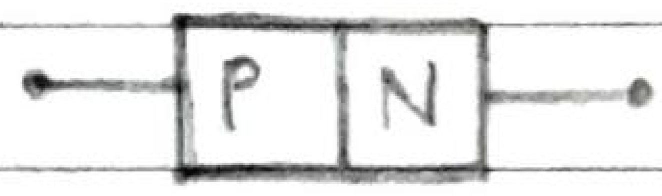
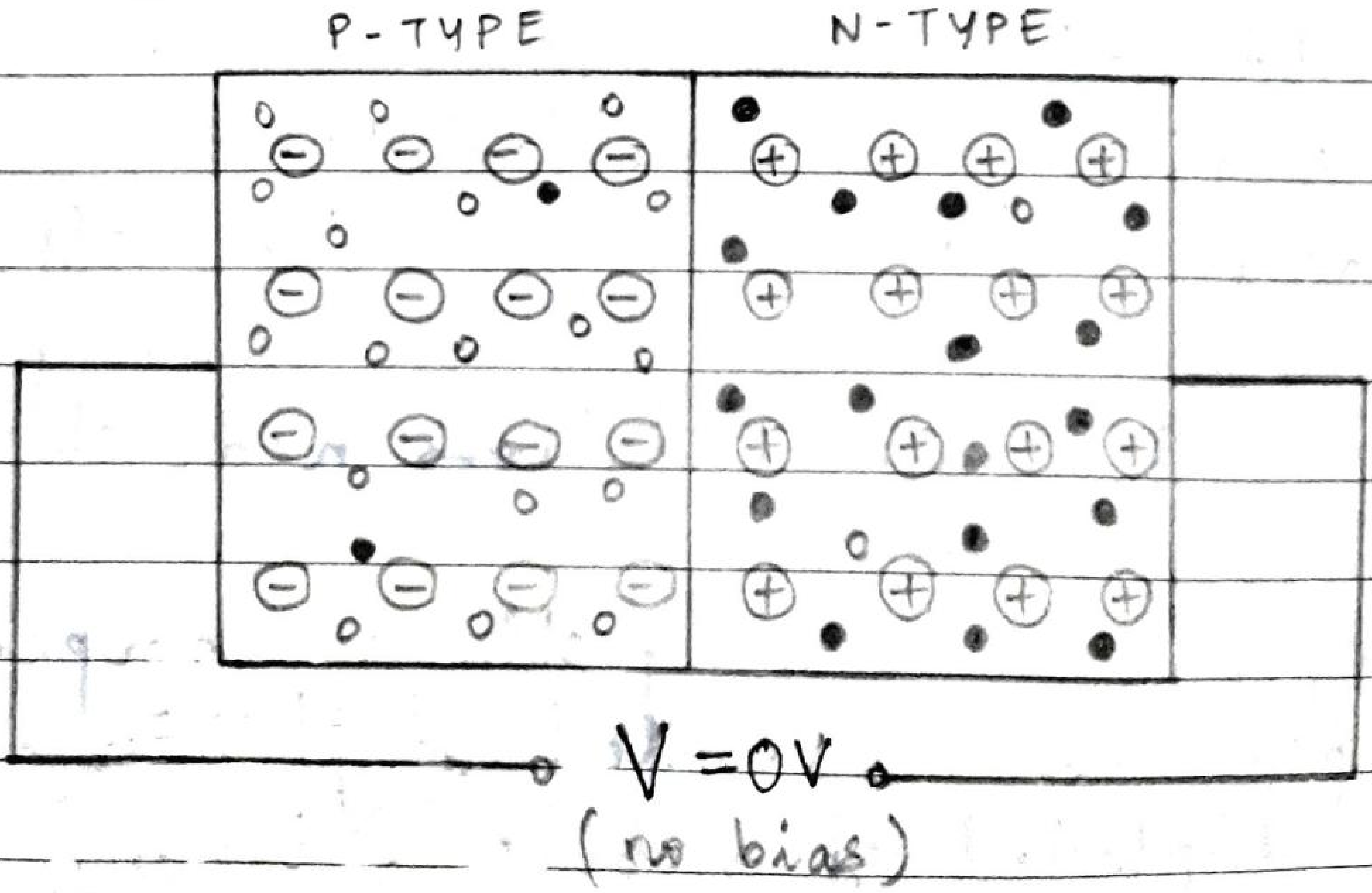
SEMICONDUCTOR DIODE

- P-Type & N-type materials used seperately are of very limited use.
- Electronic devices like Diodes & Transistors are formed by using P & N material together.
- A Semiconductor 'Diode' is formed by simply joining a P-type material to a N-type material
- Also known as 'PN-Junction'



- It is a 2-terminal device.
- Application of voltage across it, gives us 3 possibilities
  - no bias ($V = 0V$)
  - forward Bias ($V > 0$)
  - Reverse Bias ($V < 0$).

CASE I] NO APPLIED BIAS. ($V = 0V$)



As soon as P-N junction is formed, the following processes are initiated :

(1) Holes from P-region diffuse into N-region & combine with free e̅s in N-region.

(2) Free e̅s from N-region diffuse into P-region & combine with holes in N-region.

* The diffusion of holes & e̅s takes place because they move hap-hazardly due to thermal energy & also because their concentration in the two regions is different.

(3) However all holes in P-region & all free e̅s in N-region do not recombine.

The diffusion occurs for a very short time. After which, a restraining force is set up automatically. This force is called <u>Barrier</u> or <u>Potential Barrier</u>. Further diffusion is stopped by the barrier

(4) <u>**How is the barrier formed**</u> ?

When the holes & free e̅s recombine, the -ve acceptor ions in P region & the +ve donor ions in the N-region remain uncompensated.

Hence a +ve charge is built on the n-side of the junction & -ve charge is built on p-side.

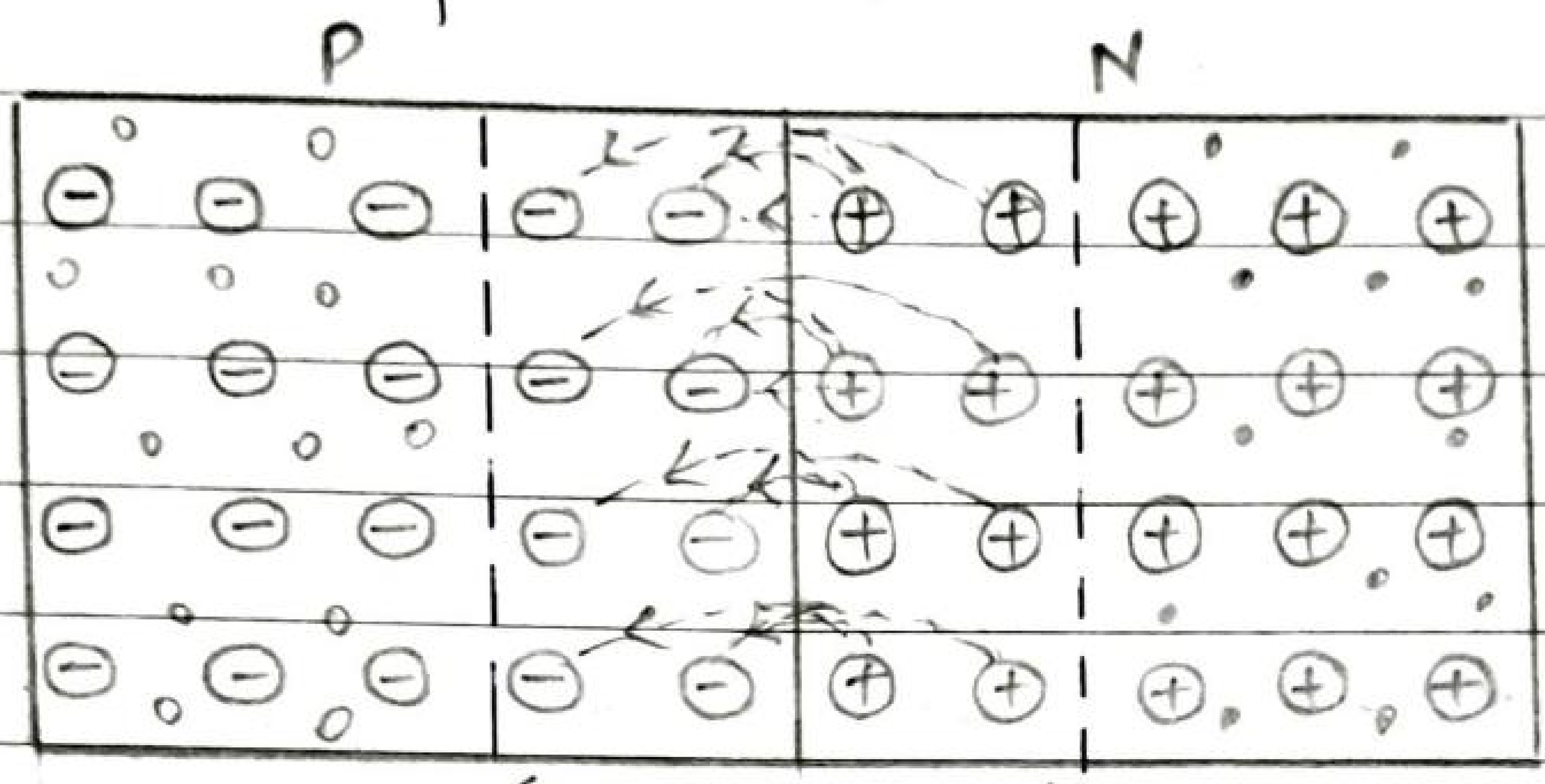
Now, additional holes trying to diffuse into the N-region are repelled by the uncompensated +ve charge. $|||^{ly}$ e̅s trying to diffuse into the P-region are repelled by the uncompensated -ve charge of the immobile ions near the j^n. Thus the barrier is formed.

(5) The region containing the uncompensated donor & acceptor ions is called <u>depletion region</u>

($\because$ it is depleted of mobile holes & free e̅s)

This region is also known as Space-charge region (Since it has immobile ions which are electrically charged).

- The electric field between the acceptor & donor ions is called Potential barrier.



Barrier / Depletion region

- The physical distance from one side of the barrier to the other is called 'width' of the barrier.
- The difference of potential from one side of the barrier to the other is called 'height' of the barrier.

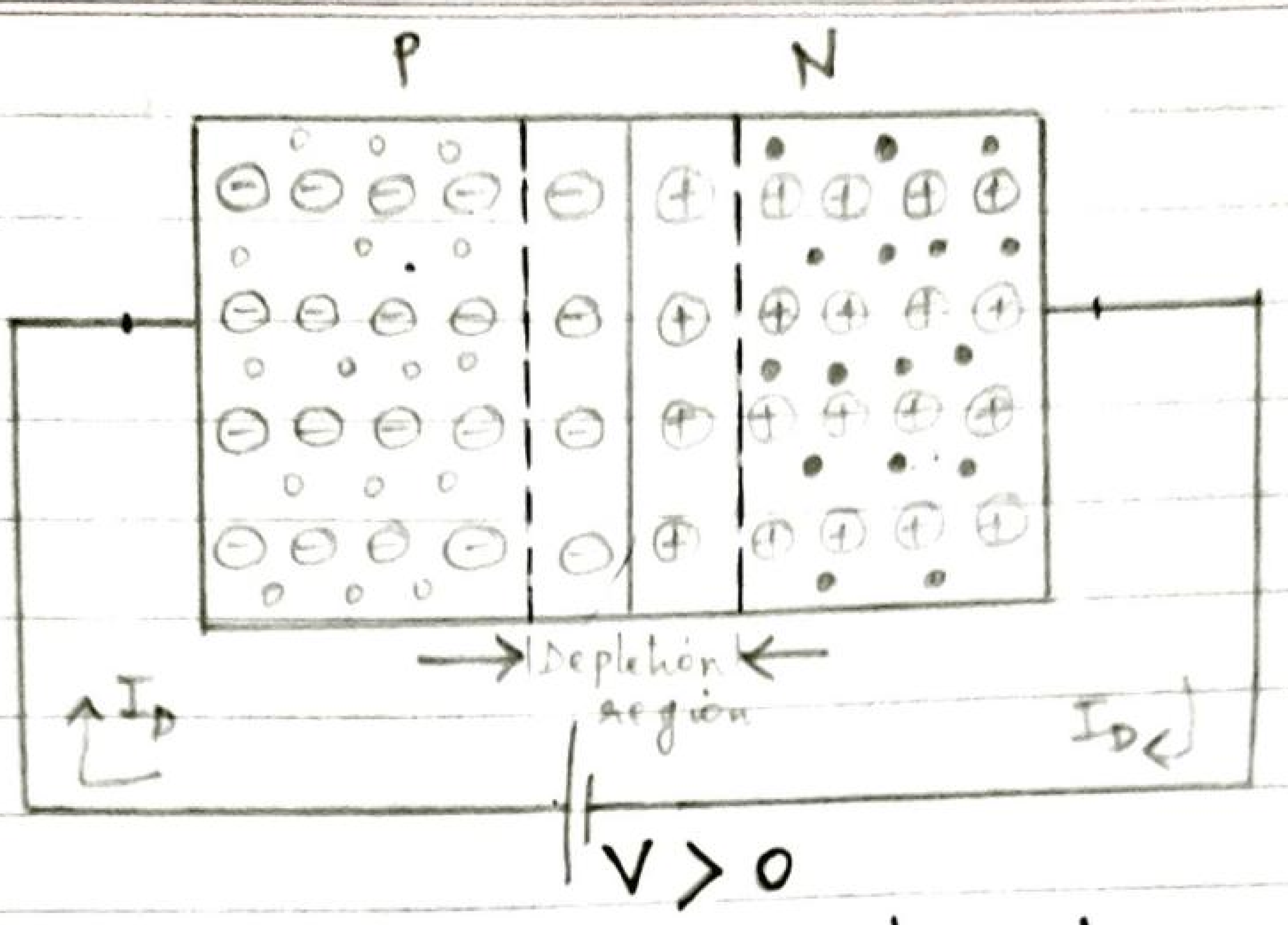
* For Si → Barrier Potential = 0.7V
For Ge → Barrier Potential = 0.3 V

* There will a very small drift current due to minority current (Barrier electric field helps them to cross) which is negligible.

CASE II] FORWARD BIAS. (V > 0).

Suppose we connect a battery to the P-N j^n such that the +ve terminal of the battery is connected to the P-side & the negative terminal is connected to the N-side, the P-N j^n is said to be Forward Biased.

PN - J^n showing FB :-



- When PN junction is FB, due to positive potential applied at the P-side, the holes are repelled from the +ve terminal of the battery & are compelled more towards the junction.
- In the same way, the e's are repelled from the -ve terminal of the battery & more towards the junction.
- These holes and e's penetrate the depletion region. This reduces the potential barrier ∴ <u>The width of the depletion region & barrier height reduces</u>. These carriers recombine.
- For each recombination of e & hole, an e from the -ve terminal of the battery enters the n-type material. It then drifts towards the junction. $|||^y$ in p-type material, an e breaks a bond in the crystal & enters the +ve terminal of the battery.

Thus e current flows thr' external circuit.

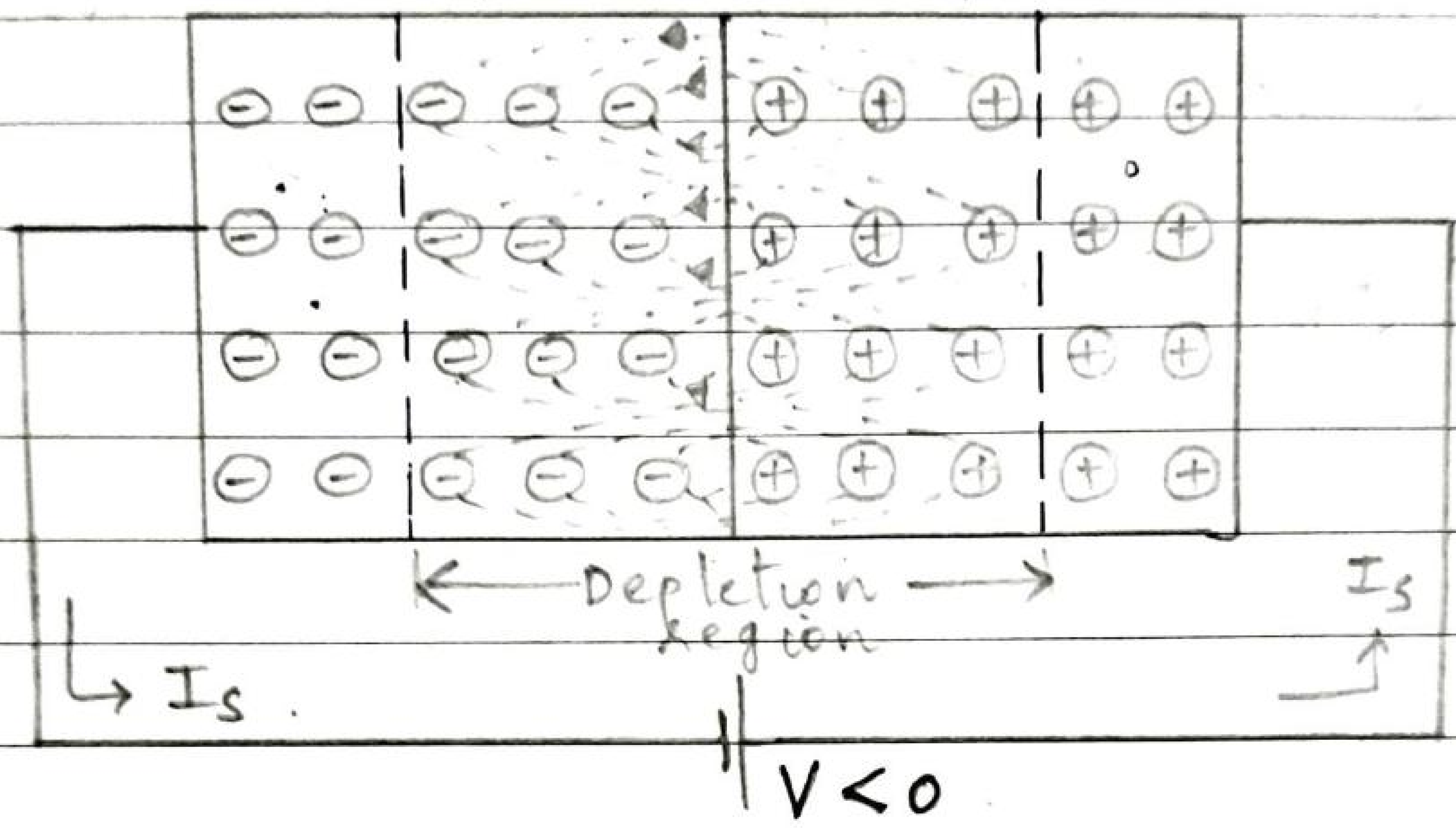
* Conventional current flows from p side to n-side. This is called the forward current.

If battery voltage is increased, barrier potential is further reduced. More majority carriers diffuse across the j^n. Thus current through PN j^n increases.

CASE III] REVERSE BIAS (V < 0).

If we connect battery to a PN-junction diode such that the +ve terminal of the battery is connected to N-side & -ve terminal to p-side, the PN j^n is said to be reverse biased

PN-J^n Showing R.B:



- When PN junction is R.B, the holes in P-region are attracted towards the -ve terminal of the battery & the $\bar{e}$s in the N-region are attracted towards +ve terminal of the battery
- Thus the majority carriers are drawn away from the j^n. This widens the depletion region & increases the barrier potential.
- This makes it more difficult for the majority carriers to diffuse across the j^n.
- However the barrier potential helps the minority carriers to cross the junction. Thus a very small current flows through the diode.
- The rate of generation of minority carriers depends on temperature (∵ minority carriers are generated by breaking of covalent bond. Temp ↑, more bonds break).

∴ The current due to minority carriers remains

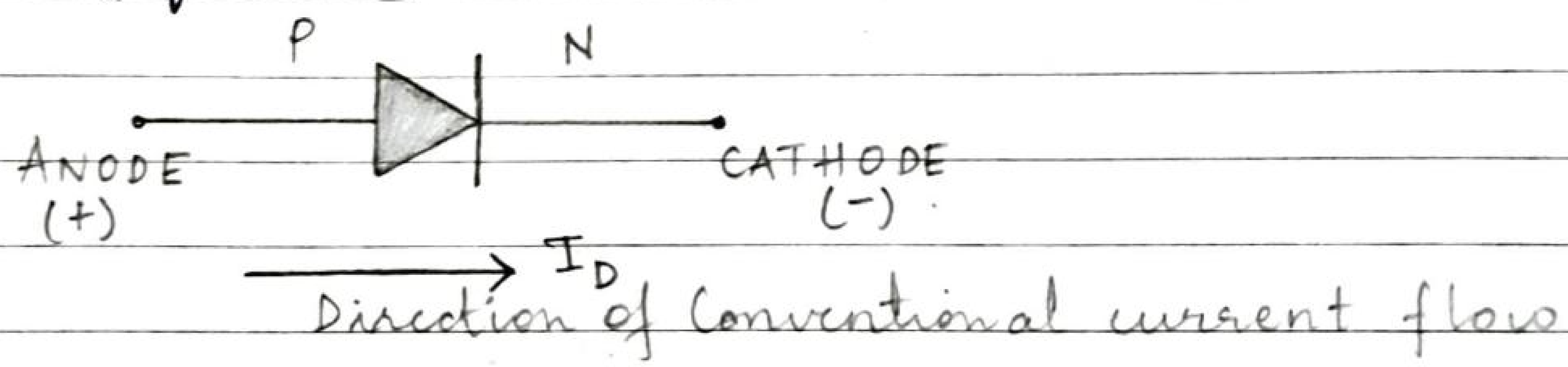
★ V → battery voltage
V_D → voltage across the diode.

same whether battery voltage is low or high. This current is called <u>Reverse Saturation current</u>. (μA in Ge & nA in Si → small current).

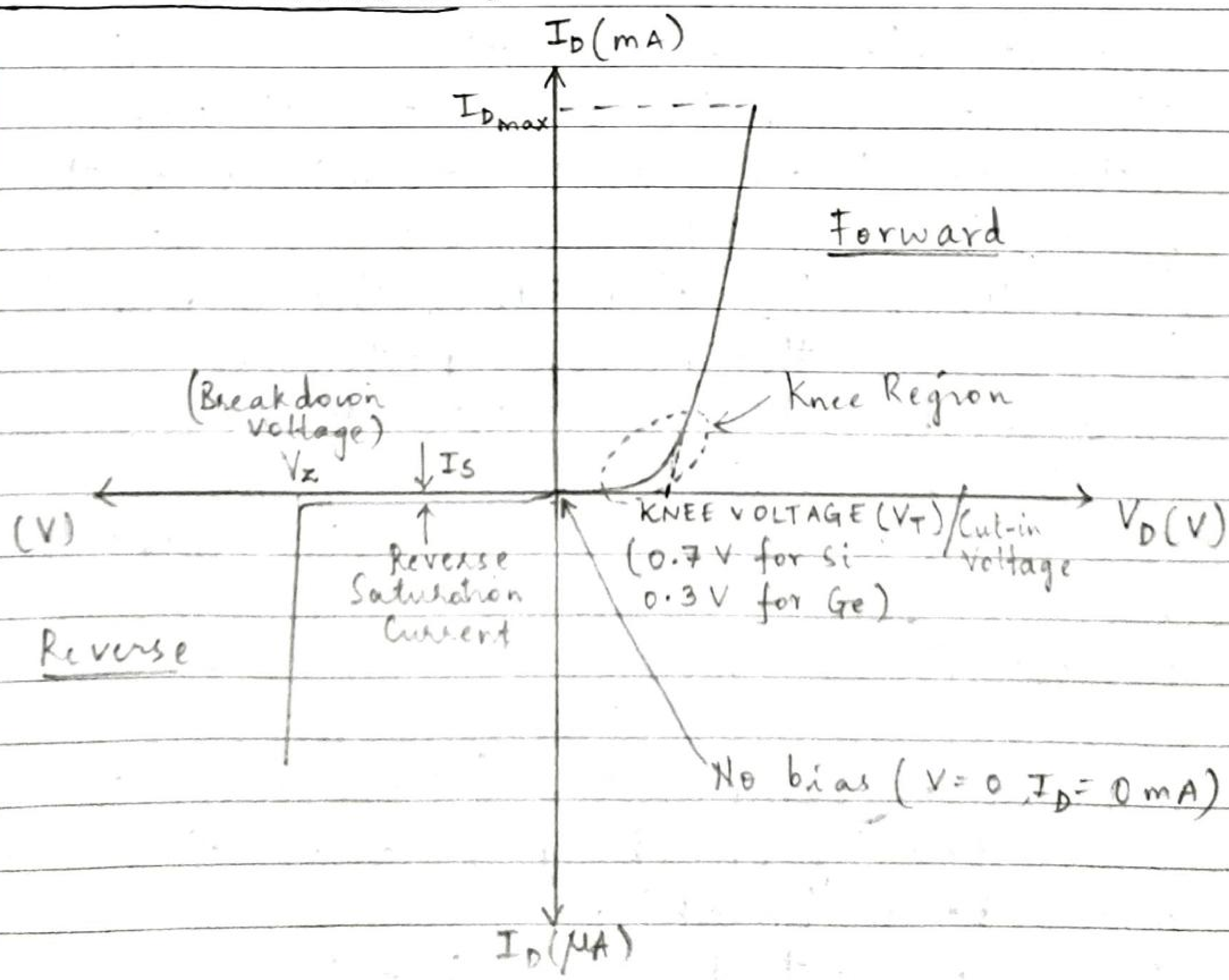
★ <u>V-I CHARACTERISTICS OF A PN-JUNCTION DIODE</u>

V-I characteristics is a graph of the voltage across the diode (V_D) & the current that flows through it (I_D).

<u>Symbol of Diode :</u>



<u>V-I Characteristics :</u>



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The V-I characteristics can be studied under 3 cases:
(i) When external voltage is zero (no bias) - potential barrier does not permit current flow $\therefore I_D = 0\,mA$.
(ii) Forward bias: Potential barrier gets reduced. Till the external voltage overcomes the barrier potential, the current is very small. As we approach the barrier potential (0.3 V for Ge, 0.7V for Si) large no of free e's & holes start to cross the j^n. Above this even a small increase in applied voltage produces a sharp increase in I_D.
This voltage at which current starts to increase rapidly is called Cut-in or Knee Voltage of the diode.
(★ After this V_D remains almost constant at 0.7 V for Si)
* If too large current passes through the diode, excessive heat will destroy the diode.
∴ A diode's data sheet has the max current I_{Dmax} that a diode can safely handle.
(iii) Reverse bias: Potential barrier is increased. No majority carrier current flows thr' the circuit. But a very small current (in μA) flows due to minority carriers. This is called reverse saturation current (I_S).
* If the reverse voltage is increased continuously, there is a point where the current increases at a very rapid rate. The potential (voltage) at which this happens is called Zener Potential (V_Z). It is also called Breakdown voltage.
This may destroy the junction permanently.