Helwan University - Faculty of Engineering (Helwan)
Electronics and Communications Engineering Department

# *Lec-2 Diodes: Structure & Operation*

**Presented By:**

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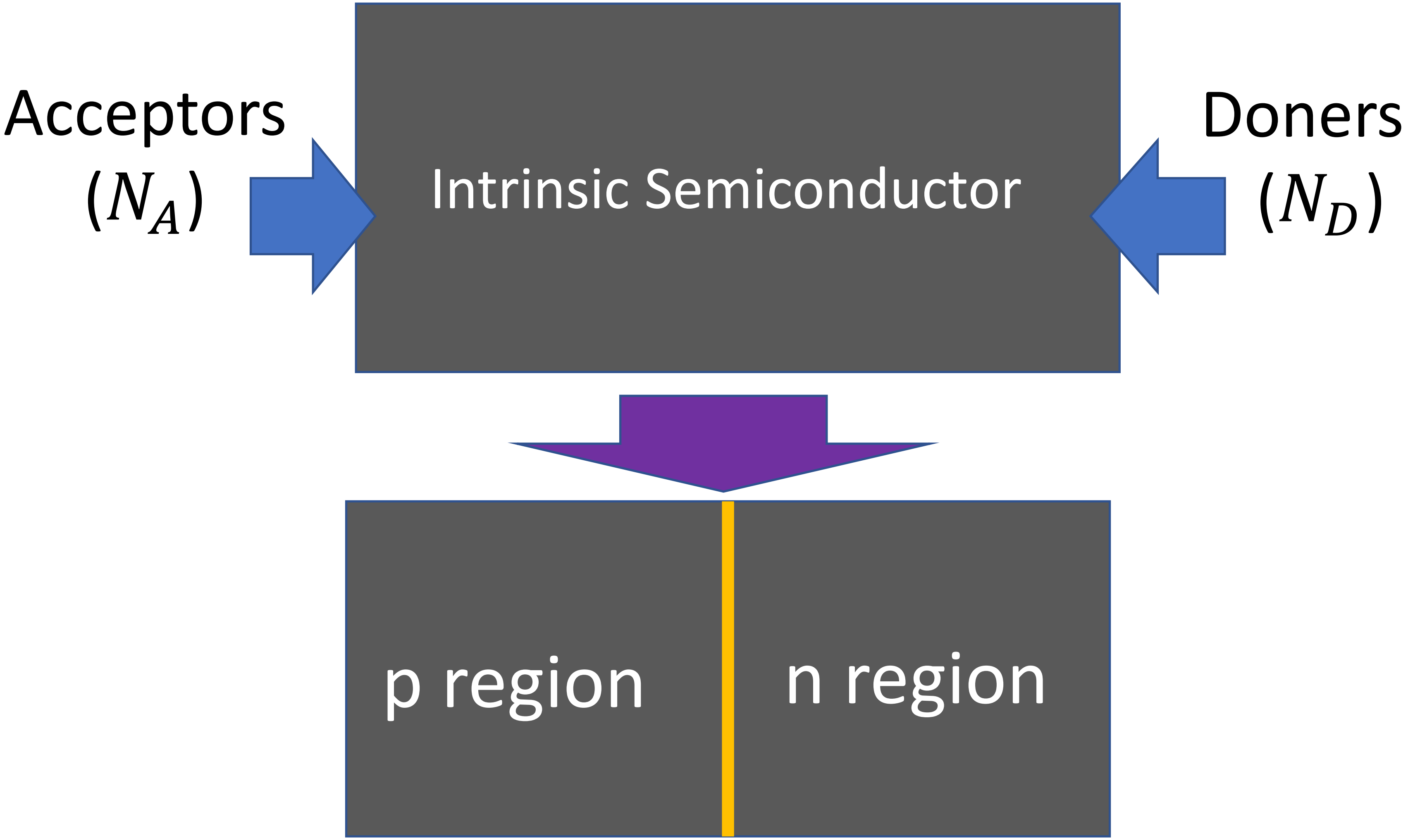
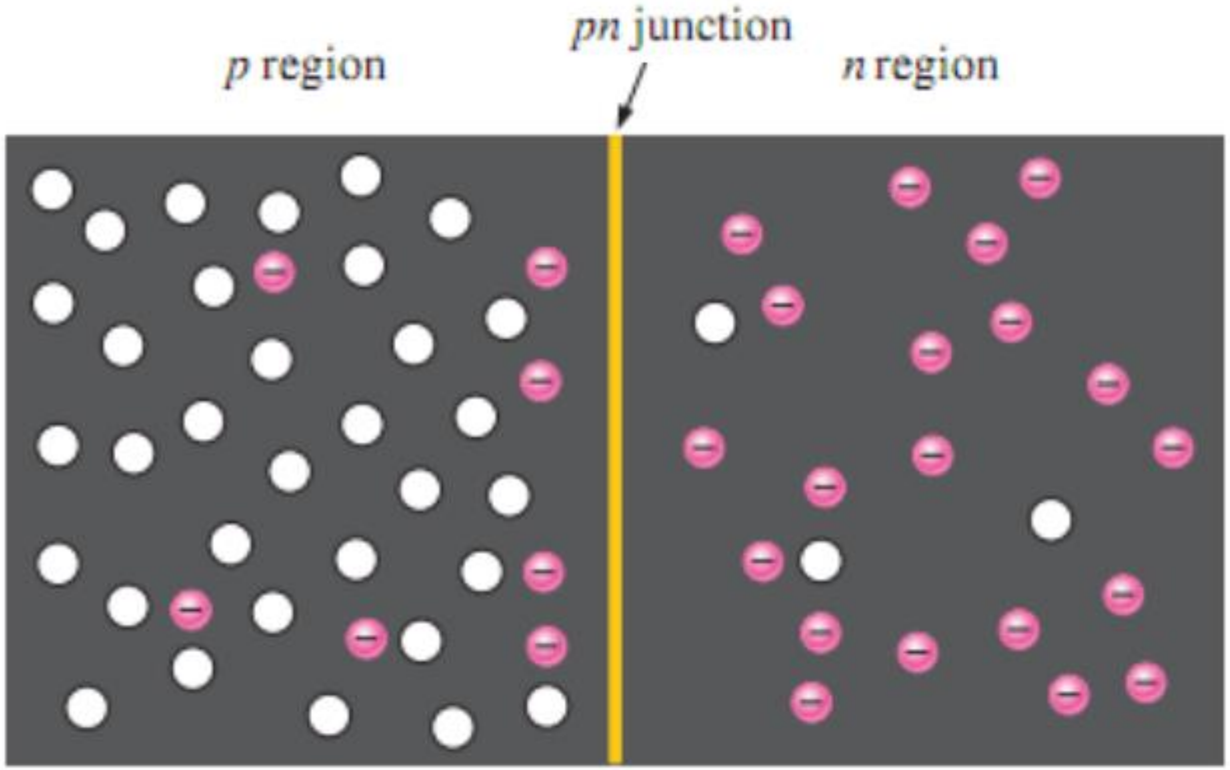
❑ If piece of intrinsic semiconductor is doped with acceptors on one side and with donors on the other side, a boundary called pn junction is formed between the resulting p region and n region and a diode is created.



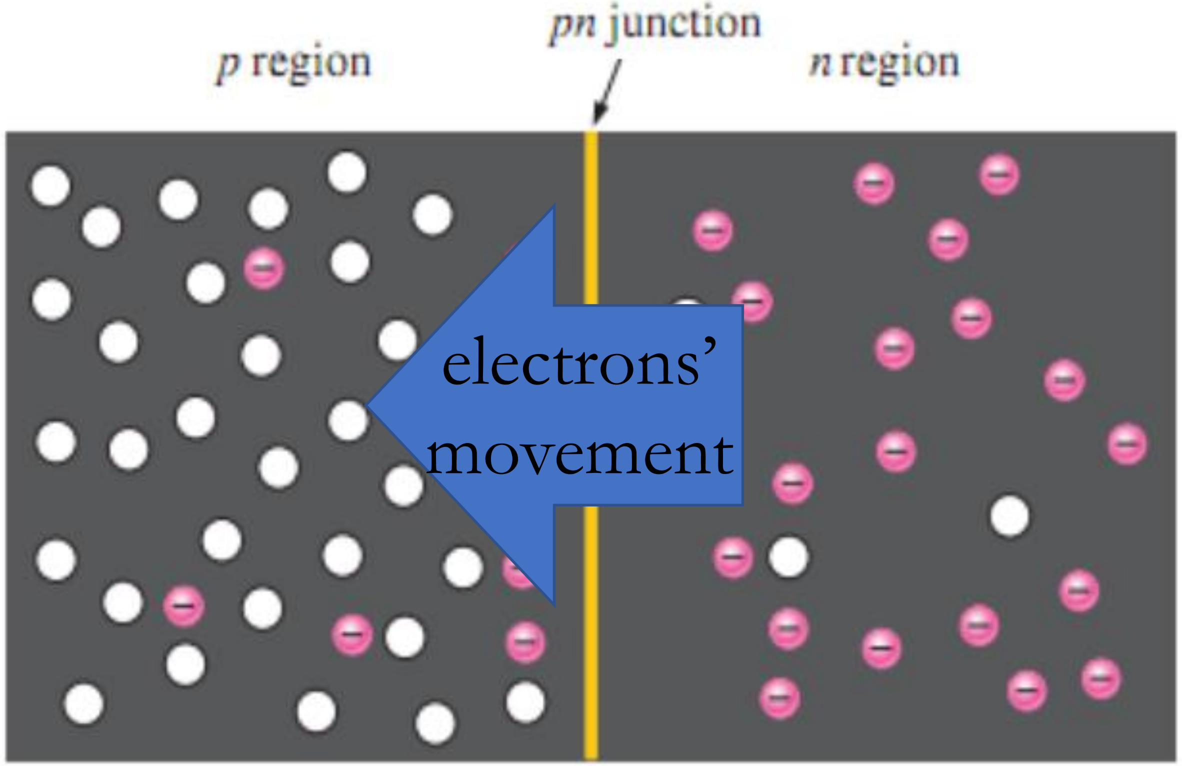
❑ The **p region** has many holes (majority carriers) from acceptor atoms and only a few thermally generated electrons (minority carriers).

❑ The **n region** has many electrons (majority carriers) from donor atoms and only a few thermally generated holes (minority carriers).



❑ **Free electrons** near the junction **in n region diffuse into p region** where they **combine with holes** near the junction.

The **p region** loses holes as the electrons and holes combine.

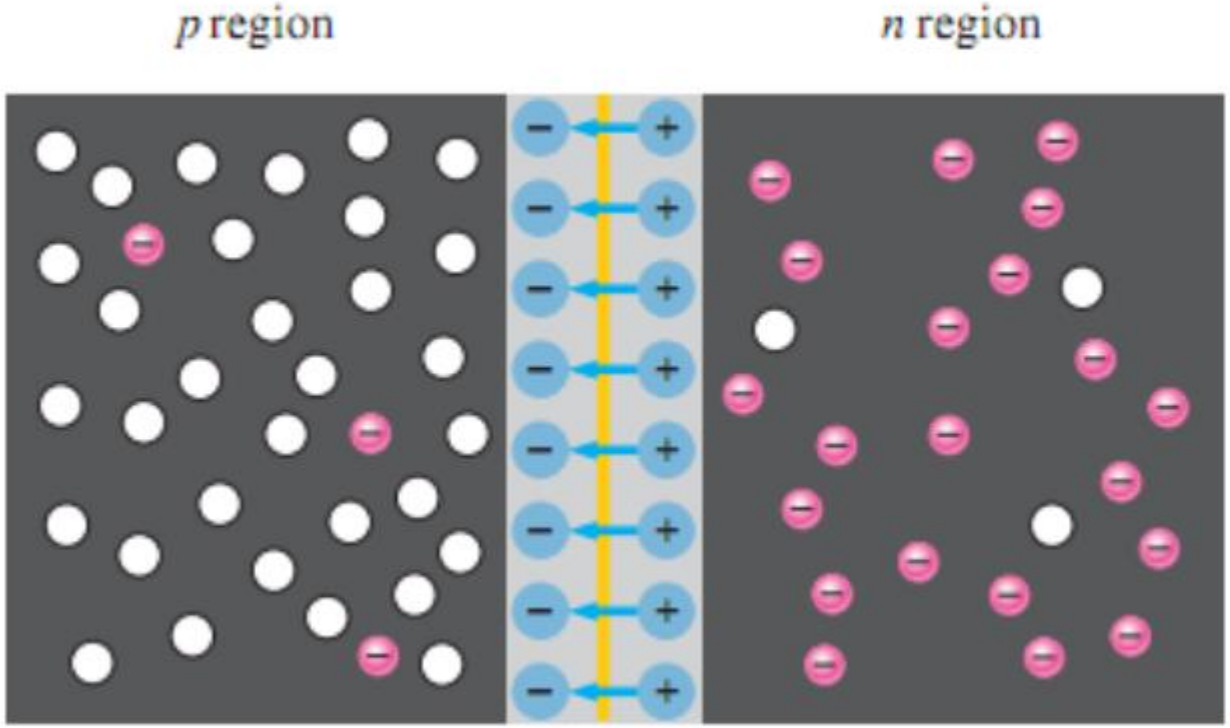



The **n region** loses free electrons as they diffuse across the junction.

- Layer of **positive charges** (donor ions) near the junction is created **in n region**.

- Layer of **negative charges** (acceptor ions) near the junction is created **in p region**.

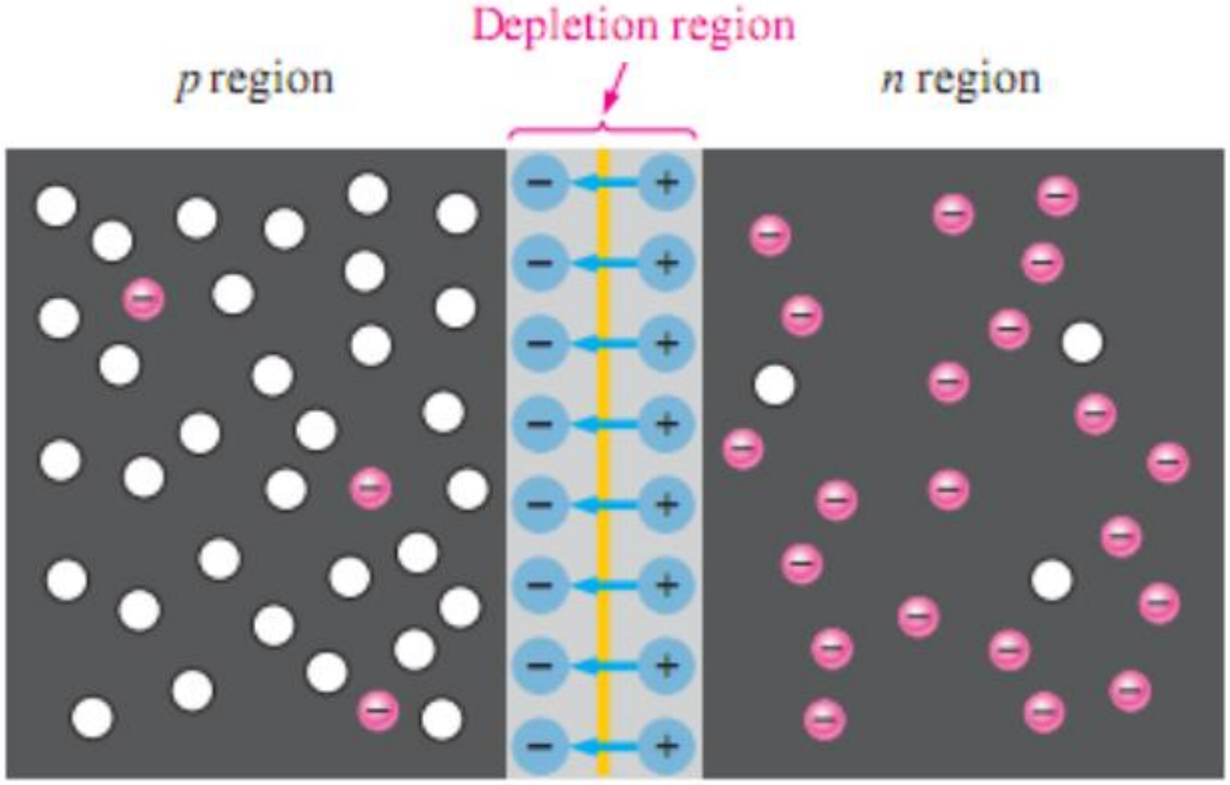
The **p region** loses holes.



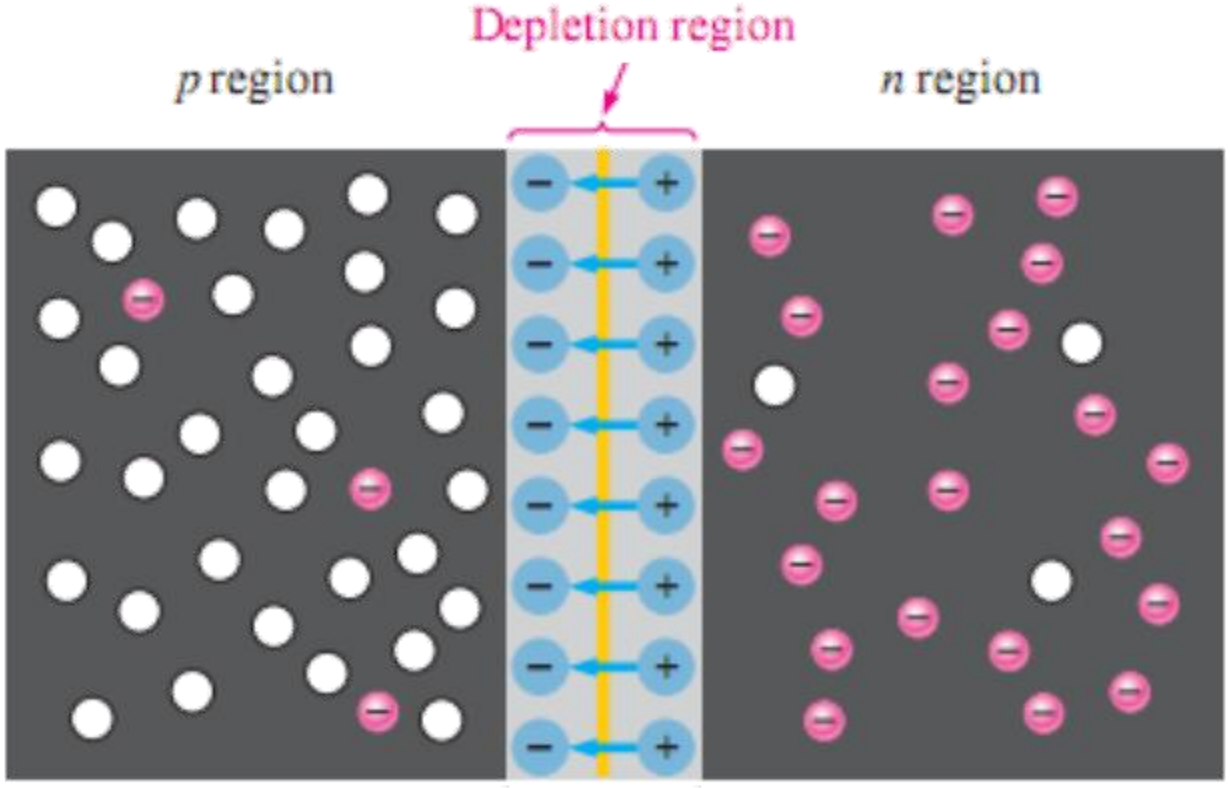

The **n region** loses free electrons.

- The region near the junction is called <u>a depletion region</u>.

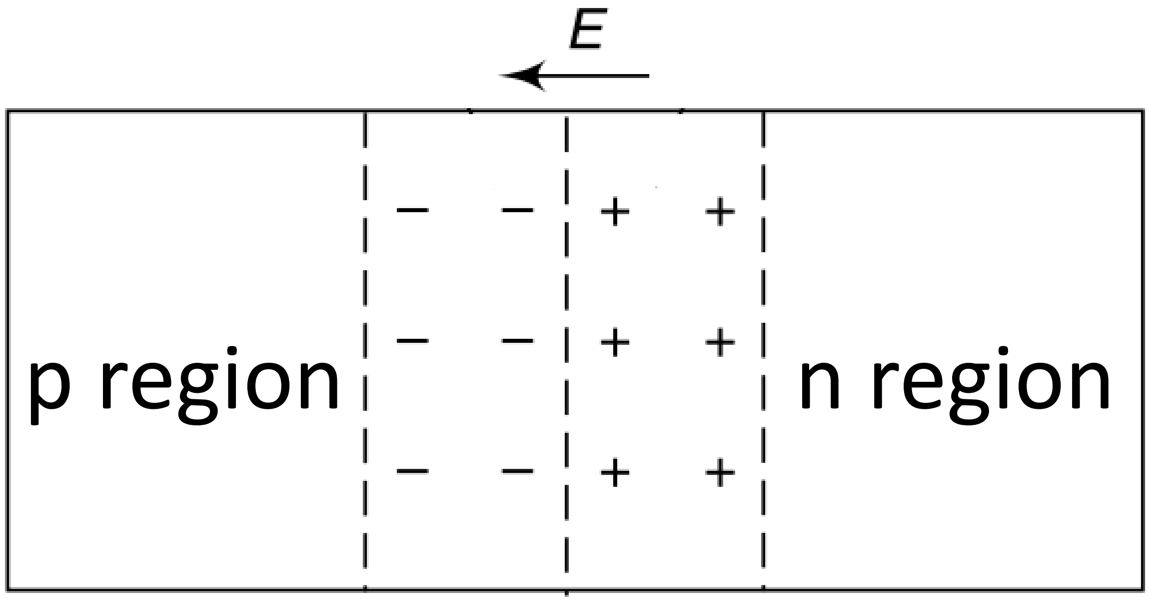
❑ The term **depletion refers** to the fact that the region near the junction is depleted (empty) of mobile charges (free electrons and holes).



- The positive and the negative **charges in the depletion region create an electric field**.

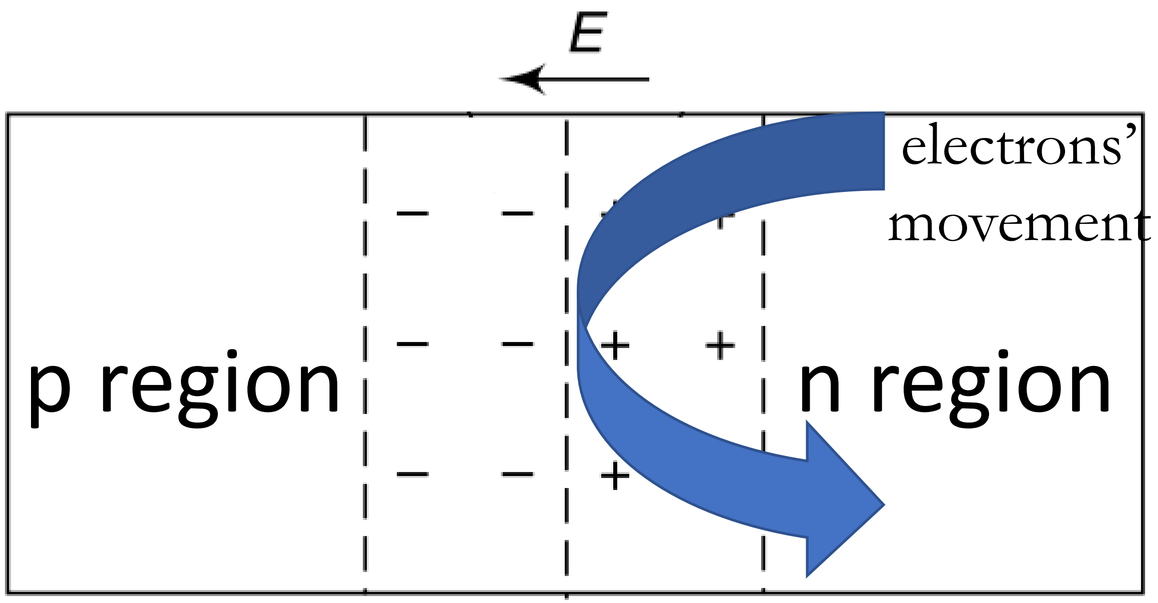


- If **electric field** ($E$) **is weak**, electrons in n region continue to diffuse across the junction, then more and more positive and negative charges are created near the junction.

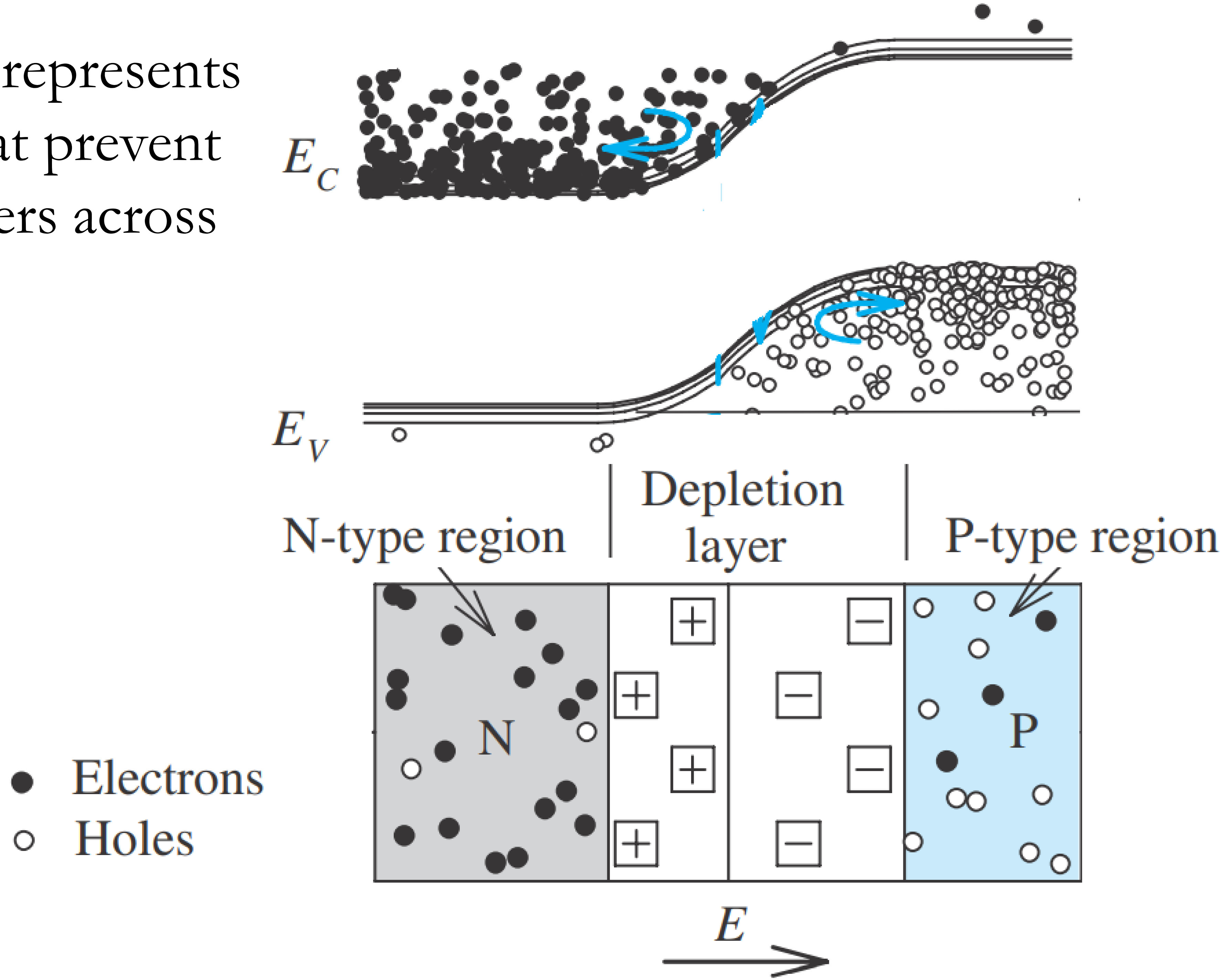



- When **electric field is large** enough, the diffusion process stops.

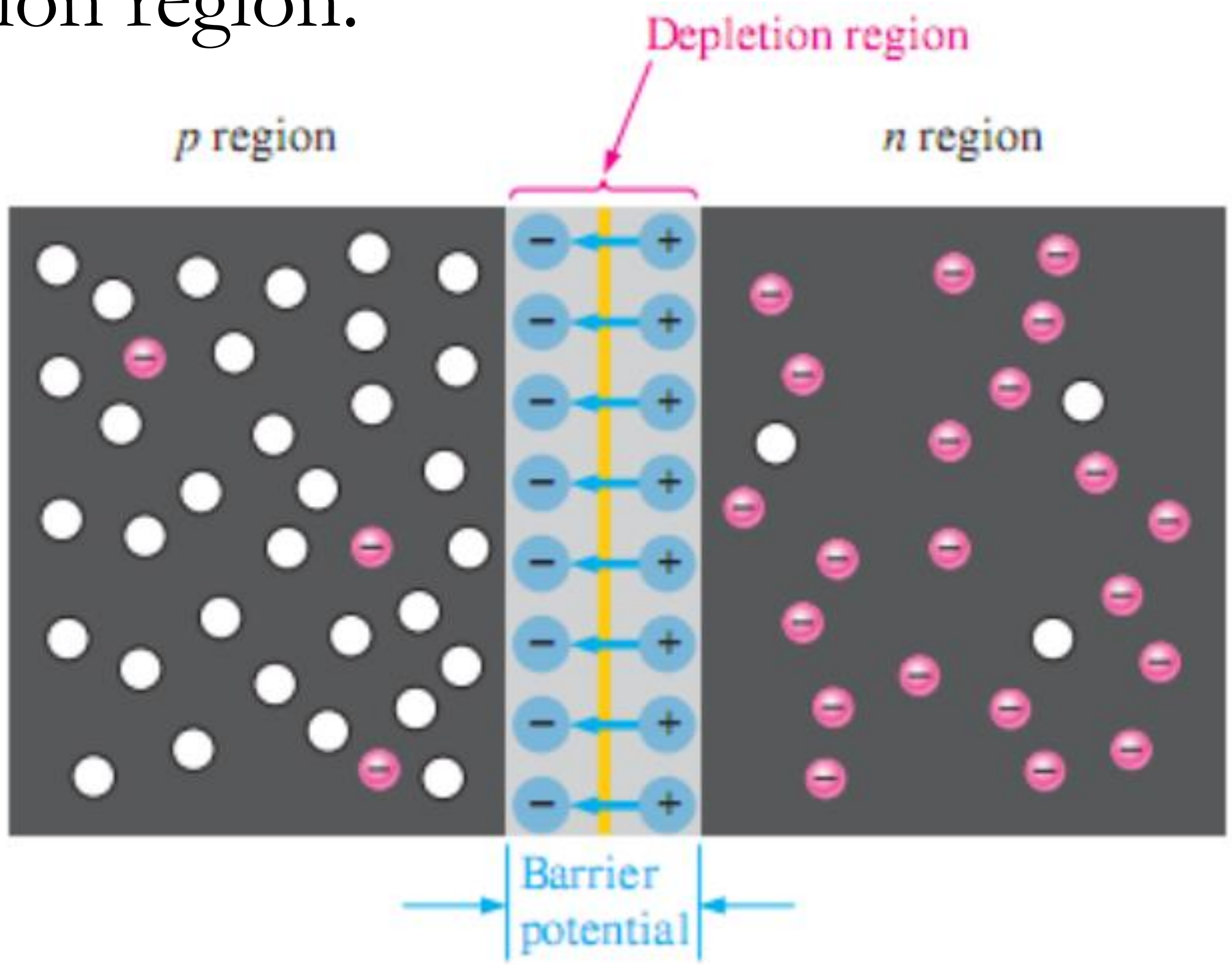
- In other words, **diffusion process stops** when the layer of negative charges is strong enough to repel any further diffusion of electrons from n region into p region.



❑ This electric field represents a barrier or a wall that prevent the flow of the carriers across the junction.



- This electric field results in a difference of potential ($V_B$) called **barrier potential** across the depletion region.



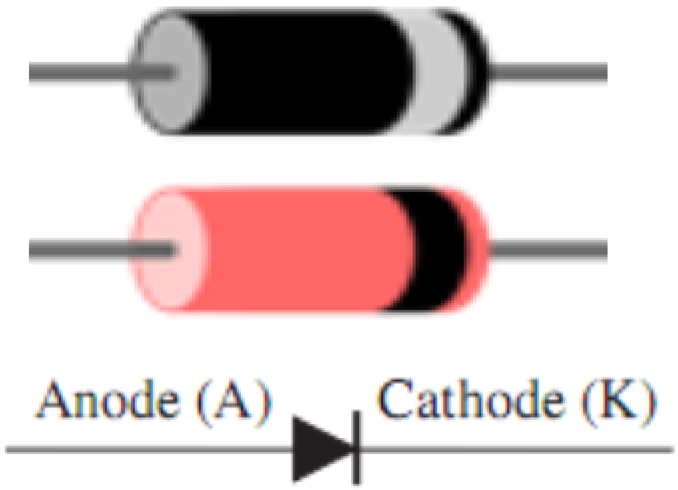

- **Barrier Potential** (difference of potential ) is expressed in volts and given by:

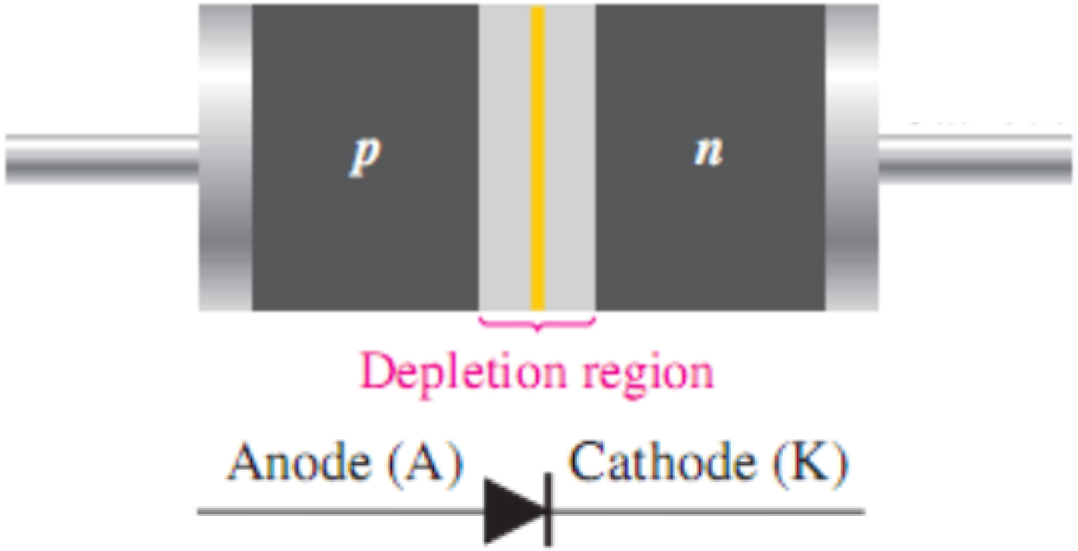
$$V_B = V_T \ln\left(\frac{N_A N_D}{n_i^2}\right)$$

*$V_T$ is thermal voltage.* *At room temp. (300 $^oK$):* $V_T = 0.025\,V$

# Diode Symbol

The **p region** of diode is called the **anode (A)** and is connected to a conductive (metal) terminal. The **n region** is called the **cathode (K)** and is connected to a second conductive terminal.



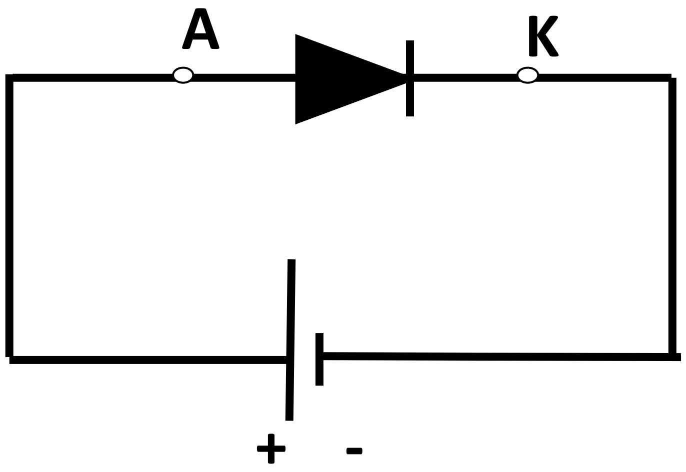

The anode is represented by a triangle, or an arrow and the cathode is represented by a vertical line.

The anode terminal is the flat side of the triangle (tail of the arrow).

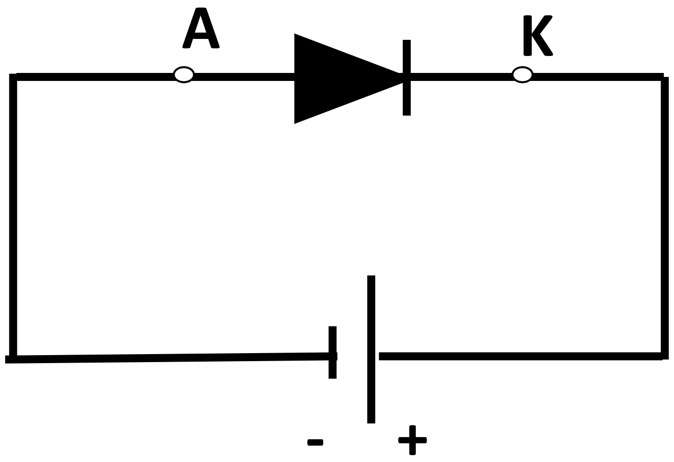
# Diode Biasing

refers to <u>applying an external voltage source across it</u> to establish certain operating conditions.

There are two biasing conditions: <u>forward</u> and <u>reverse</u>.



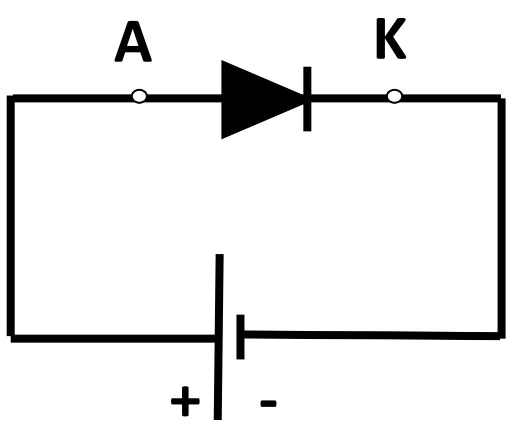

**Forward Biasing**

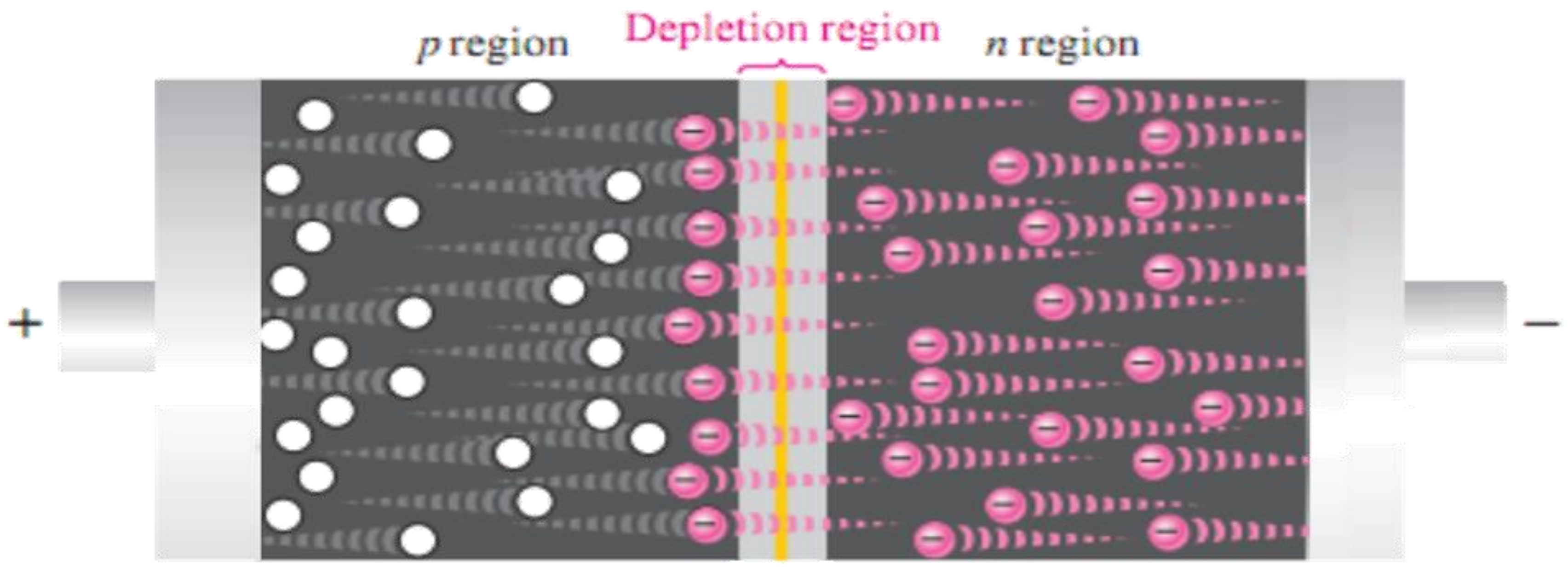



**Reverse Biasing**

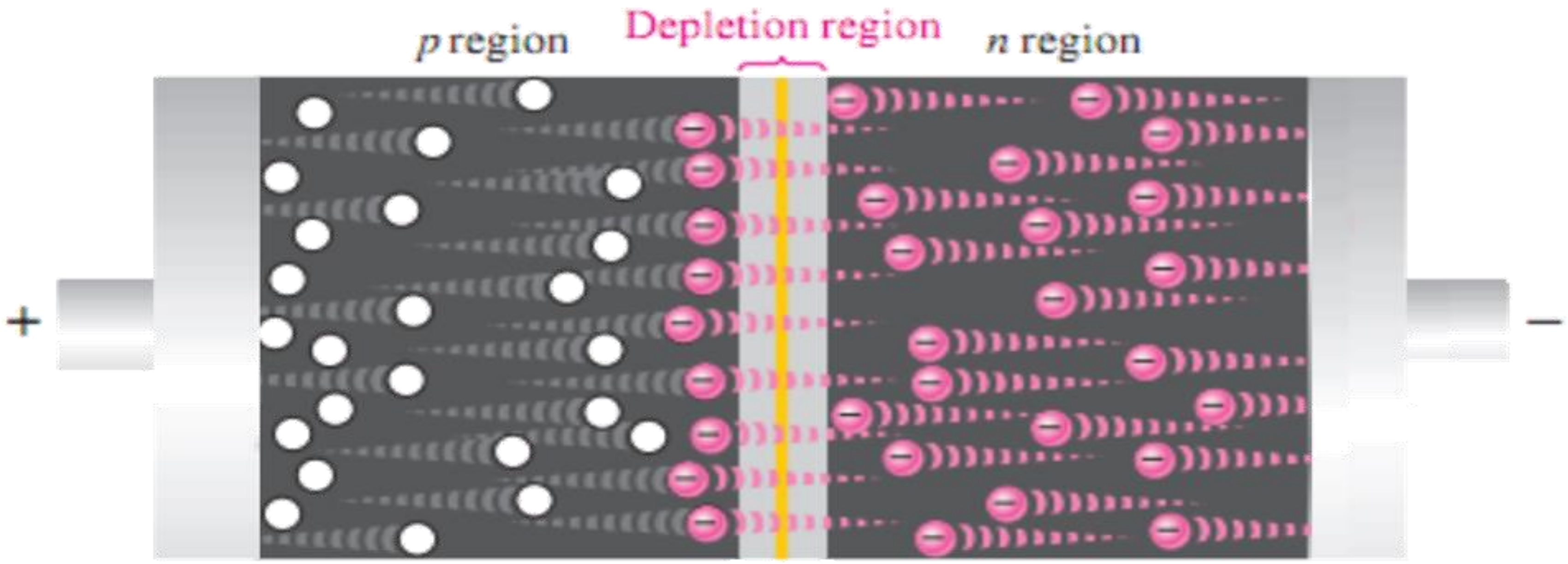
# ➢Forward Biasing

Is a condition in which the positive side of a voltage source is connected to p region (anode) of a diode and the negative side of a voltage source is connected to n region (cathode).

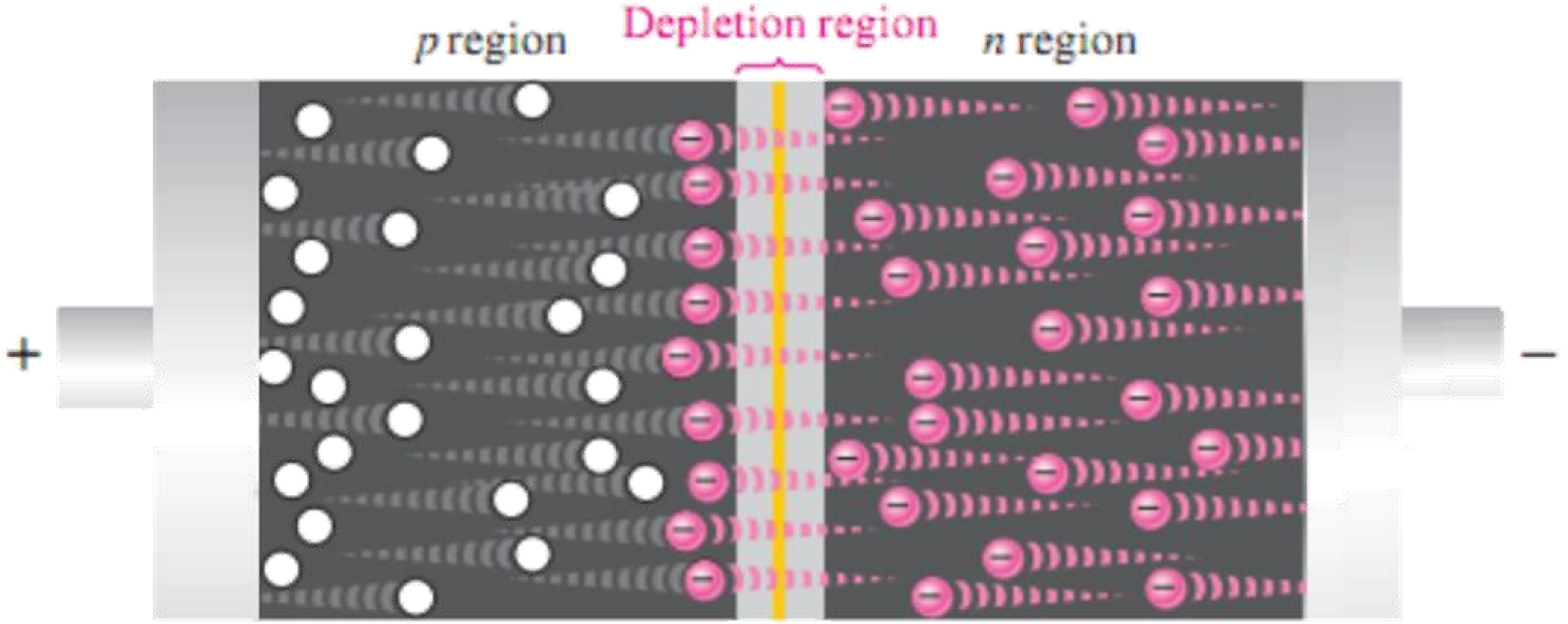


The negative side of a voltage source pushes free electrons in the n region toward the pn junction.

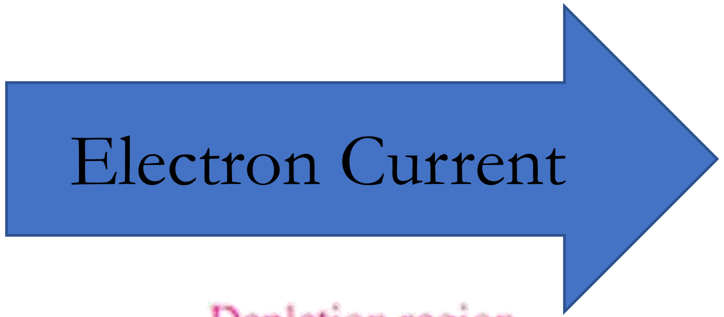


As electrons in n region flow into depletion region, the number of the positive ions is reduced.

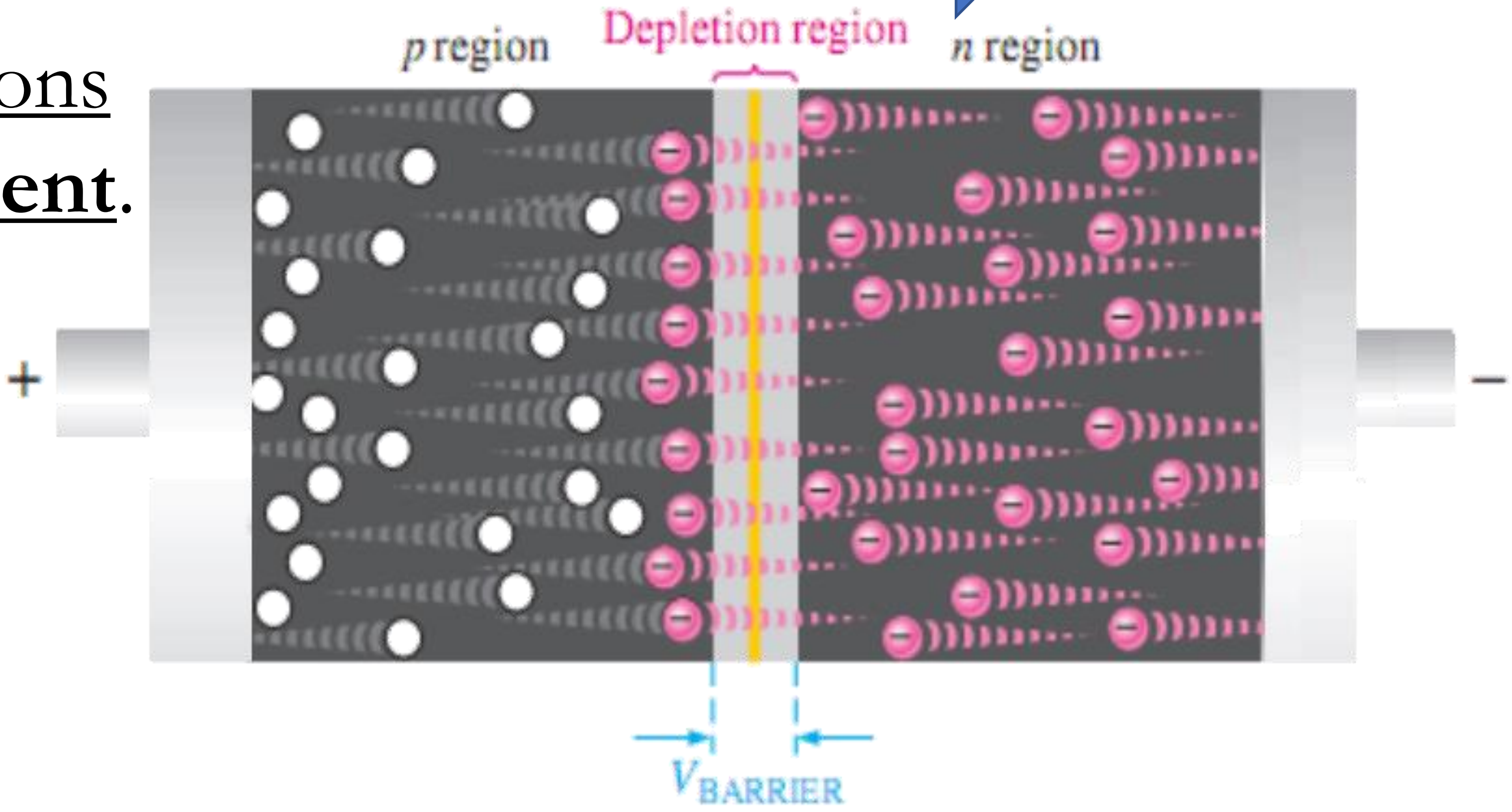



The reduction in the positive ions results in the depletion region to narrow.

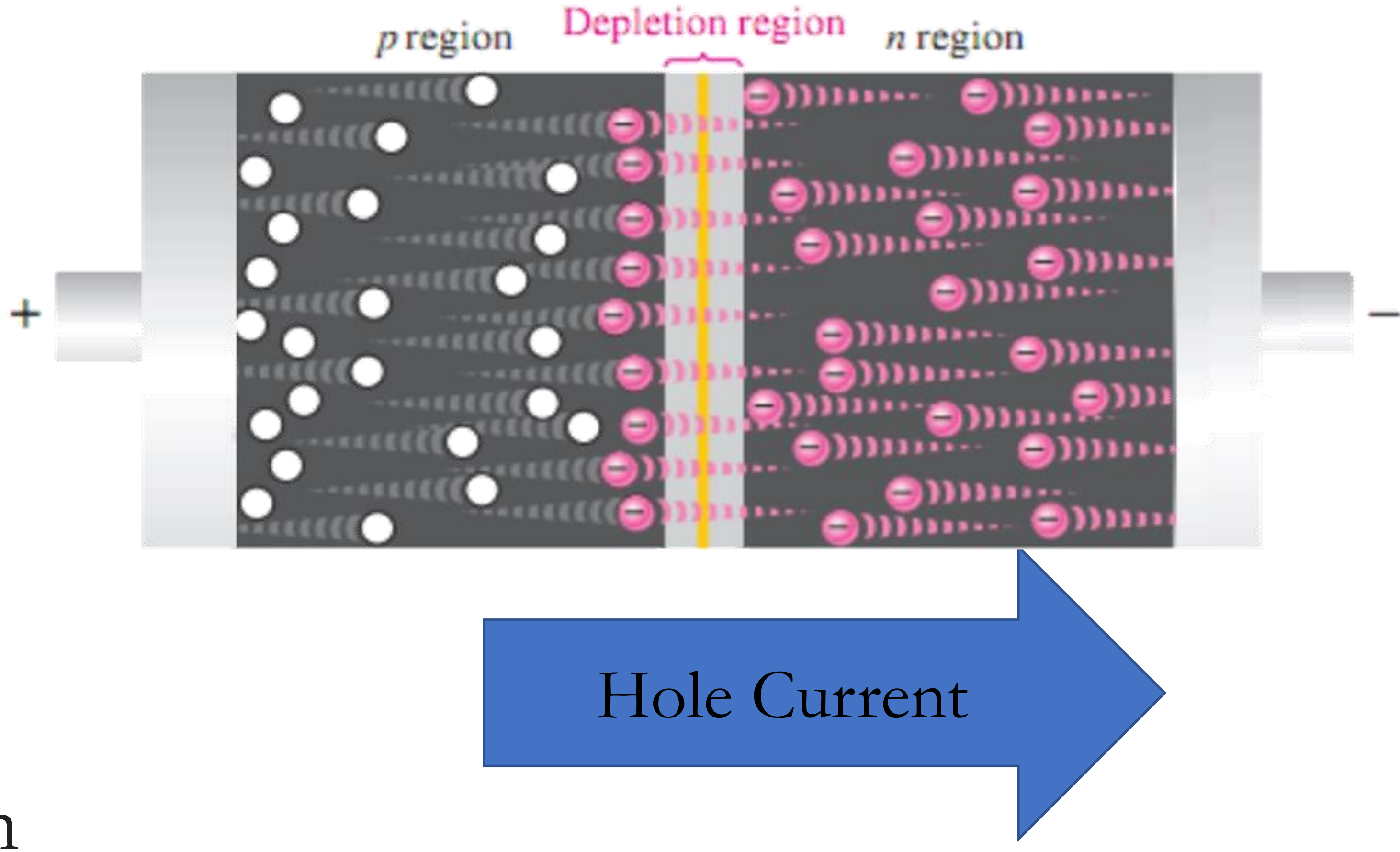
The voltage source imparts sufficient energy to free electrons to overcome the barrier potential of the depletion region and move into the p region.




This flow of free electrons results in **electron current**.



Similarly, the holes in the p region move toward the junction.




As holes in p region flow into the depletion region, number of negative ions is reduced, and the width of the depletion region is reduced.

The flow of holes results in the **hole current**.

# Forward Current ($I_f$)

$$I_f = Electron\ Current + Hole\ Current$$

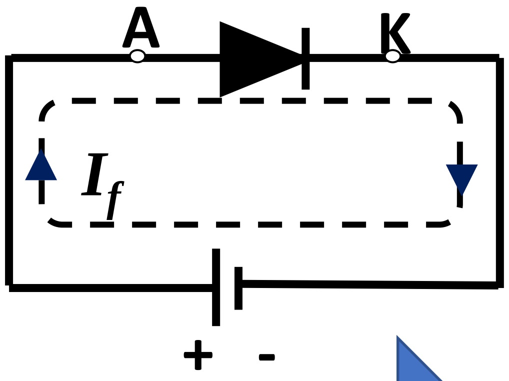
$$I_f = I_s \exp\left(\frac{V_D}{\eta\, V_T}\right)$$

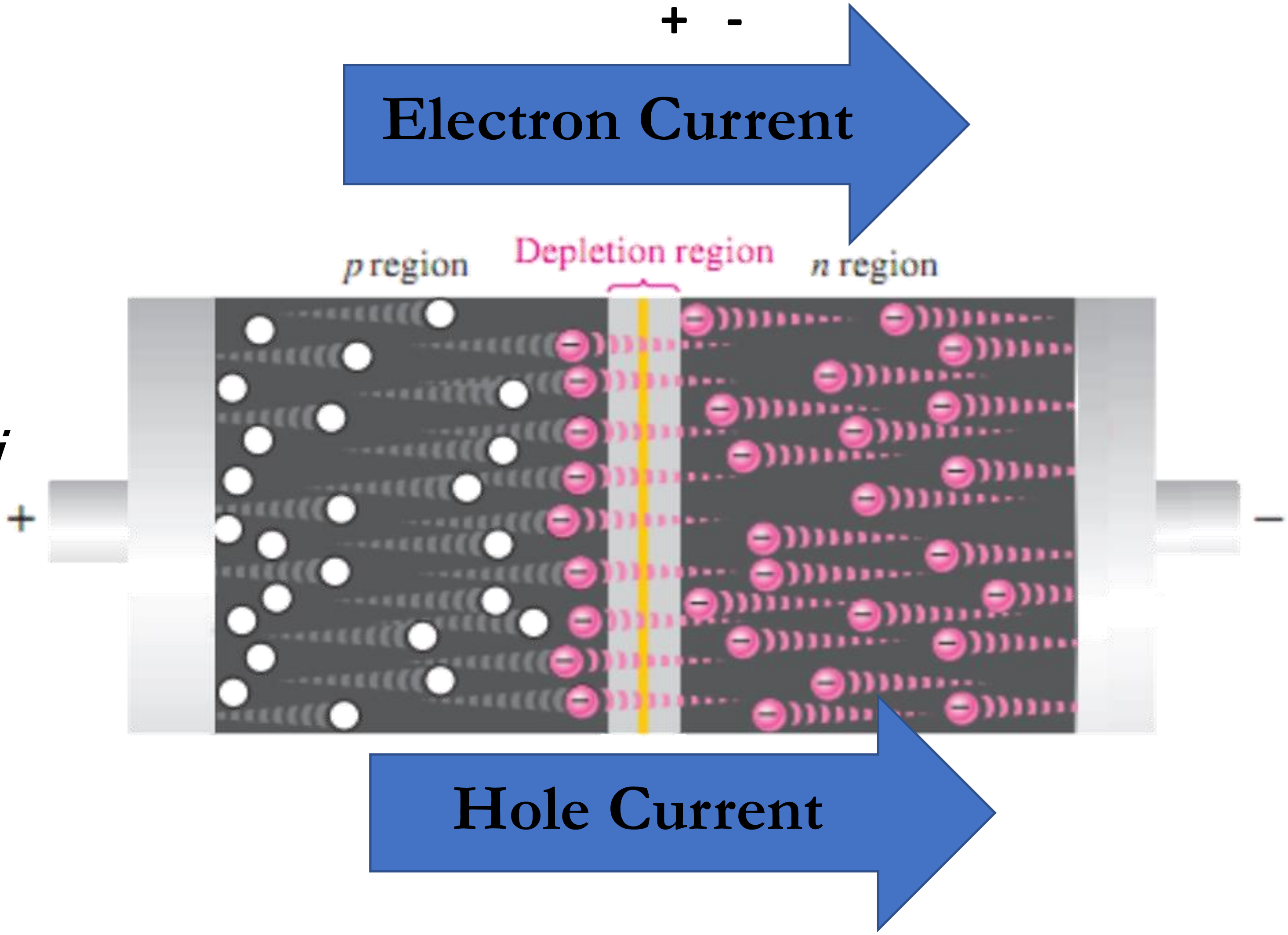
$V_D$ *is the voltage across diode*

$I_s$ *is the saturation current*

$\eta$ *is a constant =1 for Ge , 2 for Si*

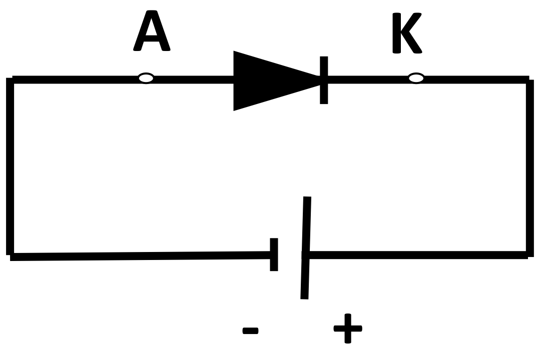
$V_T = 0.025\ V \quad at\ 300^o K$

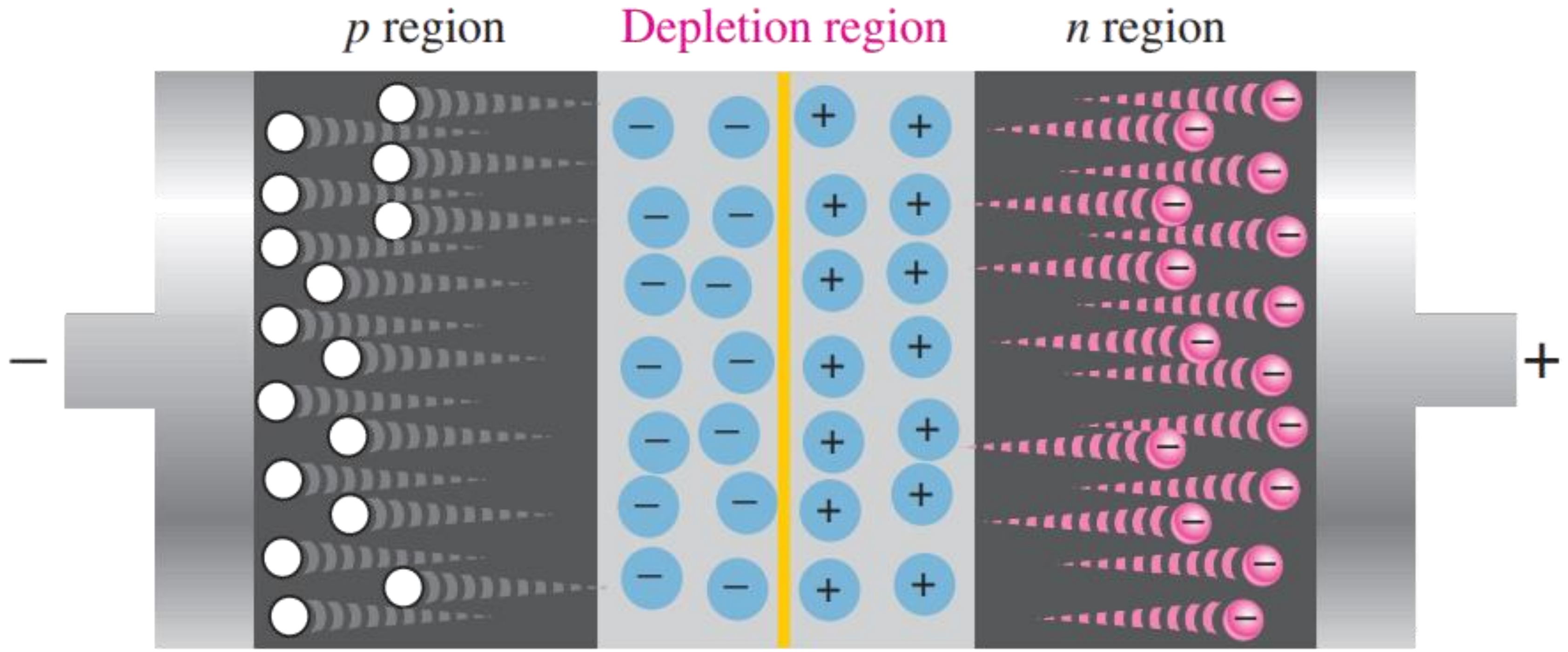


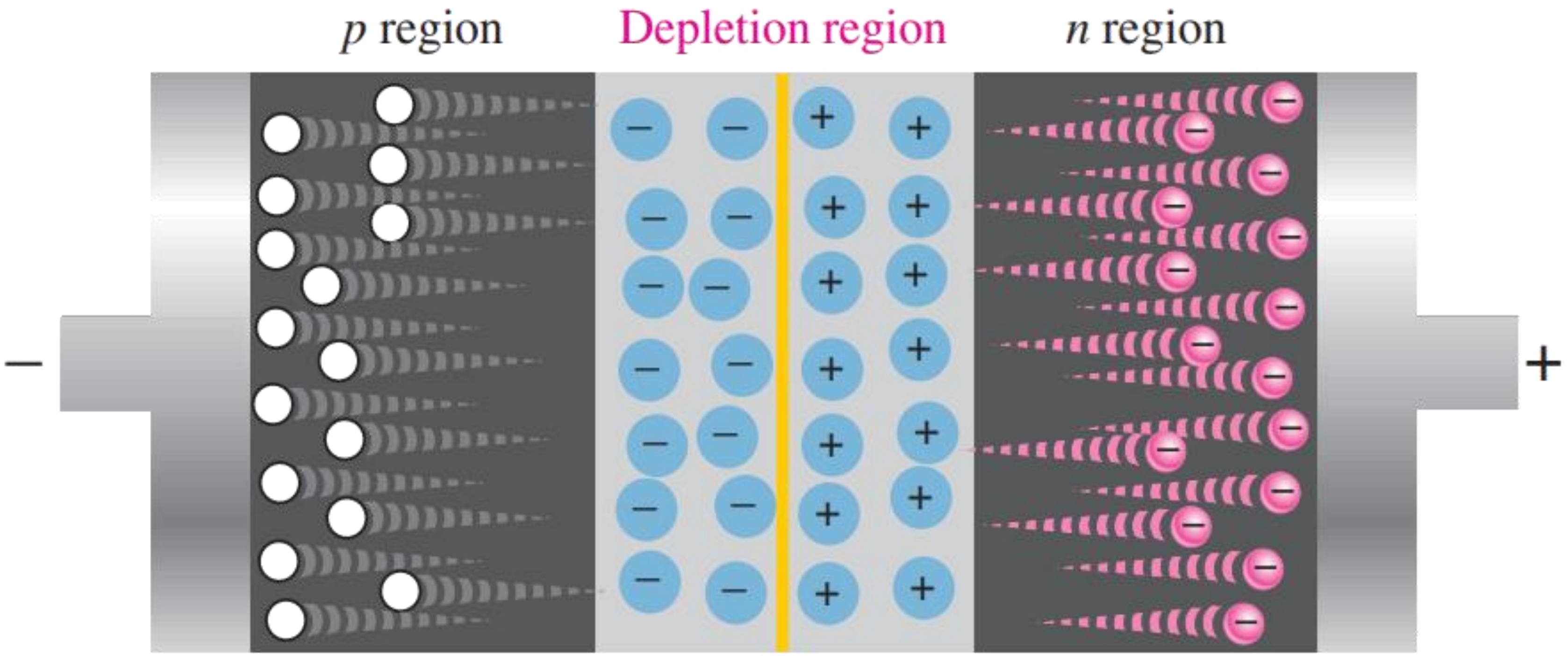
## ➢Reverse Biasing

Is a condition in which the negative side of a voltage source is connected to p region (anode) of diode and the positive side of a voltage source is connected to n region (cathode).



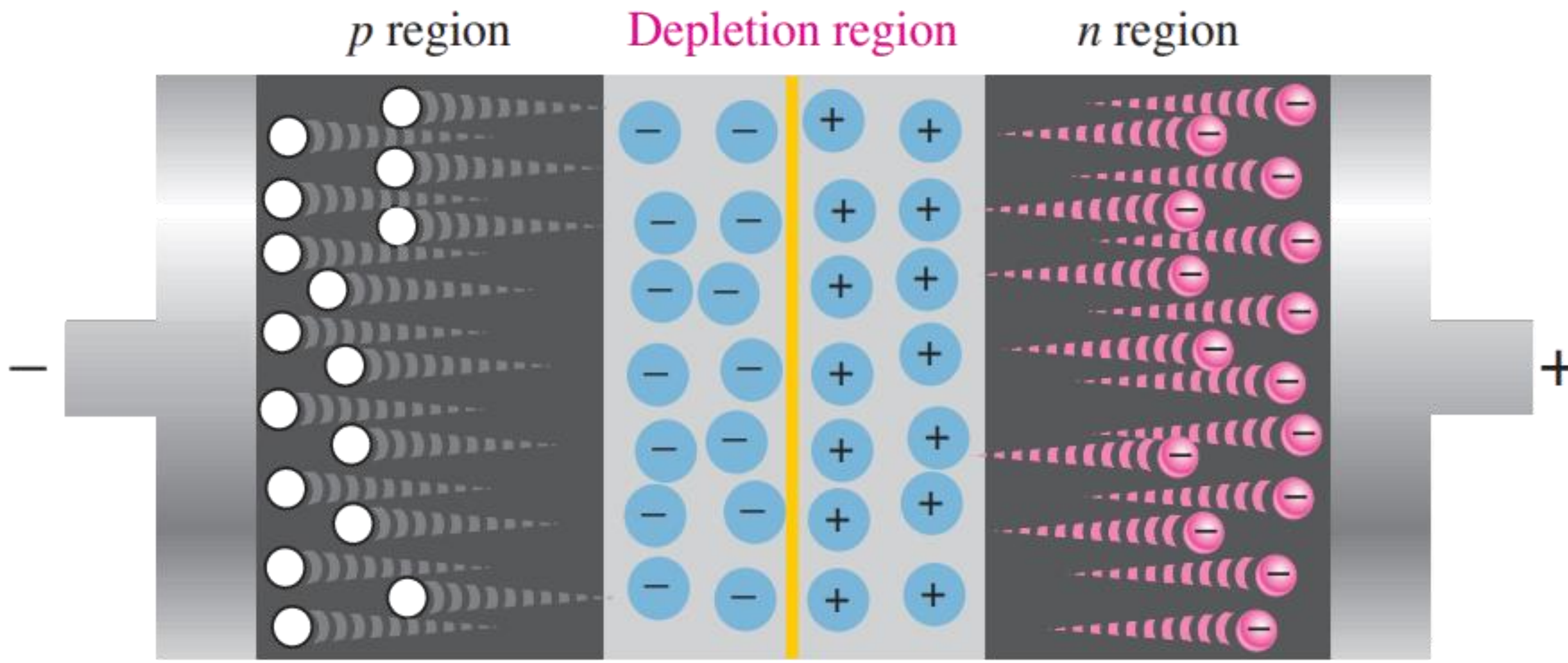



The positive side of the voltage source attracts electrons in the n region away from the junction.




Additional positive ions are created that result in a widening of the depletion region.

Similarly, holes in the p region are pulled toward the negative side of the voltage source.



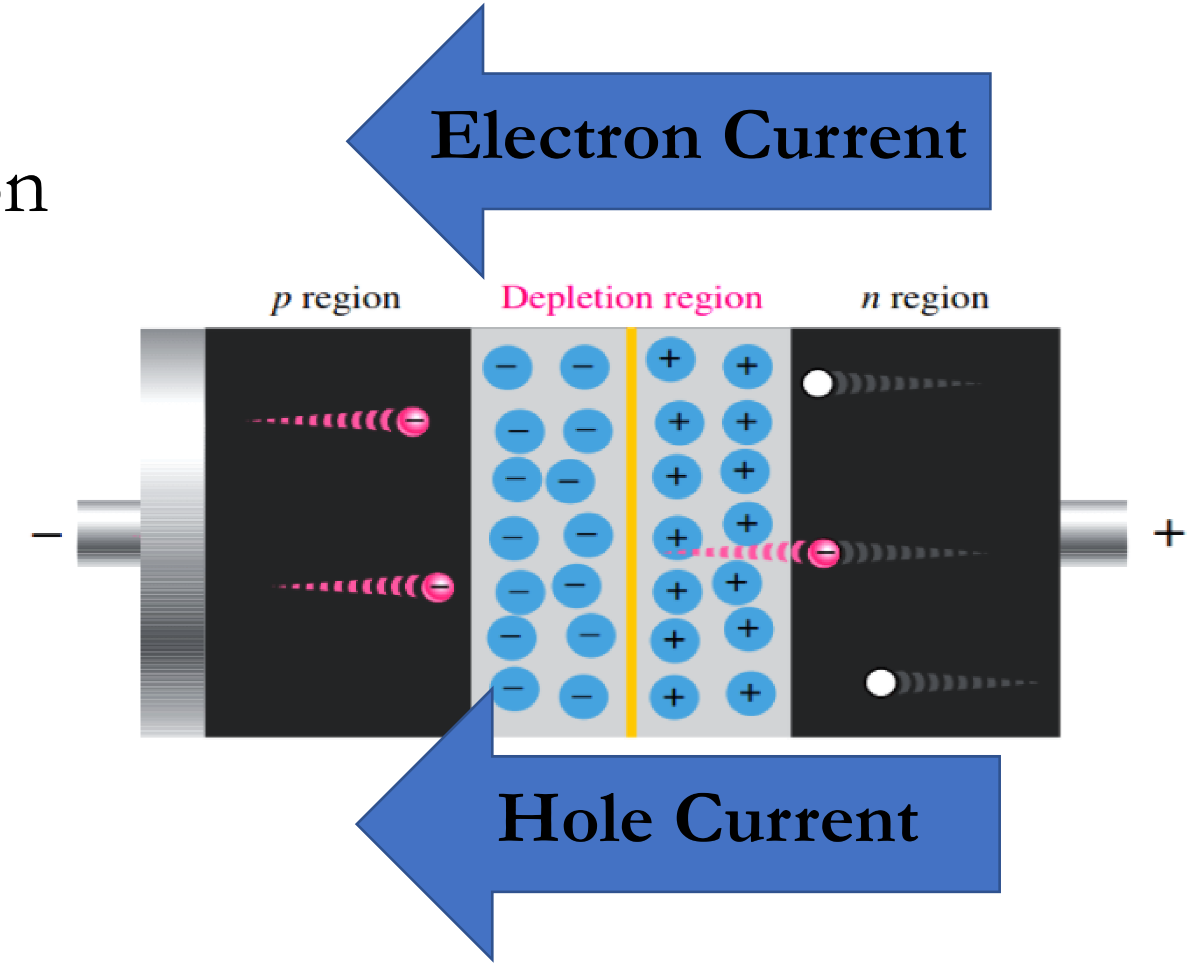

Additional negative ions are created that result in a widening of the depletion region.

# Reverse Current ($I_r$)

Minority electrons in the p region are pushed toward the junction by the negative side of voltage source and pass through the depletion region.

Similarly, minority holes in the n region move away from the positive side of voltage source.

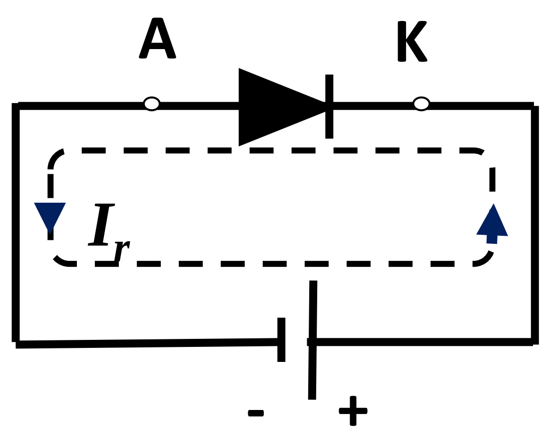
The flow of the minority carriers results in an extremely small current.

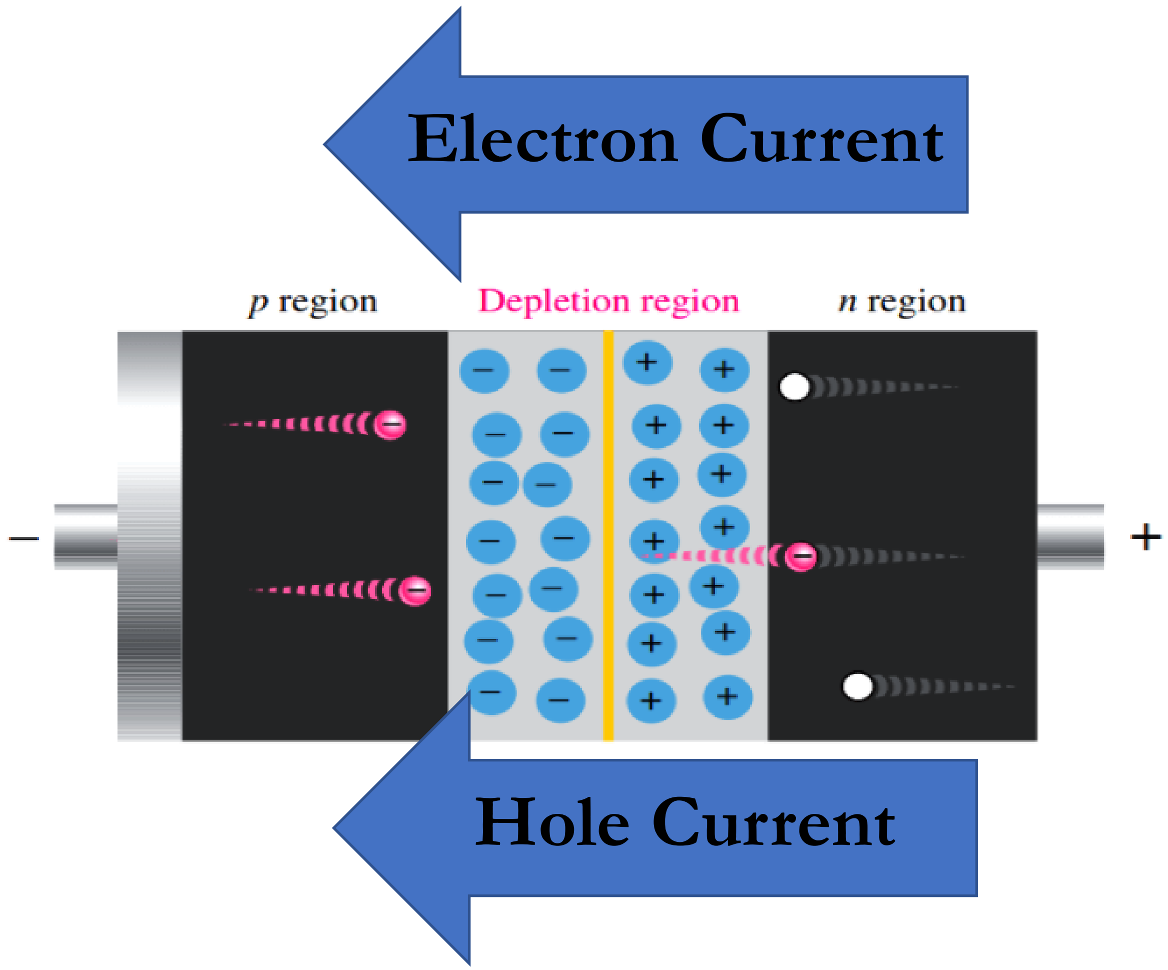


$$I_r = Electron\ Current + Hole\ Current$$

$$I_r = I_s$$

$I_s$ *is the saturation current*



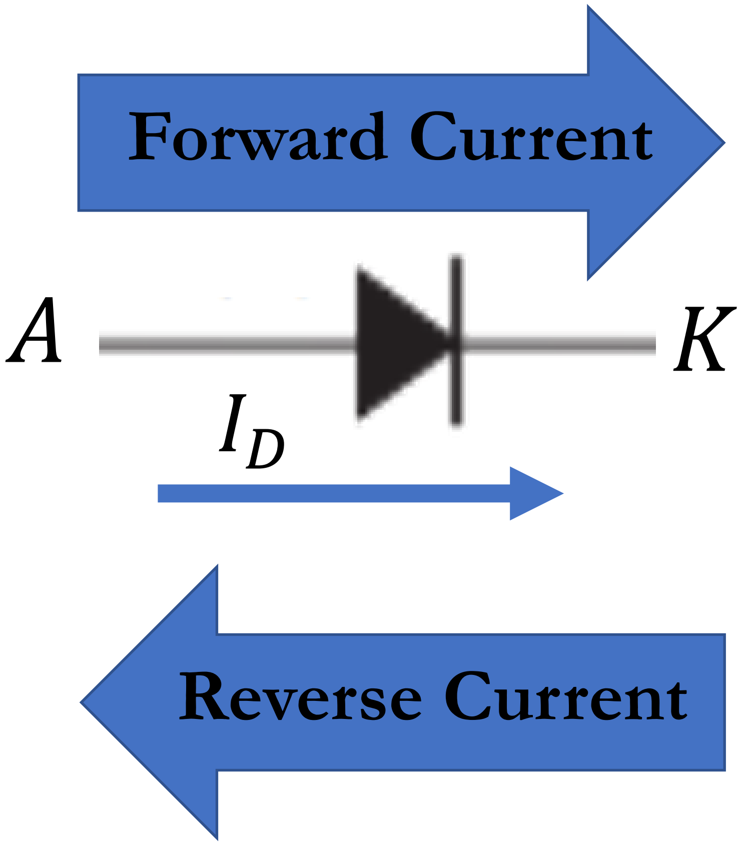
# Diode Current ($I_D$)

The arrow direction in the diode symbol indicates the direction of current through the diode.

$$I_D = I_f - I_r$$

$$I_D = I_s \exp\left(\frac{V_D}{\eta V_T}\right) - I_s$$

$$I_D = I_s \left[\exp\left(\frac{V_D}{\eta V_T}\right) - 1\right]$$



# Voltage-Current Characteristic of Diode

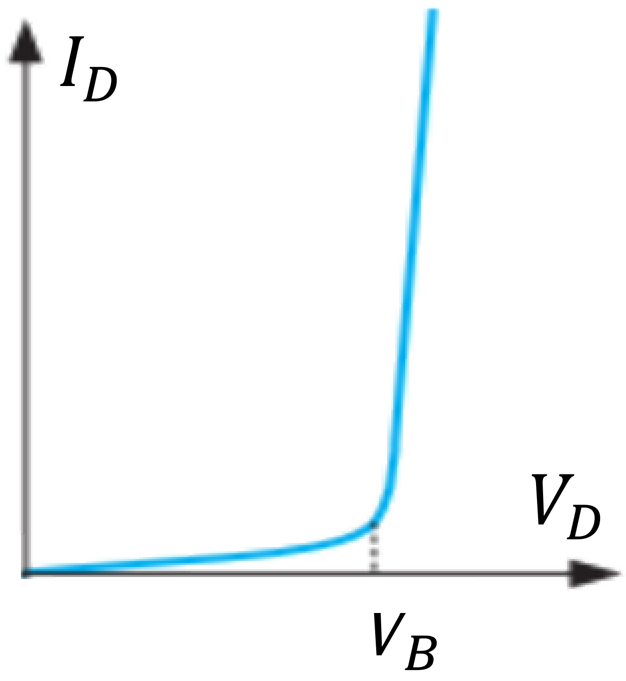
Is a graphical relationship between the voltage and the current in a diode.

- With zero volt across the diode, there is zero current.

$$I_D = I_s\left[\exp\left(\frac{V_D}{\eta\, V_T}\right) - 1\right]$$

- If a voltage across a diode is increased above zero volt and below the barrier potential, the current increases very little.

- When a voltage across a diode reaches the barrier potential, the current increases rapidly.



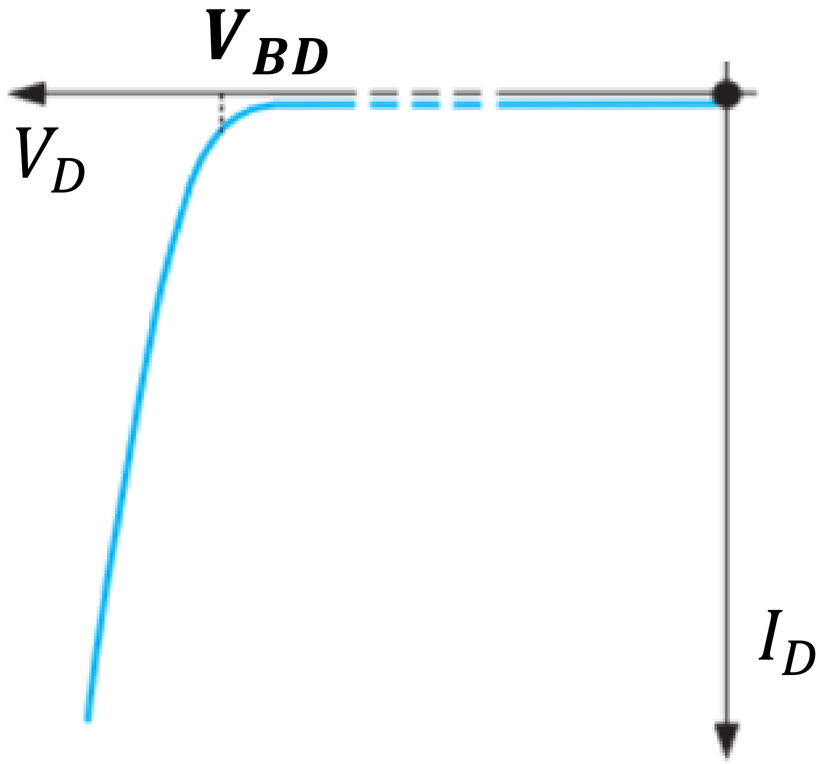
- When a reverse voltage is applied across a diode, there is an extremely small reverse current through a diode.

$$I_D = I_s\left[\exp\left(\frac{V_D}{\eta\, V_T}\right) - 1\right]$$

$$I_D = -I_s$$

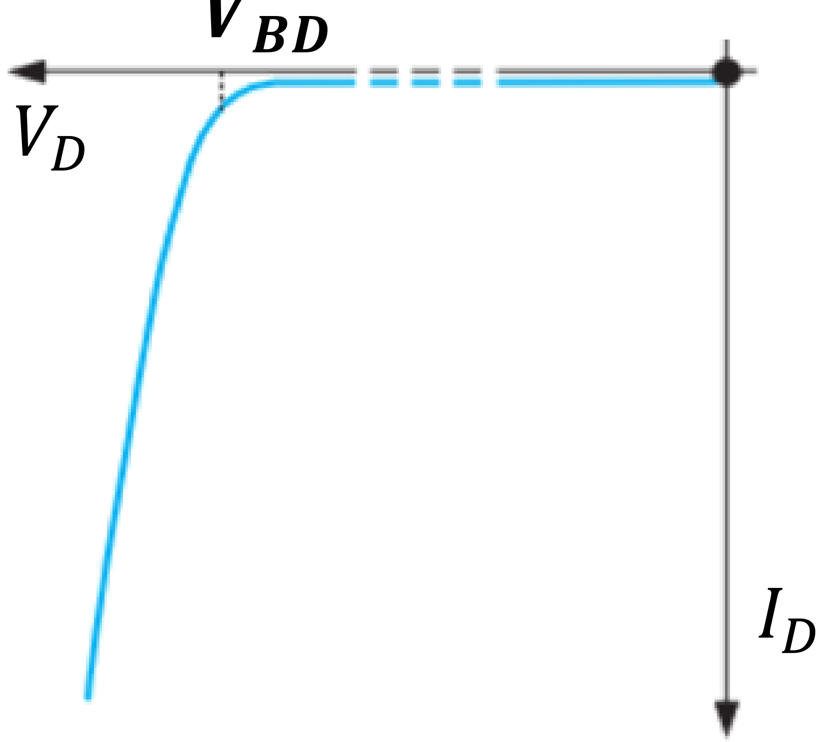
- If the reverse voltage is increased to a value called the breakdown voltage $(V_{BD})$

- The high reverse voltage $(V_{BD})$ imparts energy to the minority electrons so that they speed through the p region, they collide with atoms and knock **valence electrons** out of orbit and into the conduction band.



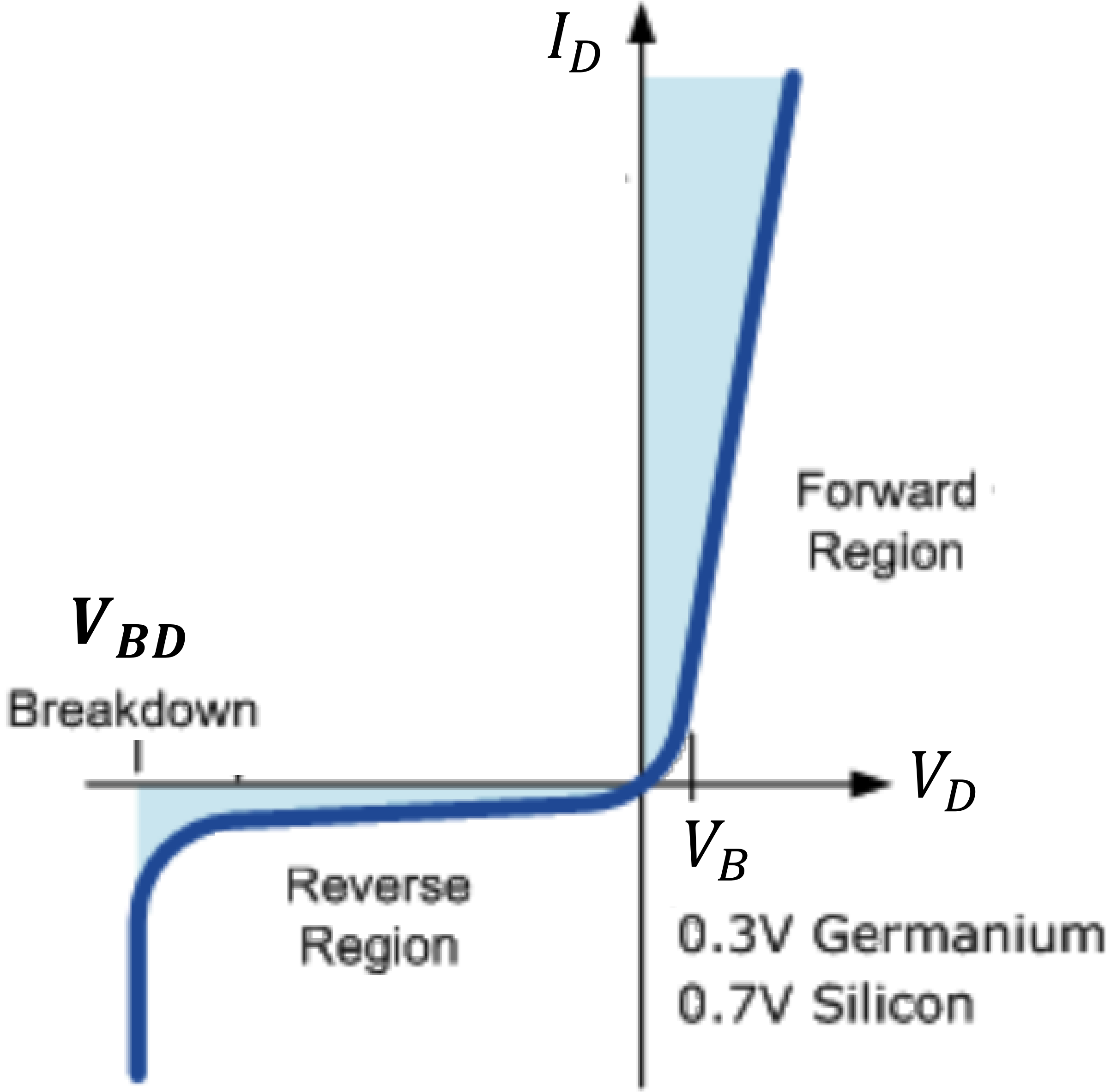

$$Drift\,Velocity:\;\; v_d = \mu_n\,E = \mu_n\,\frac{V}{L}$$

- The newly created conduction electrons repeat the process.
- As a result, the numbers of electrons quickly multiply, and the multiplication of conduction electrons is known as the avalanche effect.
- The resulting conduction electrons go through the n region and result in a very high reverse current.



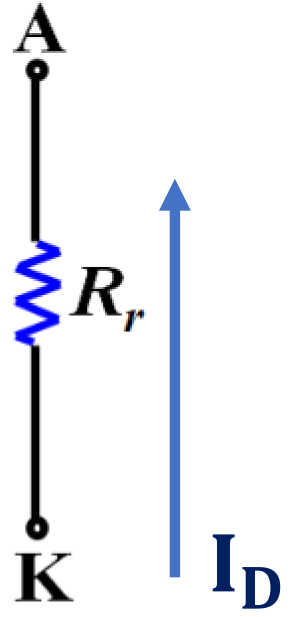

- The resulting heating from the increased reverse current will damage the diode.

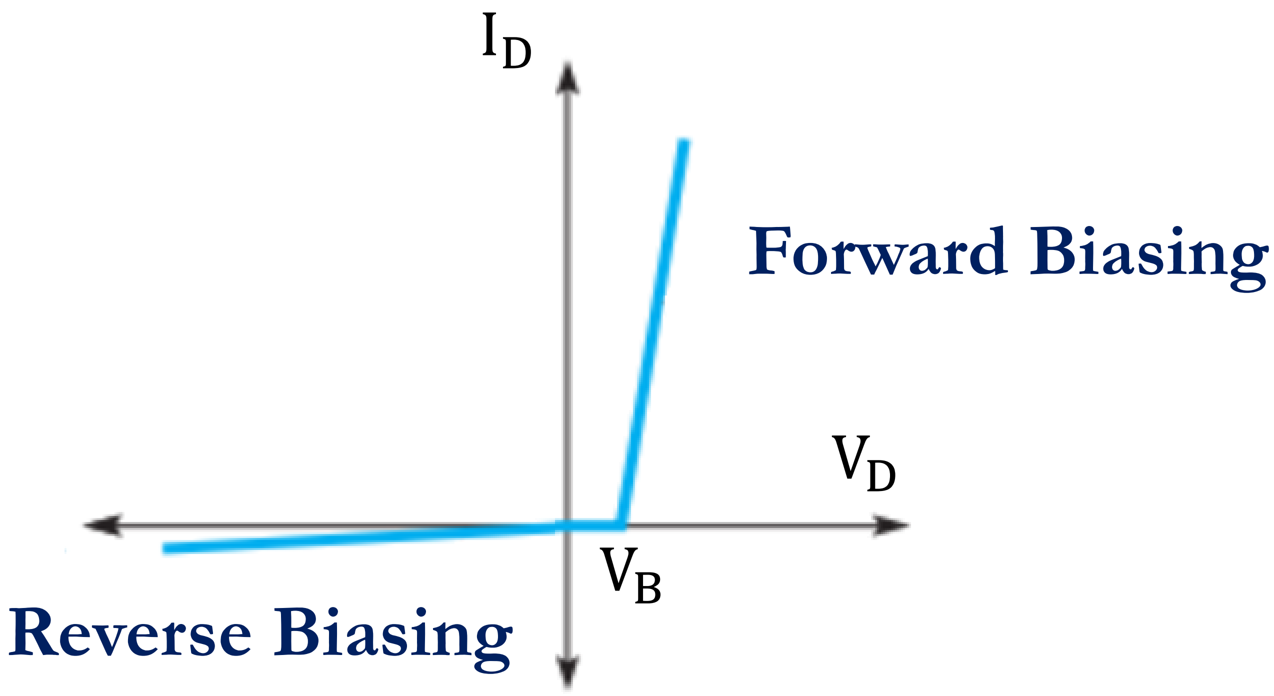
# Complete Voltage-Current Characteristic of Diode

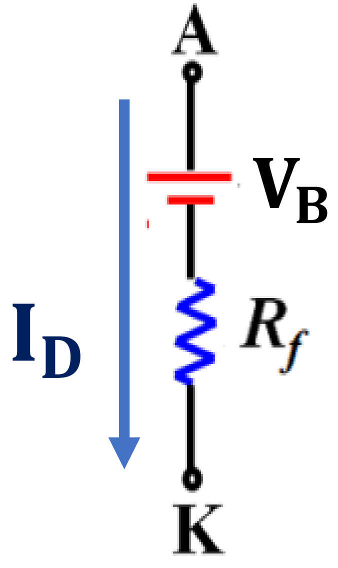



The <u>reverse voltage does not reach the breakdown voltage</u> of the diode.

# Piecewise Linear Characteristic of Practical Diode




$$V_D \leq V_B$$

$$V_{AK} \leq V_B$$

$$V_A - V_K \leq V_B$$

$$\boxed{V_A \leq V_K + V_B}$$

$$V_D > V_B$$

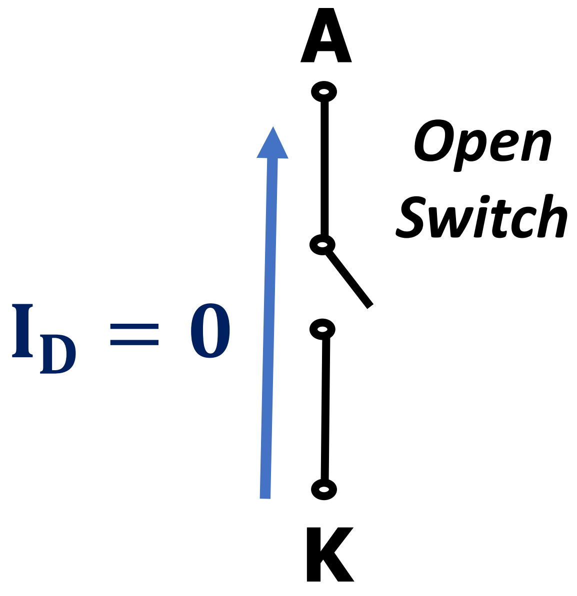
$$V_{AK} > V_B$$

$$V_A - V_K > V_B$$

$$\boxed{V_A > V_K + V_B}$$

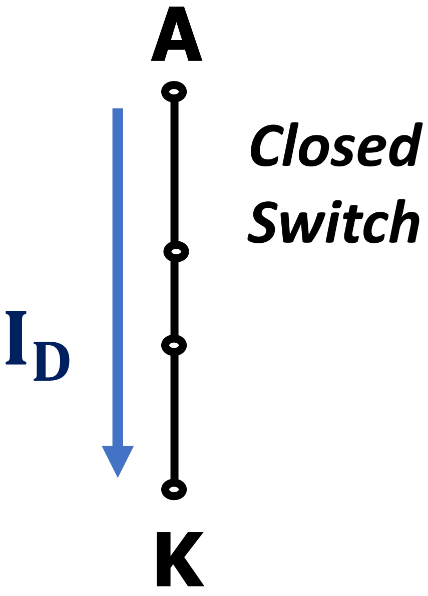
# Piecewise Linear Characteristic of Ideal Diode

## Reverse Biasing

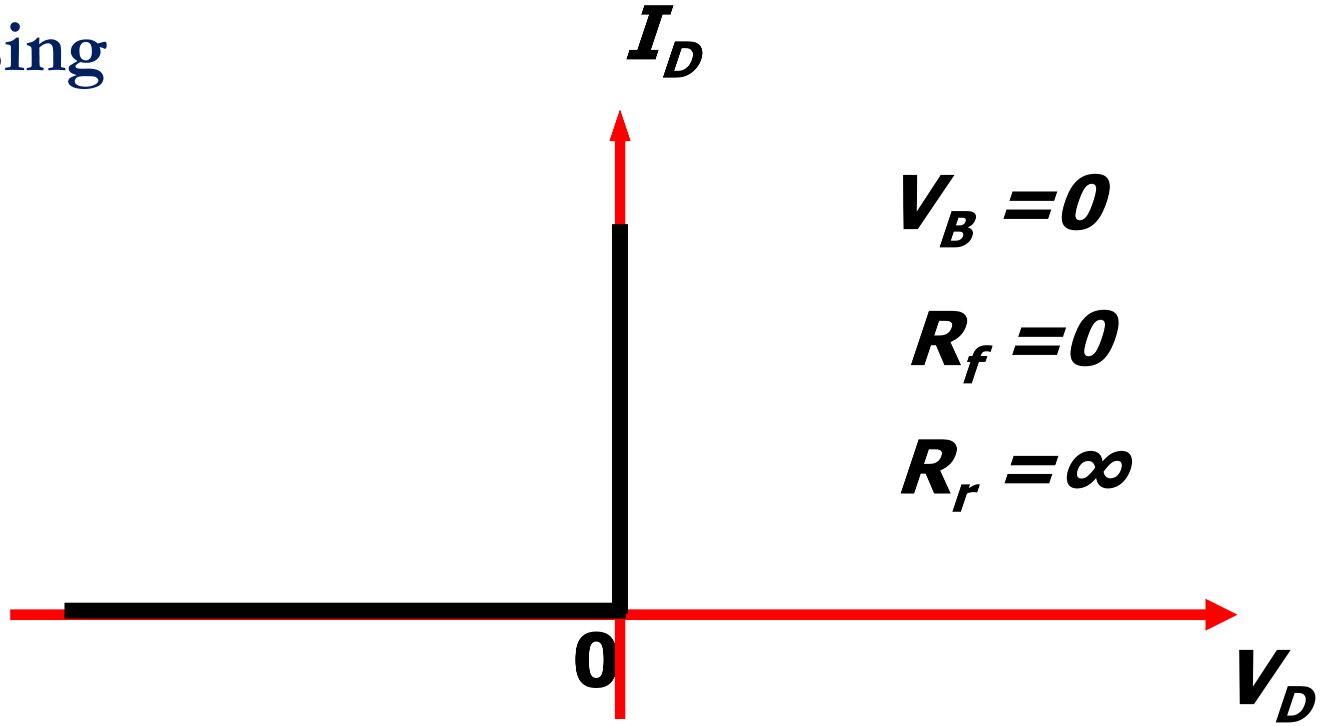



$V_A \leq V_K$

## Forward Biasing




$V_A > V_K$




Ideal diode model neglects the effect of barrier potential, forward resistance, and reverse current.