delta V_D}{\Delta I_D}\right|_{pt\ to\ pt}$$

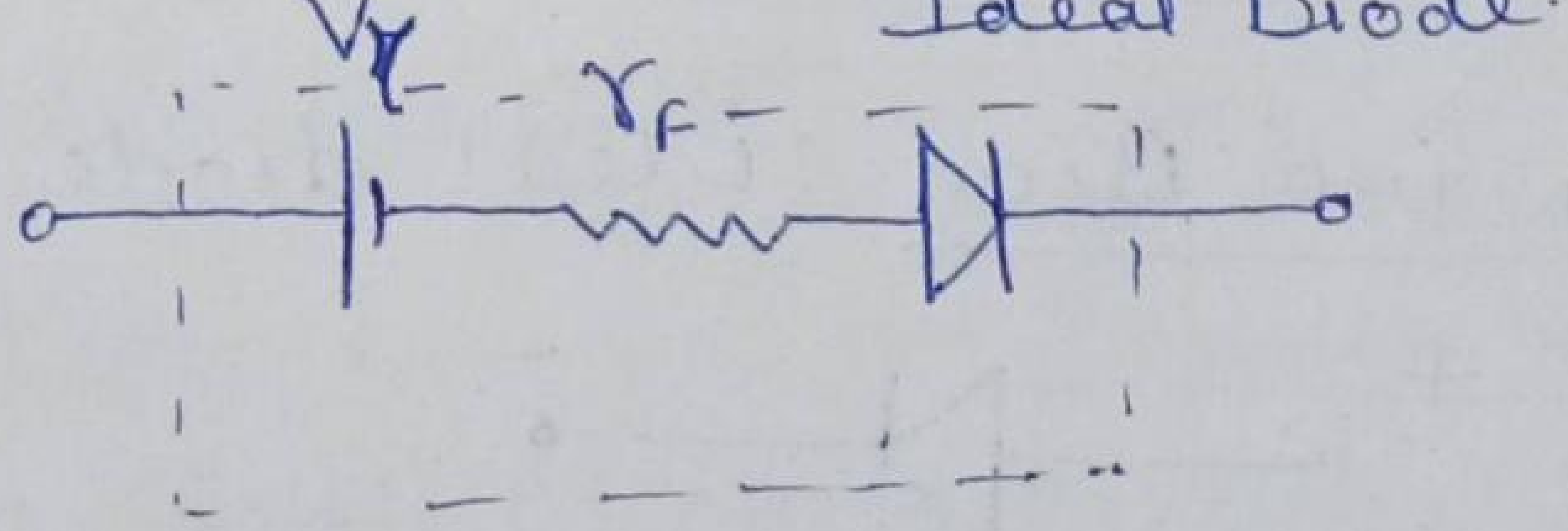
Diode Equivalent Circuits

An equivalent circuit is a combination of elements properly chosen to best represent the actual terminal characteristics of a device, system or such in particular operating region.

1) Piecewise-Linear Equivalent Circuit:

Practical diode

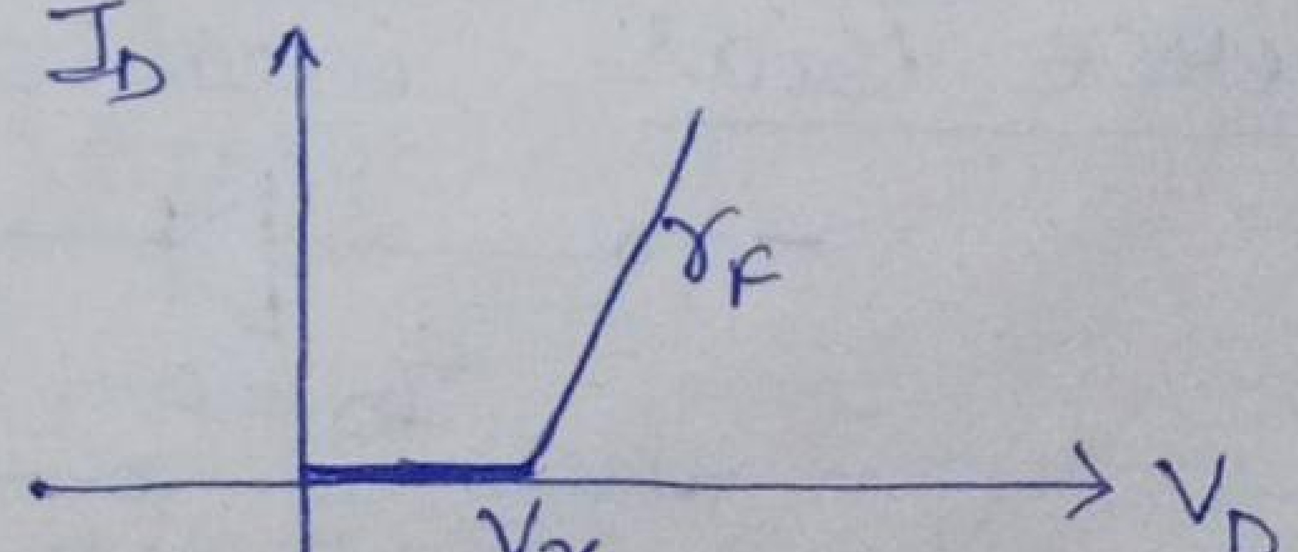
$\Rightarrow$



Piece wise linear equivalent Circuit

Cut in Voltage $\rightarrow$ $V_\gamma = 0.7\,V$ Si

$V_\gamma = 0.3\,V$ Ge

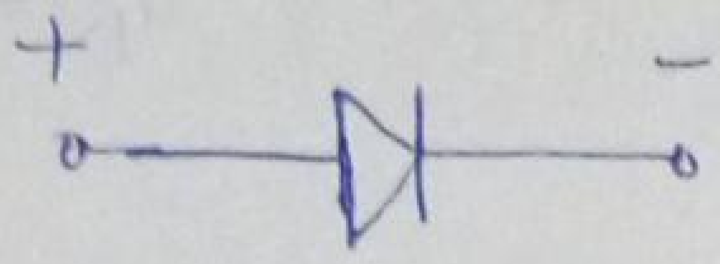


V-I characteristics

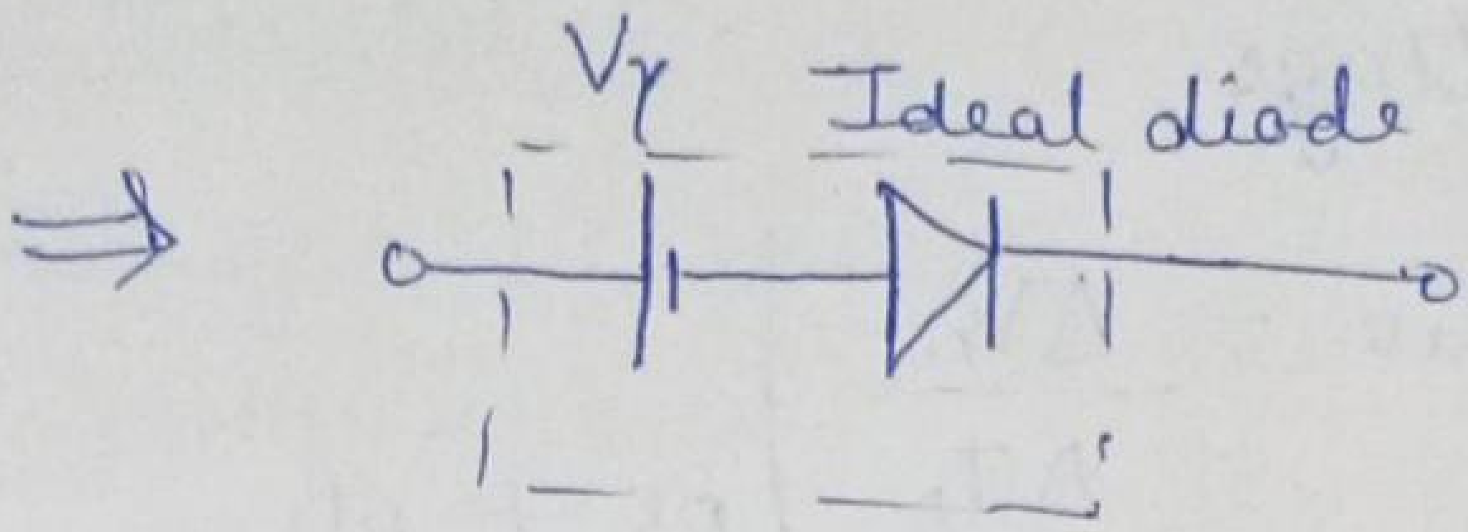
2) Simplified Equivalent Circuit

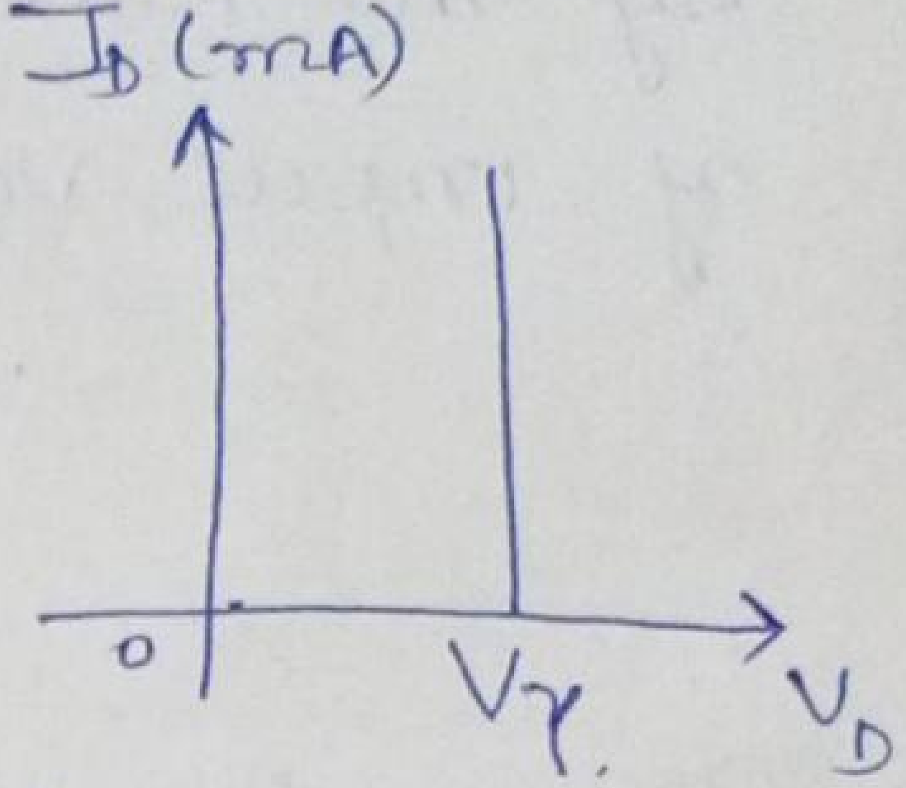
In most application the diode resistance r_F is sufficiently small in comparision to $R_{network}$

i.e. $r_F <<< R_{network}$



Practical Diode





$V_\gamma = 0.7$ Si

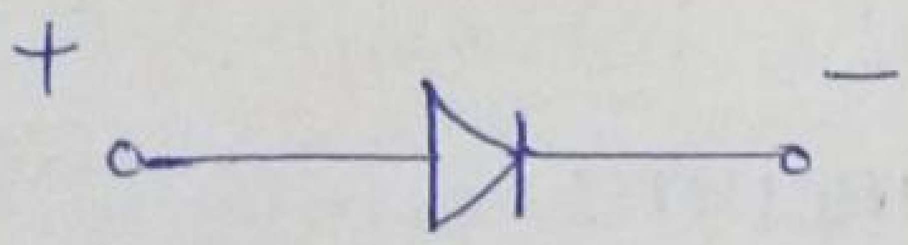
$V_\gamma = 0.3$ Ge { Cut in Voltage }

V-I characteristic

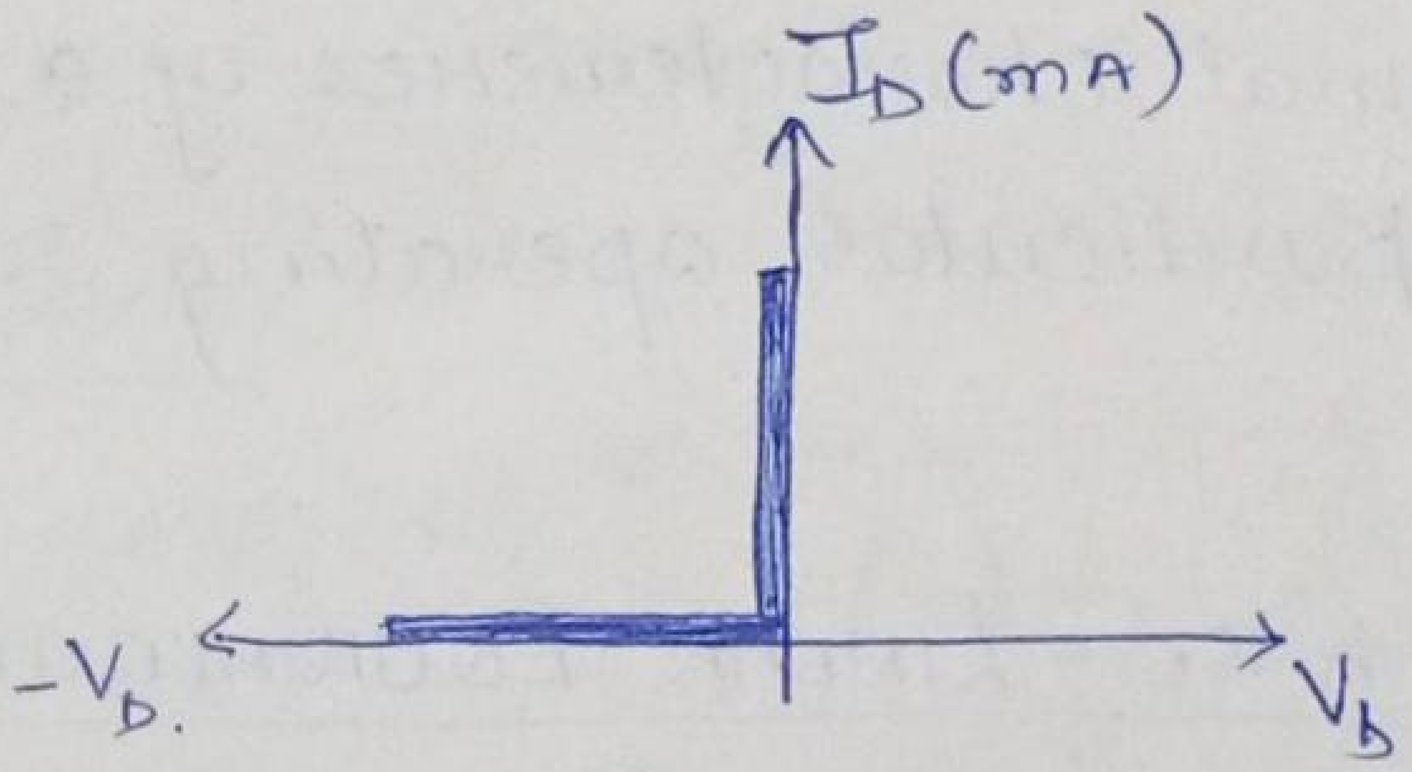
IDEAL DIODE

$R_{network} >>> r_F$

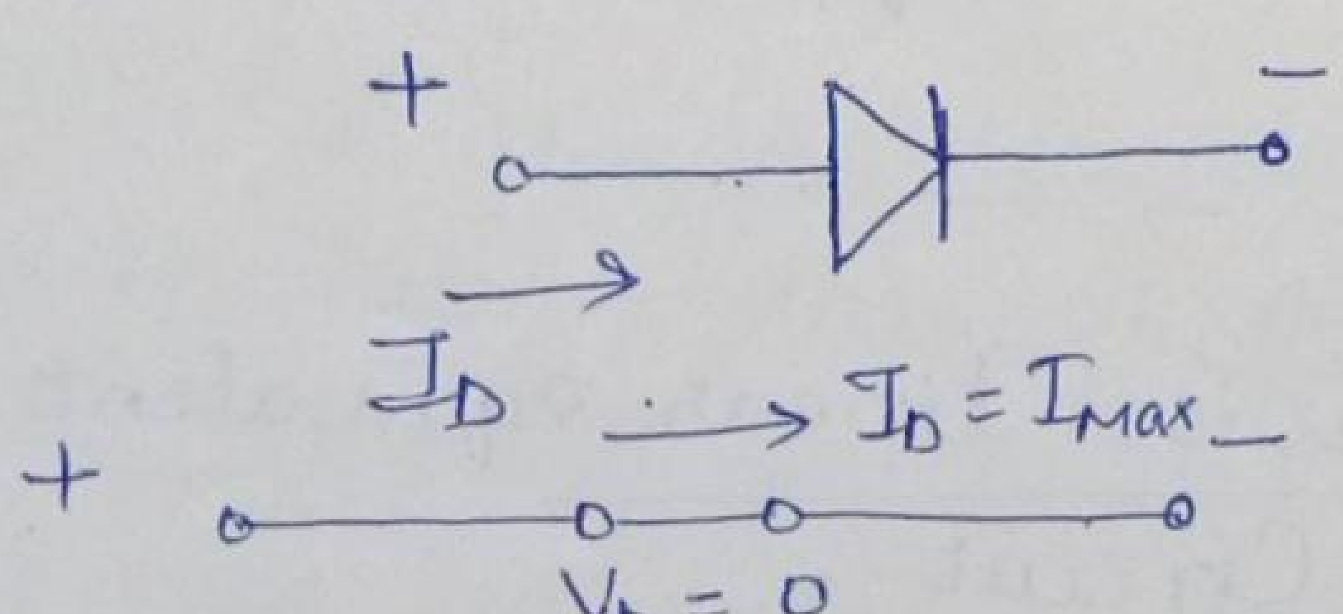
$E_{network} >> V_\gamma$



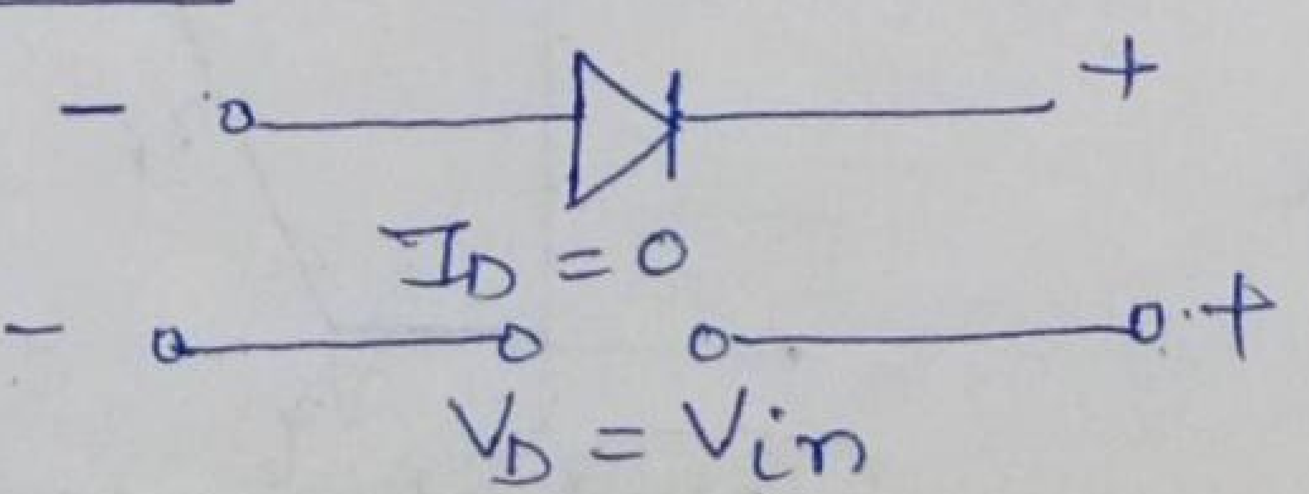
Ideal Diode



Forward Bias : ideal diode behave as short circuit



Reverse Bias : ideal diode behave as open circuit.

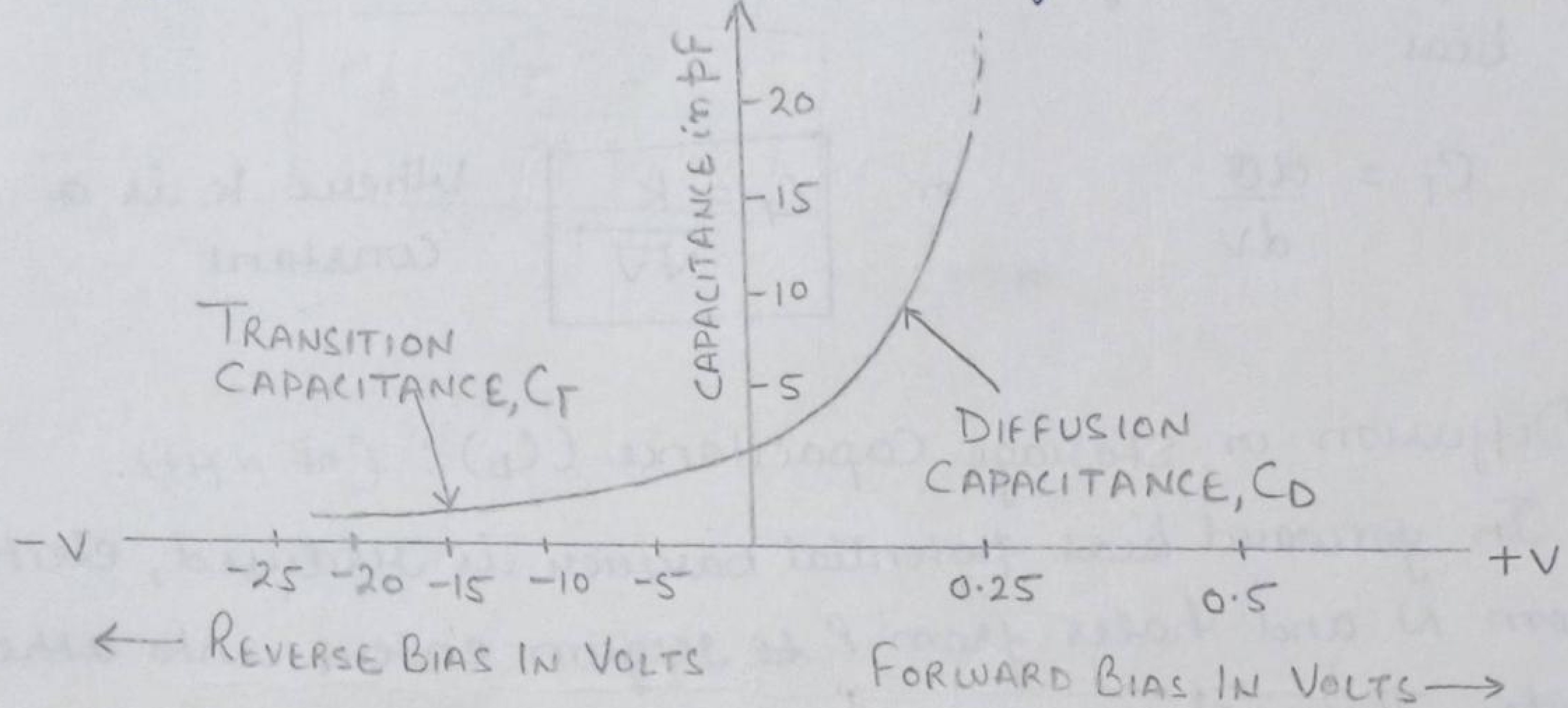


In a P-N Semiconductor diode, there are two types of Capacitive effects to be considered.

1) Transition (or Space-charge) Capacitance
2) Diffusion (or Storage) Capacitance

Both types of capacitance present in the forward and reverse-bias region, but one so outweighs the other in each region.

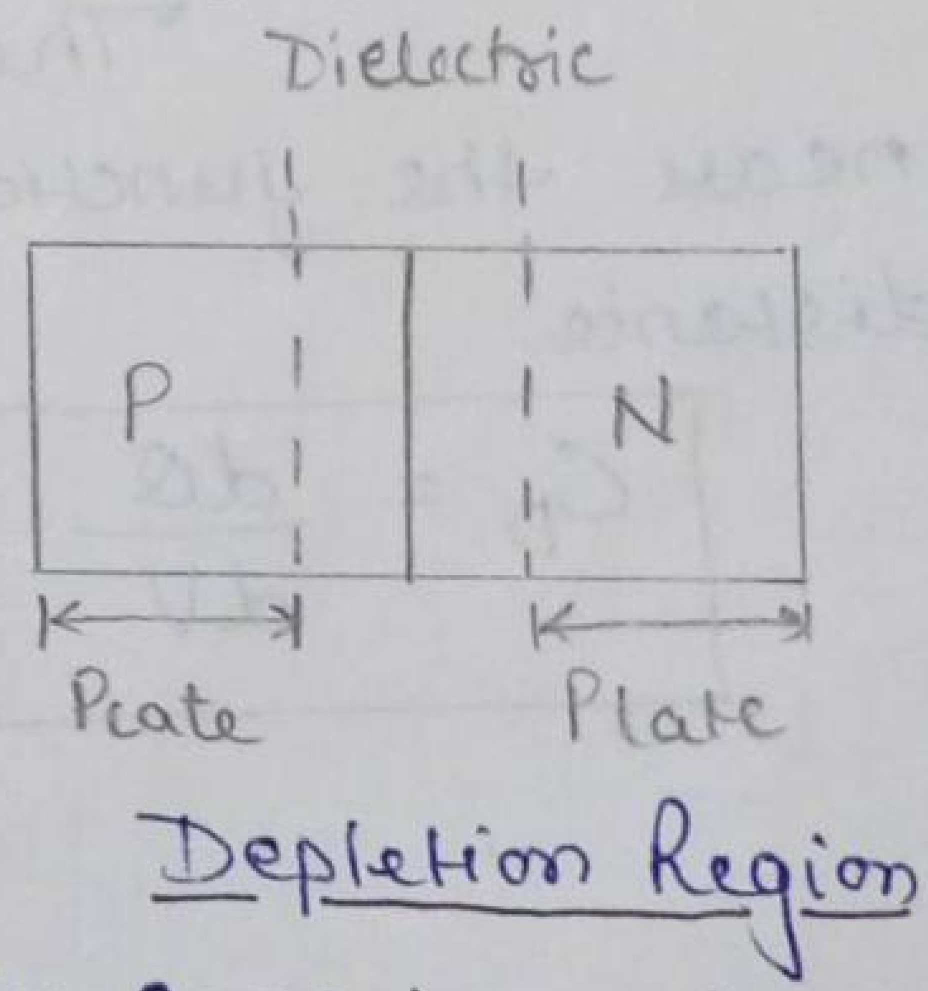
1



1) Transition (or Depletion) Capacitance : (C_T)

2

In reverse bias, the depletion region acts like an dielectric material P-type and N-type regions on either sides have a low resistance and act as the plate.



Reverse bias causes Majority carriers to move away from the junction, increasing uncovering immobile charge.

So the thickness 'W' of depletion layer increase with increase in reverse Voltage.

This increase in uncovered charge with applied Voltage is considered as capacitive effect.

$$C = \frac{\epsilon A}{d} \qquad C_T = \frac{C_0}{\left(1+\frac{V_R}{V_T}\right)^n}$$

$\epsilon_r = 16$ for Si
$\epsilon_r = 12$ for Ge

$\therefore$ C_T decreases with increase in reverse bias, as depletion layer increases with increase in reverse bias

$$C_T = \frac{dQ}{dV} \quad \text{or} \quad \boxed{C_T = \frac{K}{\sqrt{V}}}$$

Where K is a constant.

2) Diffusion or Storage Capacitance (C_D): (nf or μf)

In forward bias potential barrier is reduced, electron from N and holes from P region enters into other side. These charge carriers diffuses away from the junction and recombine.

The density of charge carrier is high near the junction and decays exponentialy with distance.

$$\boxed{C_D = \frac{dQ}{dV}}$$

dQ → change in no. of minority carriers stored outside the depletion region

dV → change in applied Voltage

$$I = \frac{Q}{\tau}$$

τ → Mean life time of charge carrier.

$$Q = \tau I$$

$$I = I_0 (e^{V/\eta V_T} - 1)$$

$$Q = \tau I_0 (e^{V/\eta V_T} - 1)$$

$$= \tau I_0 e^{V/\eta V_T}$$

$$\boxed{C_D = \frac{\tau I}{\eta V_T}}$$

$\because e^{V/\eta V_T} >> 1$

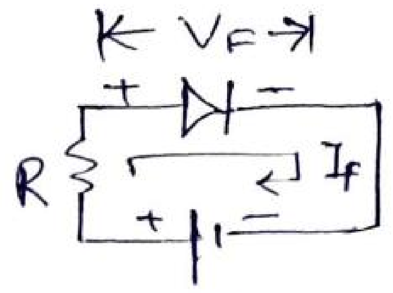
$$C_D = \frac{dQ}{dV} = \frac{d\tau I_0 e^{V/\eta V_T}}{dV}$$

$$C_D = \frac{\tau I_0}{\eta V_T} \cdot e^{V/\eta V_T}$$

$$C_D = \frac{\tau (I + I_0)}{\eta V_T}$$

$$\therefore \boxed{C_D = \frac{\tau I_f}{\eta V_T}}$$

Diode Ratings:



1) Forward Voltage drop: It is the anode to cathode voltage measured across a forward biased diode
V_F = 0.3 for germanium and 0.7V for silicon

2) Maximum forward Current: defined as the maximum value of forward current that can be allowed to pass through a forward biased diode without damaging it.

3) Average forward current: defined as the maximum average rectified current which can flow through a forward biased diode without damaging it

4) Reverse saturation current: defined as the current flowing through a diode in reverse biased state due to minority charge carriers.
⇒ nA for silicon and µA for Germanium

5) Power dissipation: defined as the maximum power a diode can dissipate without damaging itself

$P_D = V_F \times I_F$

V_F = forward voltage across diode
I_F = forward current.

6) Peak Inverse Voltage: It is maximum reverse Vol which can be applied across a diode without damaging it.

7) Junction Temperature $[T_{j(max)}]$: Maximum temperature a junction is allowed to operate at, without getting damaged

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