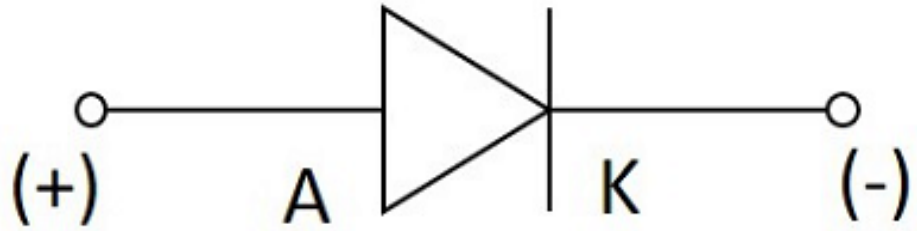
Parul® University

Diode Theory

Prof. Bijohn Joseph, Assistant Professor
Electrical Engineering

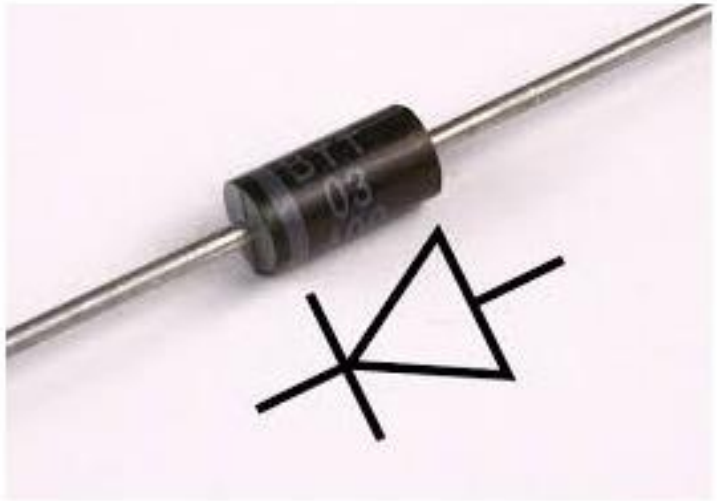
DIODE

- A semiconductor diode is a two terminal electronic component with a PN junction. This is also called as a **Rectifier**.
- The **anode** which is the **positive terminal** of a diode is represented with **A** and the **cathode**, which is the **negative terminal** is represented with **K**.



DIODE

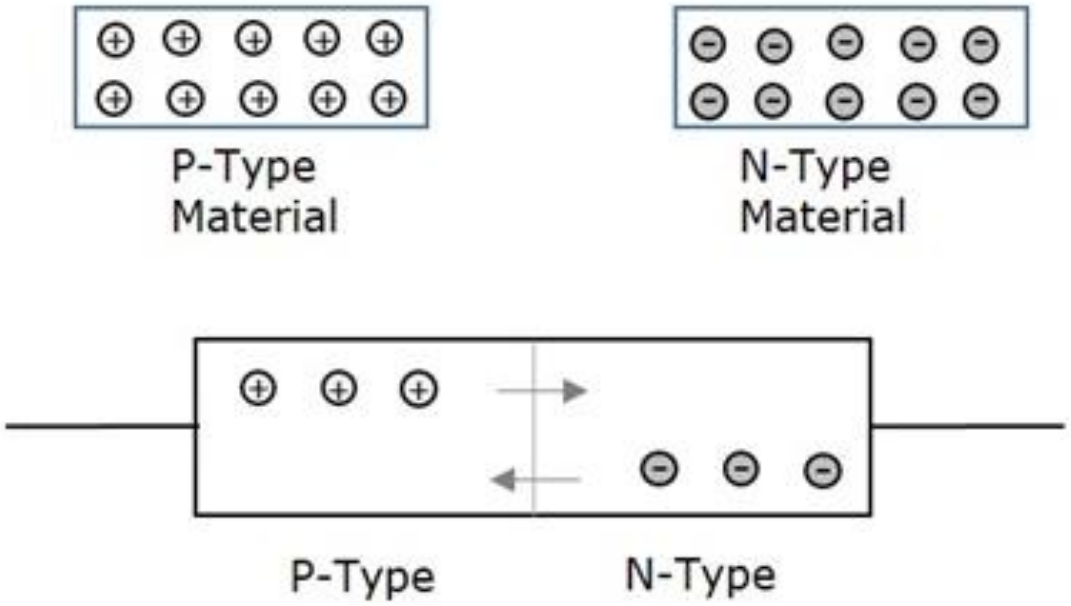
- To know the anode and cathode of a practical diode, a fine line is drawn on the diode which means cathode, while the other end represents anode.



Representing anode and cathode of a practical diode through its symbol

FORMATION OF A DIODE

- If a P-type and an N-type material are brought close to each other, both of them join to form a junction, as shown in the figure below.



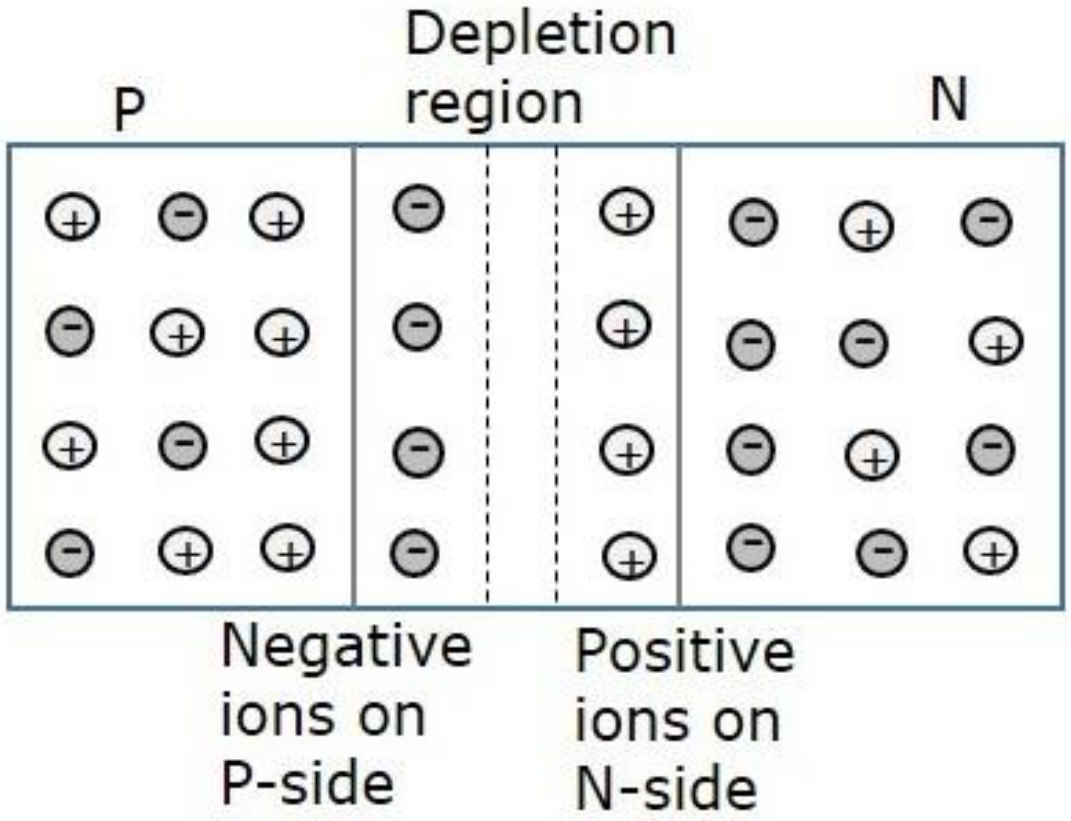
FORMATION OF A DIODE

- A P-type material has **holes** as the **majority carriers** and an N-type material has **electrons** as the **majority carriers**.
- As opposite charges attract, few holes in P-type tend to go to n-side, whereas few electrons in N-type tend to go to P-side.
- As both of them travel towards the junction, holes and electrons recombine with each other to neutralize and forms ions.
- Now, in this junction, there exists a region where the positive and negative ions are formed, called as PN junction or junction barrier.

FORMATION OF A DIODE

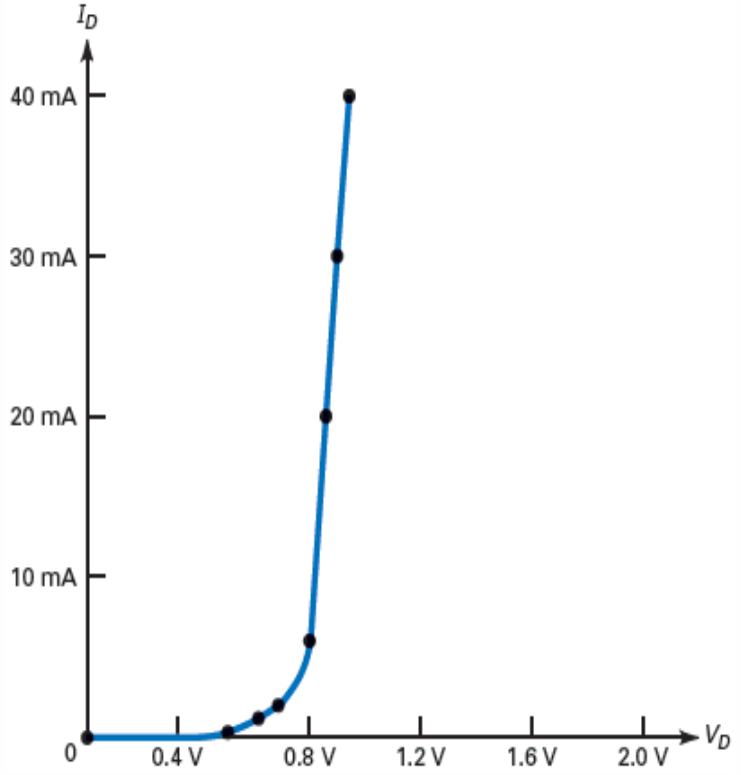
- The formation of negative ions on P-side and positive ions on N-side results in the formation of a narrow charged region on either side of the PN junction.
- This region is now free from movable charge carriers. The ions present here have been stationary and maintain a region of space between them without any charge carriers.
- As this region acts as a barrier between P and N type materials, this is also called as **Barrier junction**. This has another name called as **Depletion region** meaning it depletes both the regions.

FORMATION OF A DIODE



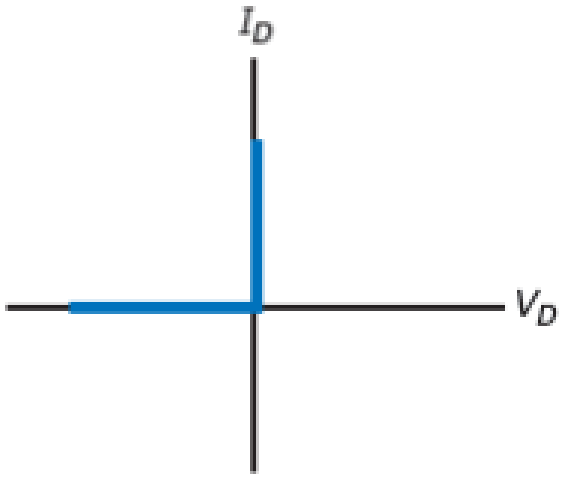
IDEAL DIODE

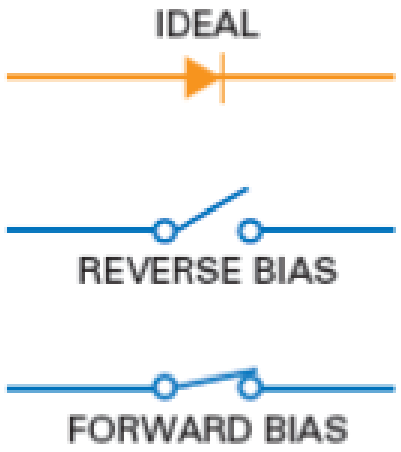
- Figure shows a detailed graph of diode current I_D versus diode voltage V_D the forward region of a diode.
- Somewhere in the vicinity of ***0.6 V*** to ***0.7 V***, the diode current increases.
- When the diode voltage is greater than ***0.8 V***, the diode current is significant and the graph is almost linear.
- Depending on how a diode is doped and its physical size, it may differ from other diodes in its maximum forward current, power rating, and other characteristics.



IDEAL DIODE

- A diode acts like a perfect conductor (zero resistance) when forward biased and like a perfect insulator (infinite resistance) when reverse biased.
- Figure shows the current-voltage graph of an ideal diode. It shows zero resistance when forward biased and infinite resistance when reverse biased.
- An ideal diode acts like a switch that closes when forward biased and opens when reverse biased.



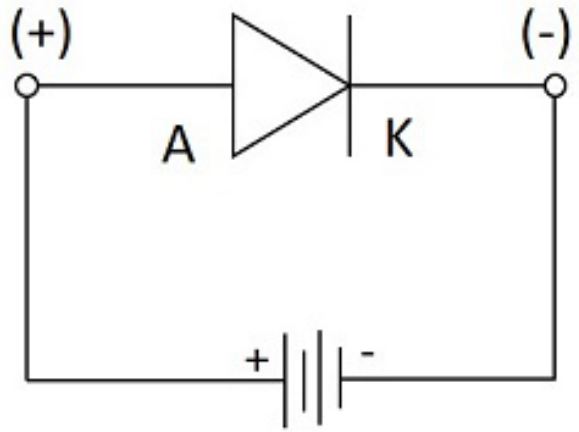


BIASING OF A DIODE

- When a diode or any two-terminal component is connected in a circuit, it has two biased conditions with the given supply. They are:-
    i. Forward biased condition
    ii. Reverse biased condition

FORWARD BIASED CONDITION

- When a diode is connected in a circuit, with its **anode to the positive** terminal and **cathode to the negative** terminal of the supply, then such a connection is said to be **forward biased** condition.
- This kind of connection makes the circuit more and more forward biased and helps in more conduction. A diode conducts well in forward biased condition.

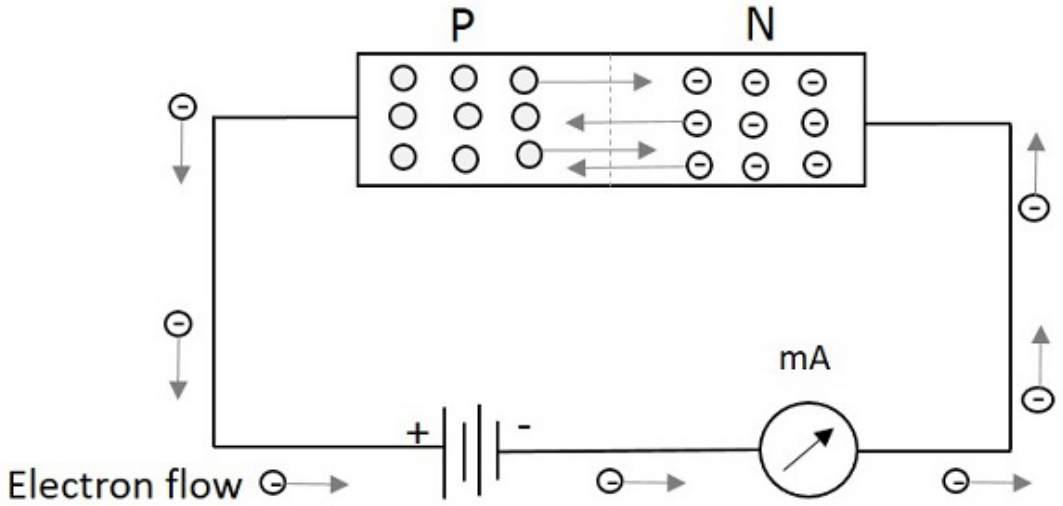


FORWARD BIASED CONDITION

- When an external voltage is applied to a diode such that it cancels the potential barrier and permits the flow of current is called as **forward bias**.
- When anode and cathode are connected to positive and negative terminals respectively, the holes in P-type and electrons in N-type tend to move across the junction, breaking the barrier. There exists a free flow of current with this, almost eliminating the barrier.
- With the repulsive force provided by positive terminal to holes and by negative terminal to electrons, the recombination takes place in the junction.
- The supply voltage should be such high that it forces the movement of electrons and holes through the barrier and to cross it to provide **forward current**.

FORWARD BIASED CONDITION

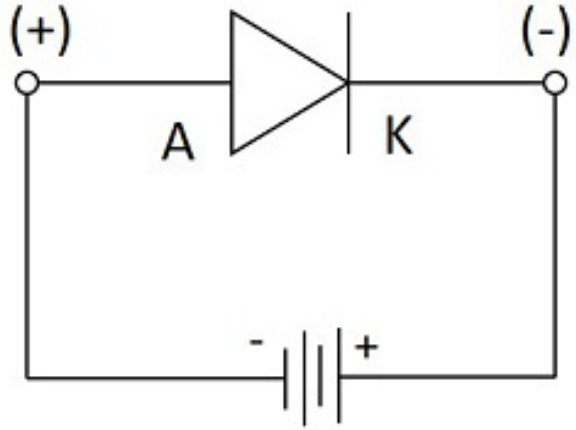
- Forward Current is the current produced by the diode when operating in forward biased condition and it is indicated by I_f.



PN junction forward biased

REVERSE BIASED CONDITION

- When a diode is connected in a circuit, with its **anode to the negative** terminal and **cathode to the positive** terminal of the supply, then such a connection is said to be **Reverse biased** condition.
- This kind of connection makes the circuit more and more reverse biased and helps in minimizing and preventing the conduction. A diode cannot conduct in reverse biased condition.

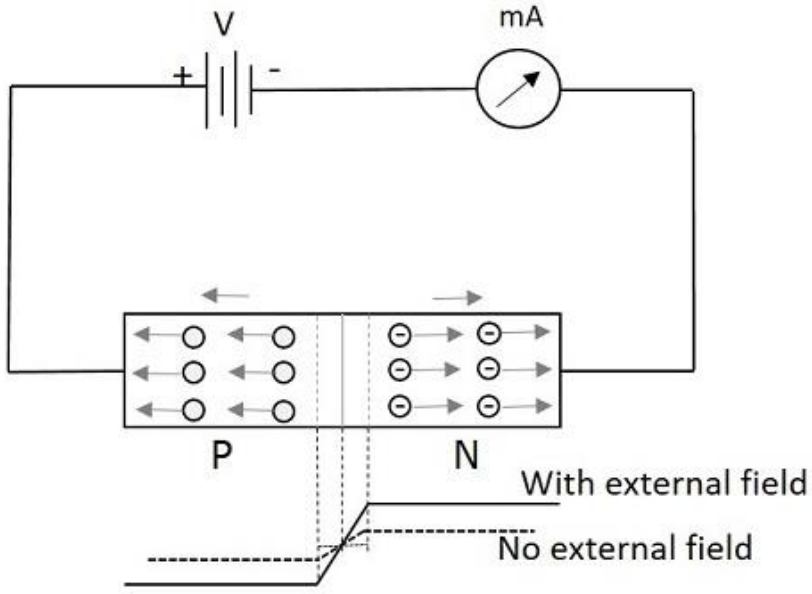


REVERSE BIASED CONDITION

- When an external voltage is applied to a diode such that it increases the potential barrier and restricts the flow of current is called as **Reverse bias**.
- When anode and cathode are connected to negative and positive terminals respectively, the electrons are attracted towards the positive terminal and holes are attracted towards the negative terminal.
- Hence both will be away from the potential barrier **increasing the junction resistance** and preventing any electron to cross the junction.
- The following figure explains this. The graph of conduction when no field is applied and when some external field is applied are also drawn

REVERSE BIASED CONDITION

- The following figure explains this. The graph of conduction when no field is applied and when some external field is applied are also drawn.
- With the increasing reverse bias, the junction has few minority carriers to cross the junction. This current is normally negligible.
- This reverse current is almost constant when the temperature is constant. But when this reverse voltage increases further, then a point called **reverse breakdown occurs**, where an avalanche of current flows through the junction.



PN junction reverse biased

REVERSE BIASED CONDITION

- **Reverse current** is the current produced by the diode when operating in reverse biased condition and it is indicated by $\mathbf{I_r}$.
- Hence a diode provides high resistance path in reverse biased condition and doesn't conduct, where it provides a low resistance path in forward biased condition and conducts.
- Thus we can conclude that a diode is a one-way device which conducts in forward bias and acts as an insulator in reverse bias. This behavior makes it work as a rectifier, which converts AC to DC.

REVERSE BIASED CONDITION

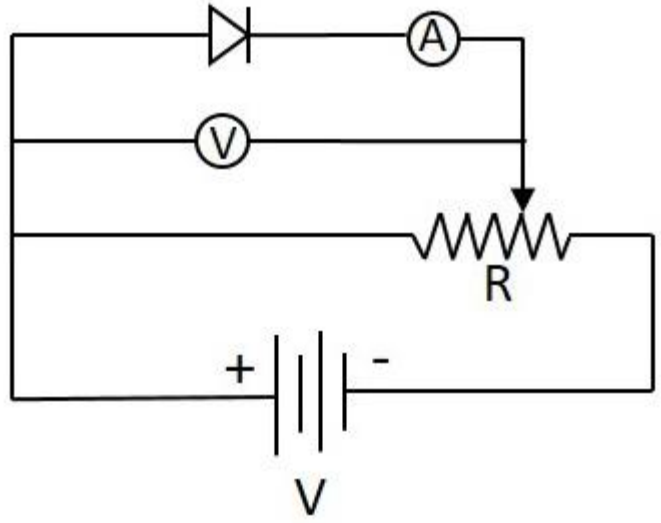
- During the reverse bias, current produced through minority carriers exist known as "**Reverse current**".
- As the reverse voltage increases, this reverse current increases and it suddenly breaks down at a point, resulting in the permanent destruction of the junction.

PEAK INVERSE VOLTAGE

- Peak Inverse Voltage is shortly called as **PIV**.
- It states the maximum voltage applied in reverse bias.
- The Peak Inverse Voltage can be defined as "**The maximum reverse voltage that a diode can withstand without being destroyed**".
- Hence, this voltage is considered during reverse biased condition. It denotes how a diode can be safely operated in reverse bias.

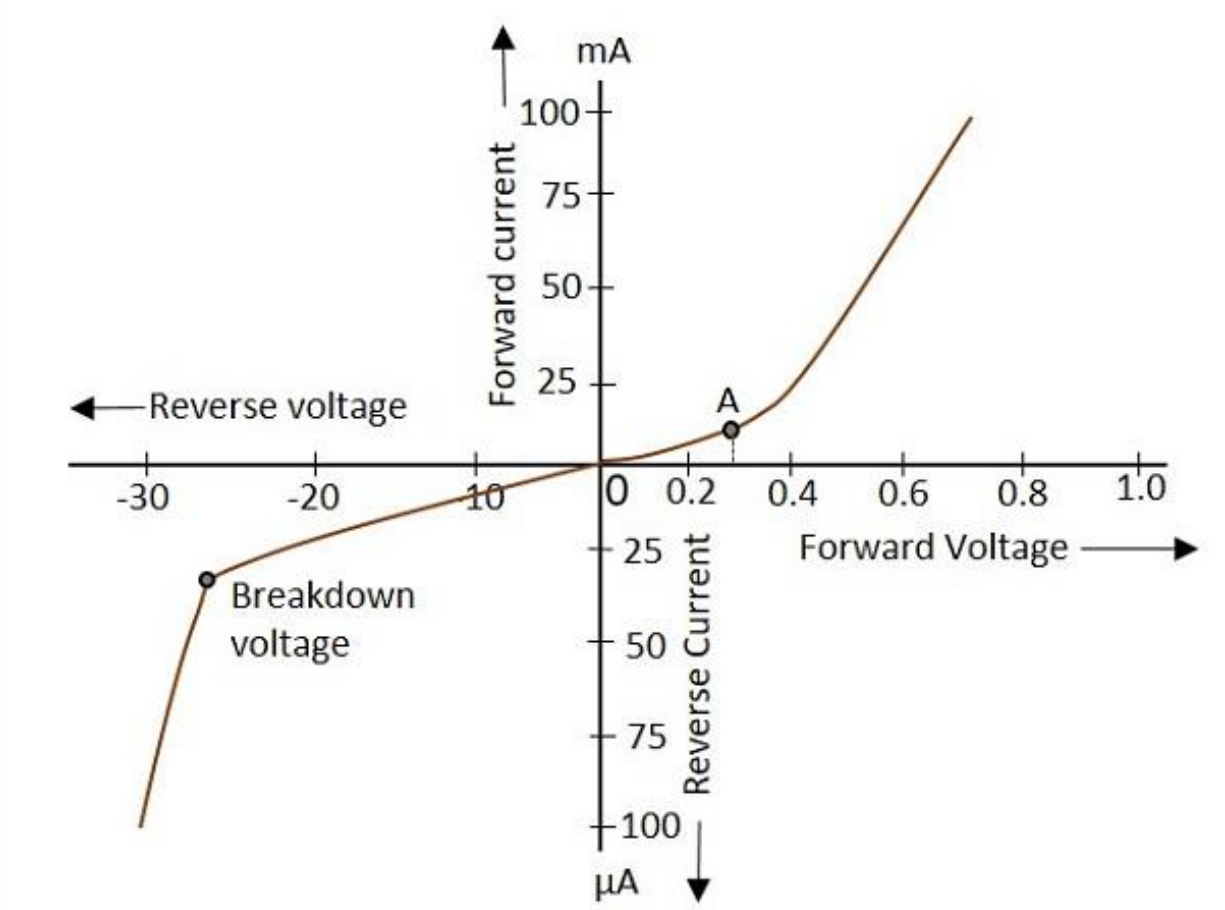
V - I CHARACTERISTICS OF A DIODE

- A Practical circuit arrangement for a PN junction diode is as shown in the following figure. An ammeter is connected in series and voltmeter in parallel, while the supply is controlled through a variable resistor.
  - During the operation, when the diode is in forward biased condition, at some particular voltage, the potential barrier gets eliminated. Such a voltage is called as **Cut-off Voltage** or **Knee Voltage**.
  - If the forward voltage exceeds beyond the limit, the forward current rises up exponentially and if this is done further, the device is damaged due to overheating.



A Practical diode circuit

V - I CHARACTERISTICS OF A DIODE



BULK RESISTANCE

- Above the knee voltage, the diode current increases rapidly. This means that small increases in the diode voltage cause large increases in diode current.
- After the barrier potential is overcome, all that prevent the current is the ohmic resistance of the p and n regions.
- In other words, if the p and n regions were two separate pieces of semiconductor, each would have a resistance that you could measure with an ohmmeter, the same as an ordinary resistor.

BULK RESISTANCE

- The sum of the ohmic resistances is called the bulk resistance of the diode.
- It is defined as: $R_B = R_P + R_N$
- The bulk resistance depends on the size of the p and n regions and how heavily doped they are. Often, the bulk resistance is less than 1 Ω.

DC RESISTANCE OF A DIODE

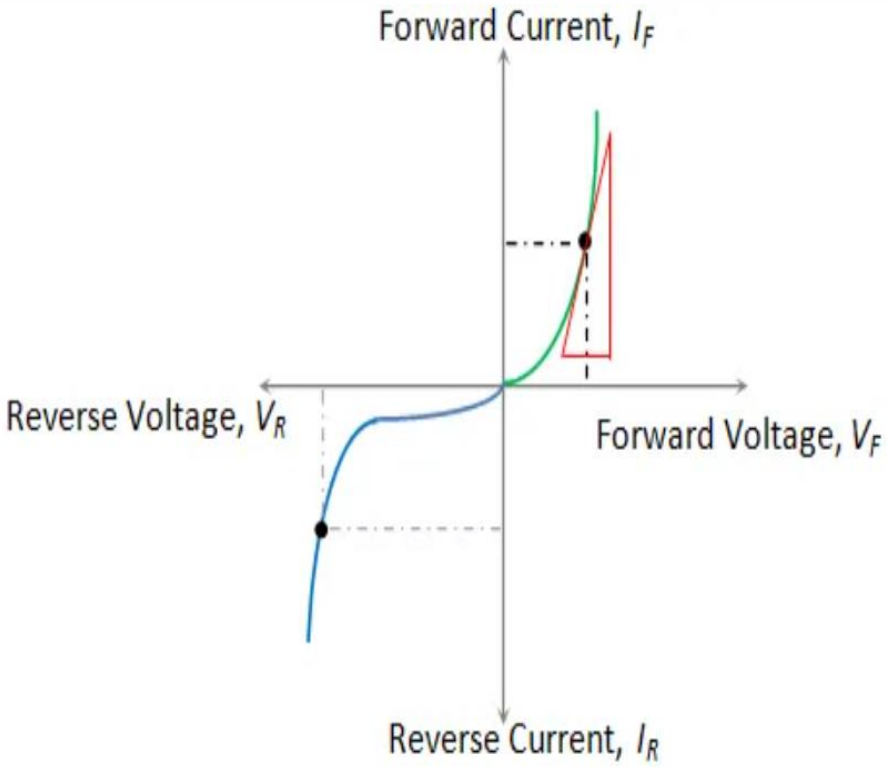
- Resistance is the opposition offered to the flow of current through the device.
- Hence, **diode resistance** can be defined as the effective opposition offered by the diode to the flow of current through it.
- Ideally speaking, a diode is expected to offer zero resistance when forward biased and infinite resistance when reverse biased. However, no device can ever be ideal.
- Thus, practically speaking, every diode is seen to offer a small resistance when forward biased, and a considerable resistance when reverse biased.
- One can characterize the given diode regarding its forward and reverse resistances.

FORWARD RESISTANCE

- Even after forward biasing, the diode will not conduct until it reaches a minimum threshold voltage level.
- After the applied voltage exceeds this threshold level, the diode starts to conduct. We refer the resistance, offered by the diode under this condition as the forward resistance of the diode.
- That is, the forward resistance is nothing but the resistance offered by the diode when the diode is working in its forward biased condition.

REVERSE RESISTANCE

- When we connect the diode in reverse biased condition, there will be a small current flowing through it which is called the reverse leakage current.
- We can attribute the cause behind this to the fact that when the diode functions in its reverse mode, it will not be completely free of charge carriers.
- That is, even in this state, one can experience the flow of minority carriers through the device.

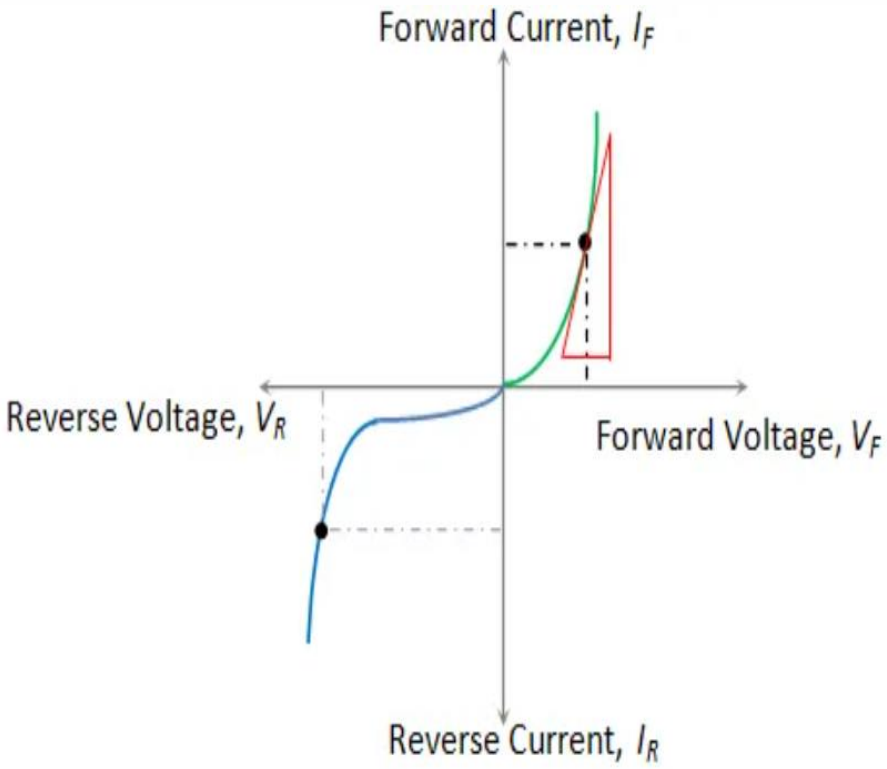


REVERSE RESISTANCE

- Due to this current flow, the diode exhibits reverse resistance characteristic which is shown by the purple dotted line in figure.
- The mathematical expression for the same is similar to that for the forward resistance and is given by

$$R_r = \frac{V_r}{I_r}$$

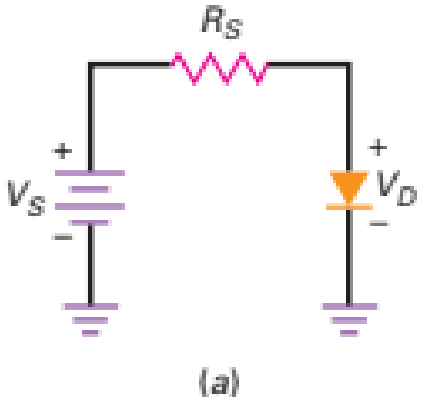
where, V_r and I_r are the reverse voltage and the reverse current respectively.



LOAD LINE

- The load line, a tool used to find the exact value of diode current and voltage. Load lines are useful with transistors.
- The equation of load line is given by

$$I_d = \frac{V_s - V_D}{R_s}$$



(a)

where, V_s and V_d are the Supply voltage and the Diode voltage and R_s is the series resistance respectively.

SURGE CURRENT

- Before the power is turned on, the filter capacitor is uncharged.
- At the first instant the power is applied, this capacitor looks like a short.
- Therefore, the initial charging current may be very large.
- All that exists in the charging path to impede the current is the resistance of the transformer windings and the bulk resistance of the diodes.
- **The initial rush of current when the power is turned on is called the surge current.**

READING A DATA SHEET

- A data sheet, or specification sheet, lists important parameters and operating characteristics for semiconductor devices.
- Also, essential information such as case styles, pinouts, testing procedures, and typical applications can be obtained from a component's data sheet.
- Semiconductor manufacturers generally provide this information in data books or on the manufacturer's website.

DIODE AS AN UNCONTROLLED SWITCH

- A semiconductor switch with **no control input** is said to be uncontrolled.
- The diode turns off and acts as an open switch
- Device switching depends on supply voltage.
- Hence, **the diode operates as an uncontrollable switch**.