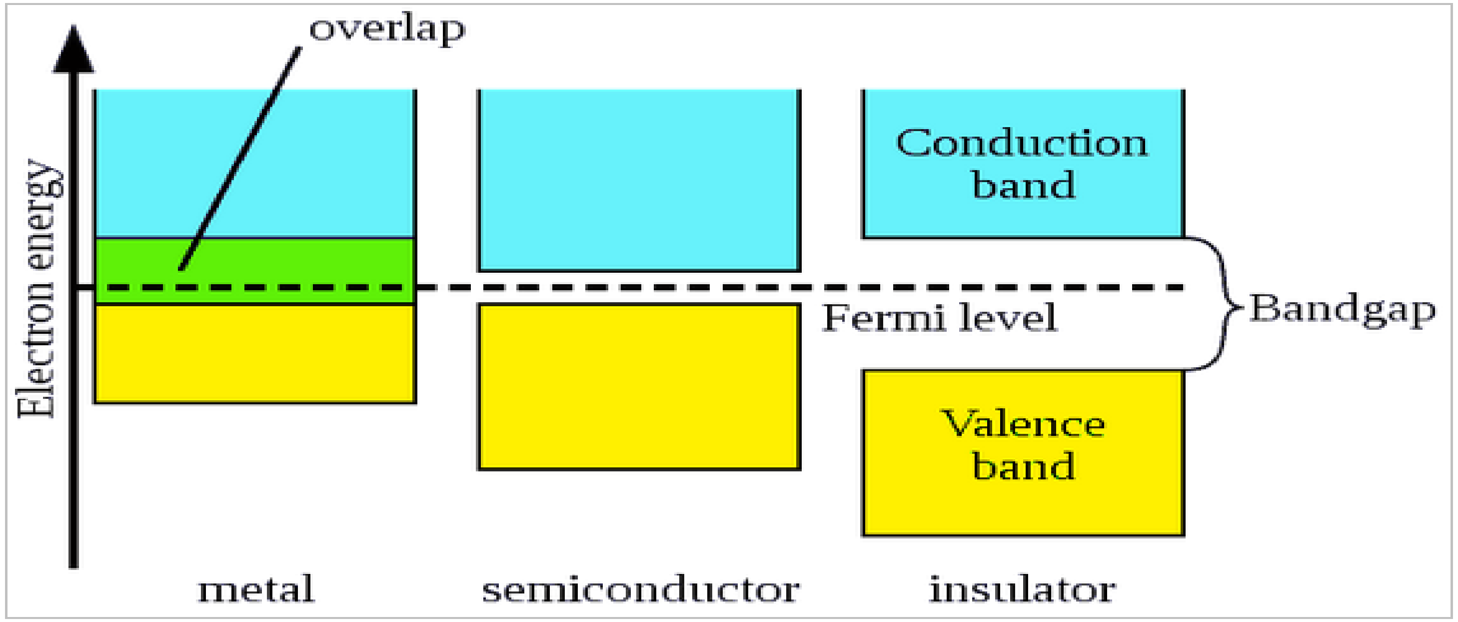
# Semiconductors (An Introduction)

In terms of the electrical property, material can be categorized in three parts.

1. Conductors
2. Insulators
3. Semiconductors



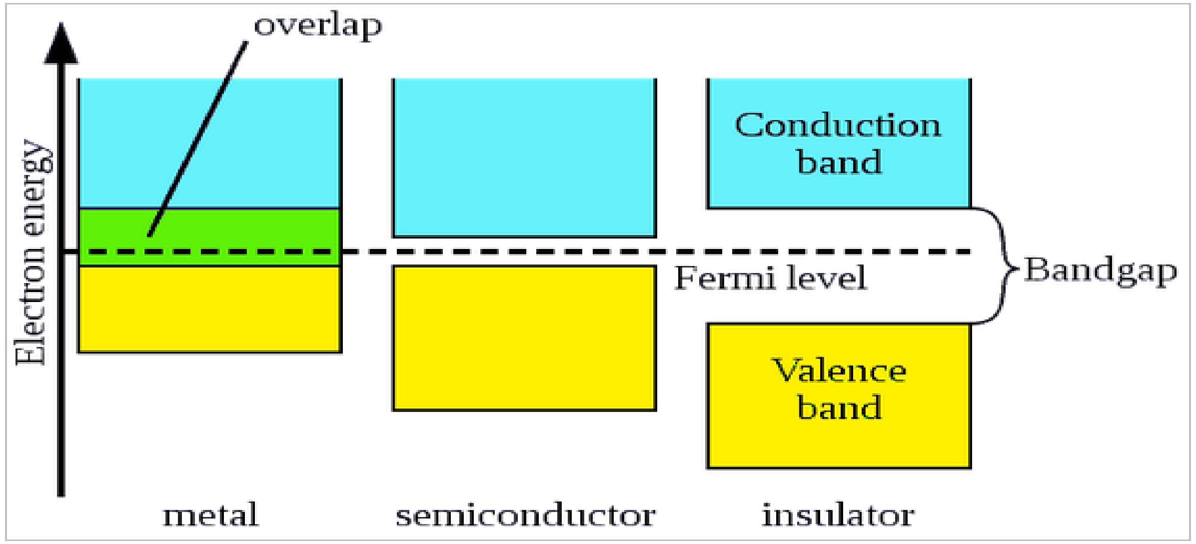

- Energy band gap
- Temperature Coefficient of resistance

# Semiconductors (An Introduction)

Examples:

1. Conductors: Gold, Copper, Silver, Aluminum, etc.
2. Insulators: Rubber, Glass, Wood, Mica, etc.
3. Semiconductors: Silicon, Germanium, Selenium, GaAs, etc.

- Energy band gap
- Temperature Coefficient of resistance



- At room temperature ,electrons and holes while in random motion, may encounter with each other, to form pairs. This recombination results in the release of heat, which breaks another covalent bond. When the temperature increases, the rate of generation of electrons and holes increase, thus rate of recombination increases, which results in the increase of densities of electrons and holes. As a result, conductivity of semiconductor increases and resistivity decreases, which means the negative temperature coefficient.

# Semiconductors

## Advantages

1. The semiconductor device has a small size, so the circuits involving devices are very compact.
2. No heating is required so semiconductor devices are set into operation as soon as the circuit is switched on.
3. Semiconductor devices occupy less space on any type of printed circuit board.
4. Semiconductor devices require low voltage operation.
5. Low power consumption.

## Disadvantages

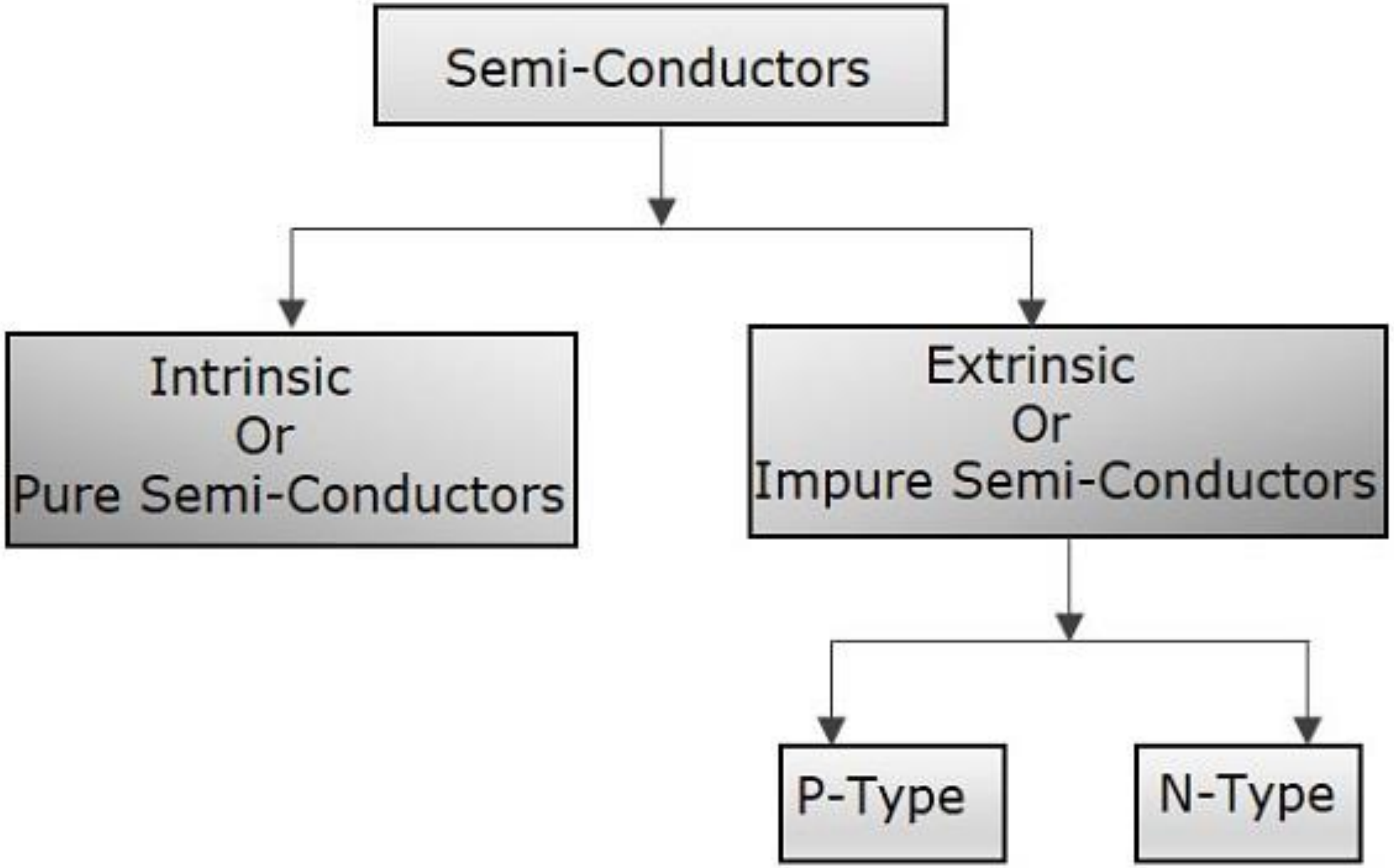
1. Conductivity changes with variations in the temperature.
2. Extra components required for stabilization.
3. Easily damaged (by exceeding power limits, by reversing polarity of operating voltage, by excess heat when soldering into circuit).

# QUICK QUIZ (POLL)

The resistivity of a semiconductor _____________ conductors and insulators

A. More than that of
B. Lies between that of
C. Less than that of
D. None of the above

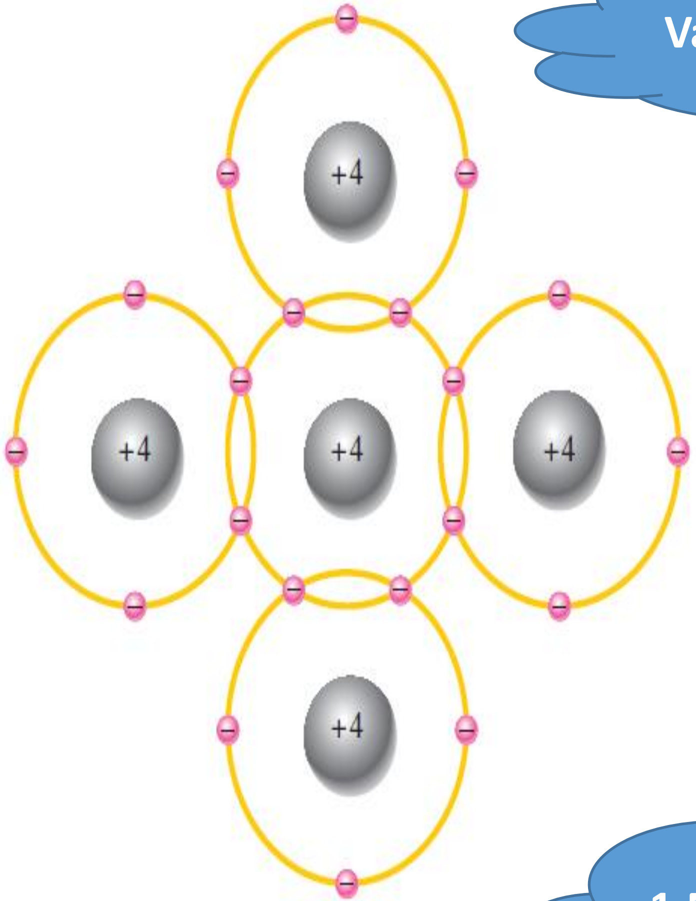
# Types of Semiconductors

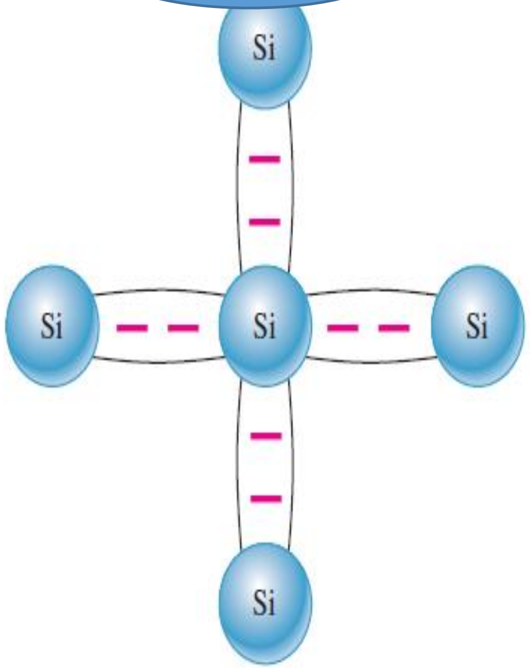


# Silicon and Germanium

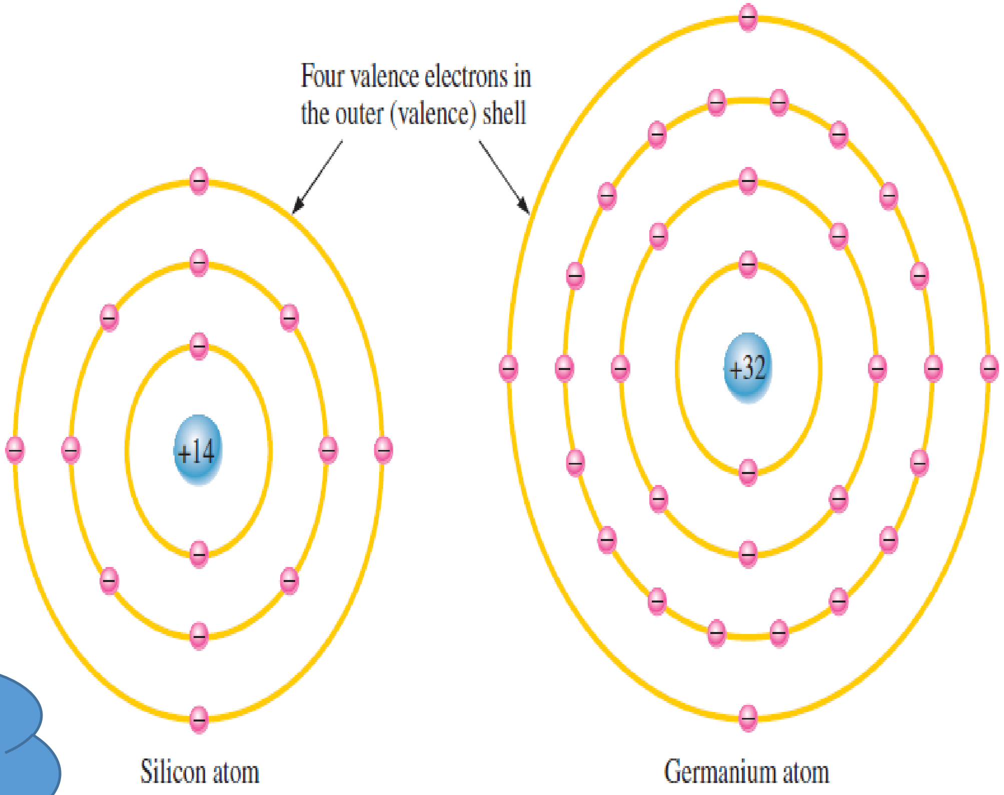
3.At absolute zero temperature intrinsic semiconductor behaves as insulator.

2.No movement from Valence band to conduction band

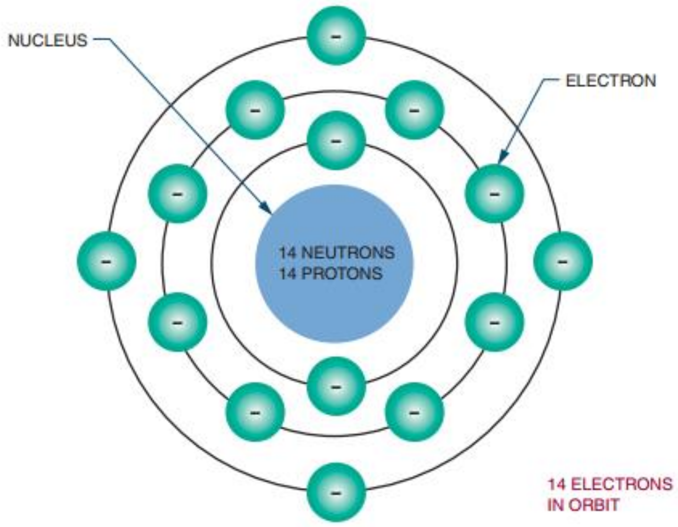



1.No energy (all freeze or colder temperature )

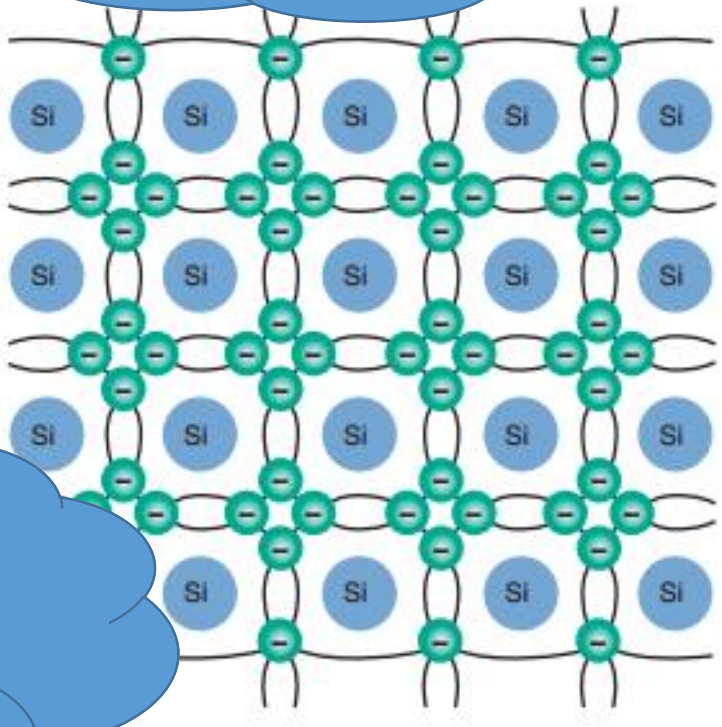


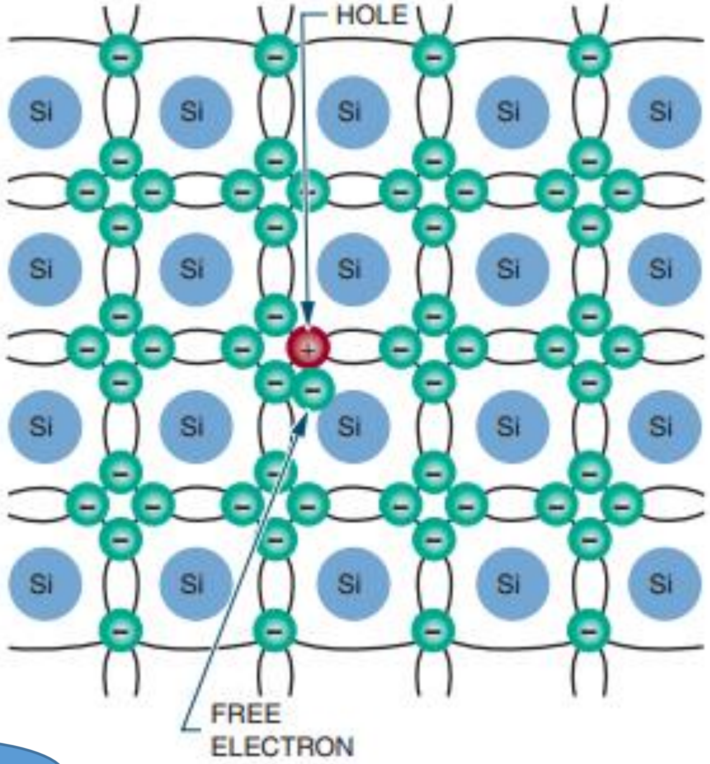
# Pure Silicon (Intrinsic)




**valence electrons** which are loosely attached to the nucleus

**At Room temperature**




**Sharing of valence e called …bonding ??**

**1.Electron-hole pair generation**
**2.Recombination (generation of heat ) again breaking of bonds**
**3. Negative temperature coefficient**

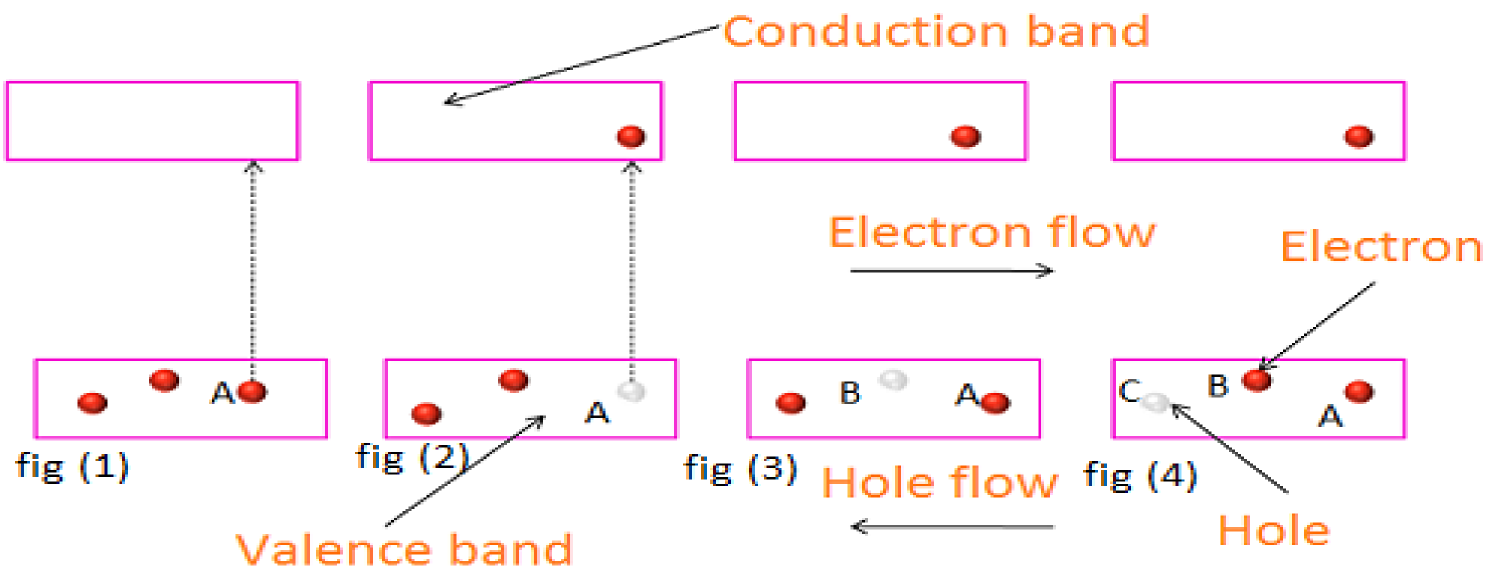
**Movement of electron from valence to conduction band results electron current and have negative charge**

# Explanation Slide

# Concept of Hole Current

- Semiconductors distinguish themselves from metals and insulators by the fact that they contain an "almost-empty" conduction band and an "almost-full" valence band.
- The concepts of holes is introduced based on the notion that it is a whole lot easier to keep track of the missing particles in an "almost-full" band, rather than keeping track of the actual electrons in that band.
- Holes are missing electrons. They behave as particles with the same properties as the electrons would have occupying the same states except that they carry a positive charge. This definition is illustrated further with the figure which presents the simplified energy band diagram in the presence of an electric field.

# Concept of Hole Current



# Summarize Intrinsic Semiconductors

- A Semiconductor in its extremely pure form is said to be an intrinsic semiconductor. The properties of this pure semiconductor are as follows:

1. The electrons and holes are solely created by thermal excitation.
2. The number of free electrons is equal to the number of holes.
3. Electron and hole current both present in pure semiconductor
4. The conduction capability is small at room temperature

**How conductivity can be increased?**

# QUICK QUIZ (POLL)

A semiconductor has generally ……………… valence electrons.

A. 3

B. 4

C. 5

D. 6

# QUICK QUIZ (POLL)

A semiconductor is formed by ___________ bonds

A. Covalent
B. Electrovalent
C. Co-ordinate
D. None of the above

# Extrinsic Semiconductor-Doping in Semiconductors

- An impure semiconductor, which is formed by doping a pure semiconductor is called as an **extrinsic semiconductor**.
- There are two types of extrinsic semiconductors depending upon the type of impurity added. They are N-type extrinsic semiconductor and P-Type extrinsic semiconductor.

- The process of adding impurities to the semiconductor materials is termed as doping. The impurities added, are generally pentavalent and trivalent impurities.

1. Pentavalent Impurities

- The pentavalent impurities are the ones which has five valence electrons in the outer most orbit. Example: Bismuth, Antimony, Arsenic, Phosphorus
- The pentavalent atom is called as a donor atom because it donates one electron to the conduction band of pure semiconductor atom.

2. Trivalent Impurities

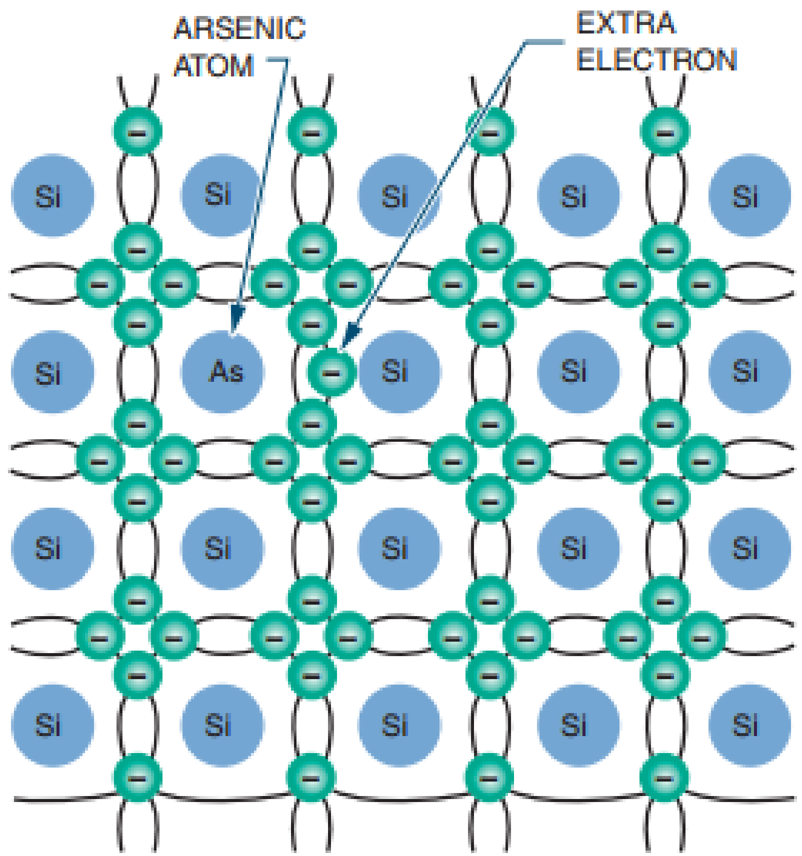
- The trivalent impurities are the ones which has three valence electrons in the outer most orbit. Example: Gallium, Indium, Aluminum, Boron
- The trivalent atom is called as an acceptor atom because it accepts one electron from the semiconductor atom.

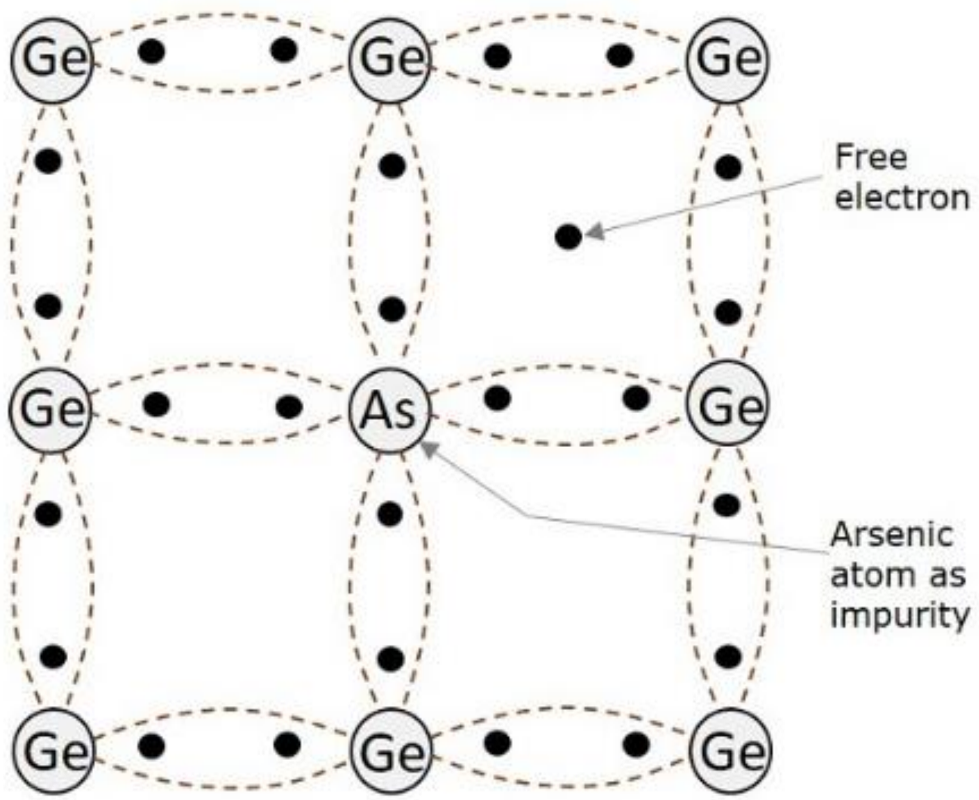
# Explanation Slide

# N-Type Extrinsic Semiconductors

- A small amount of pentavalent impurity is added to a pure semiconductor to result in N-type extrinsic semiconductor. The added impurity has 5 valence electrons.
- For example, if Arsenic atom is added to the germanium atom, four of the valence electrons get attached with the Ge atoms while one electron remains as a free electron.

Silicon semiconductor material doped with an arsenic atom.



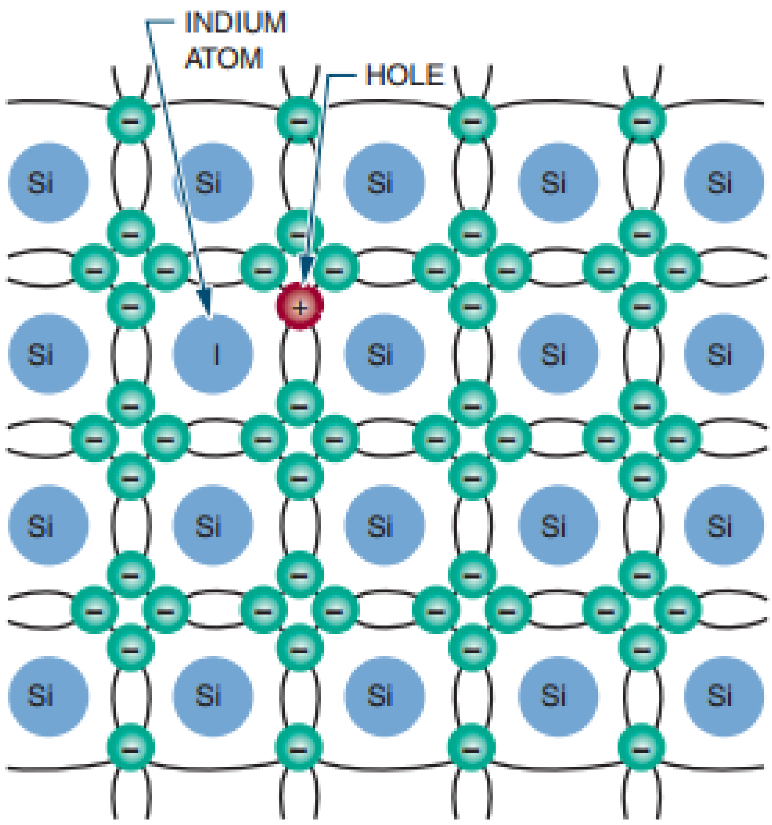



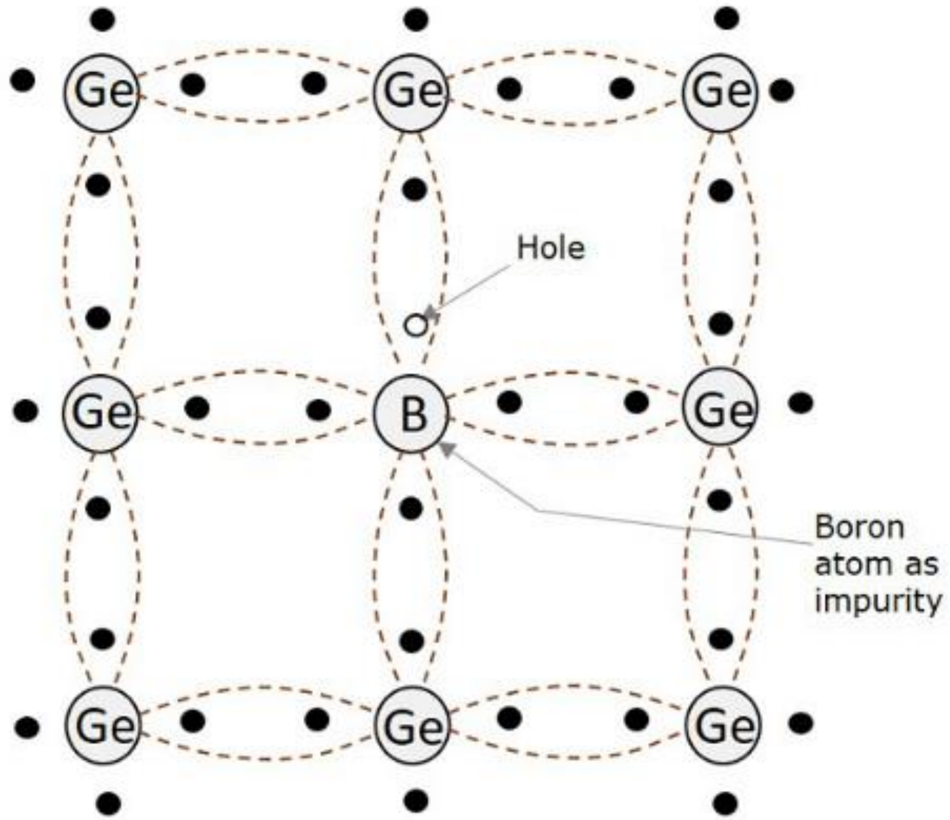

- **In N-type extrinsic semiconductor, as the conduction takes place through electrons, the electrons are majority carriers and the holes are minority carriers.**
- **As there is no addition of positive or negative charges, the electrons are electrically neutral.**

# P-Type Extrinsic Semiconductors

- A small amount of trivalent impurity is added to a pure semiconductor to result in P-type extrinsic semiconductor. The added impurity has 3 valence electrons.
- For example, if Boron atom is added to the germanium atom, three of the valence electrons get attached with the Ge atoms, to form three covalent bonds. But, one more electron in germanium remains without forming any bond.
- As there is no electron in boron remaining to form a covalent bond, the space is treated as a hole. This is as shown in the following figure.

Silicon semiconductor material doped with an indium atom.




- **In P-type extrinsic semiconductor, as the conduction takes place through holes, the holes are majority carriers while the electrons are minority carriers.**
- **The impurity added here provides holes which are called as acceptors, because they accept electrons from the germanium atoms.**
- **As the number of mobile holes remains equal to the number of acceptors, the P-type semiconductor remains electrically neutral.**

# Why Electrical Neutral (P and N type)

**But n-type and p-type semiconductors are electrically neutral. This is because that excess negative electron of an n-type crystal is balanced by the positively charged nucleus of an arsenic atom.**

**On the other hand, positively charged hole produced in the p-type crystal is balanced by the excess negative charge of the germanium-silicon atom. That means, n-type and p-type materials are actually electrically neutral.**

# Formation Of P Type and N type

# QUICK QUIZ (POLL)

**When a pentavalent impurity is added to a pure semiconductor, it becomes ………**

A. An insulator

B. An intrinsic semiconductor

C. p-type semiconductor

D. n-type semiconductor

# QUICK QUIZ (POLL)

**An n-type semiconductor is ………**

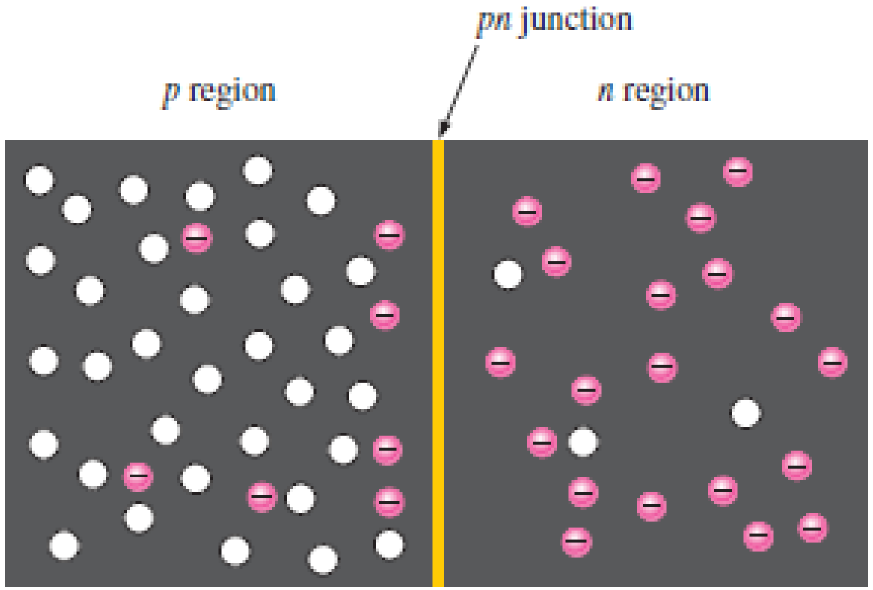
A. Positively charged
B. Negatively charged
C. Electrically neutral
D. None of the above

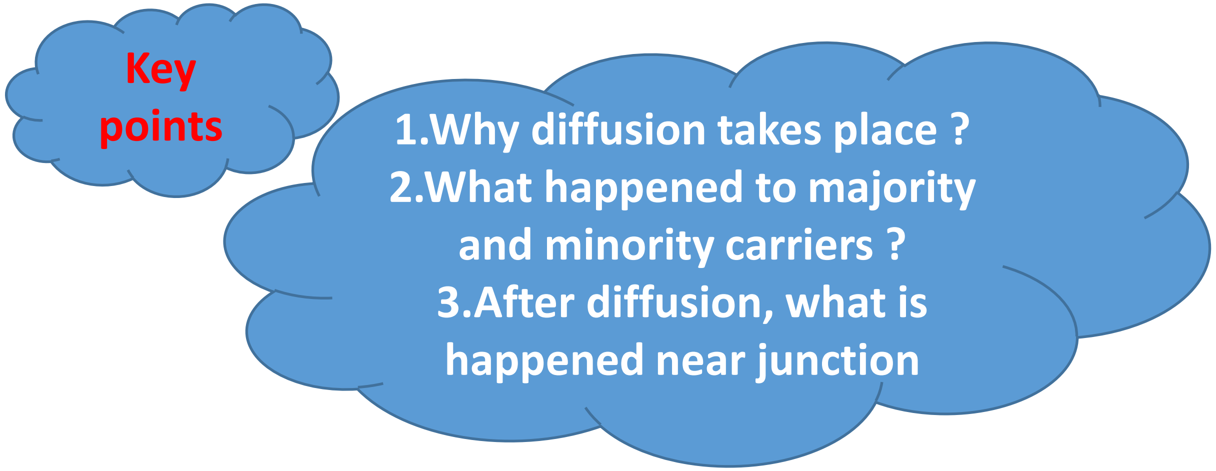
# PN Junction Diode

A PN-junction diode is formed when a p-type semiconductor is fused to an n-type semiconductor creating a potential barrier voltage across the diode junction.

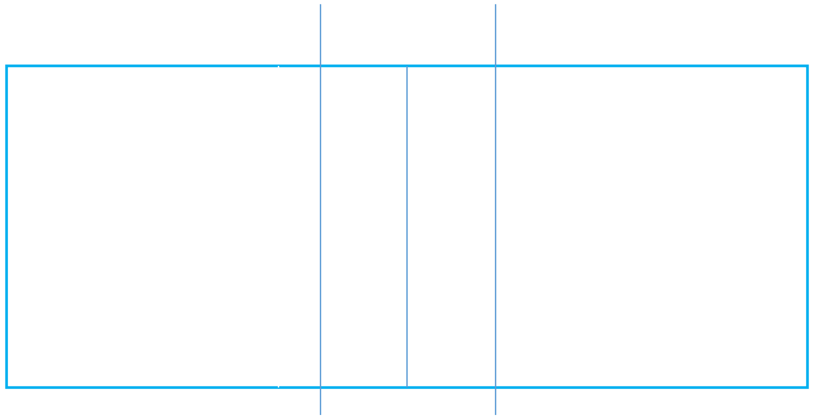
The basic silicon structure at the instant of junction formation showing only the majority and minority carriers.

Free electrons in the *n region near the pn junction begin to diffuse across the* junction and fall into holes near the junction in the *p region.*



# Explanation Slide

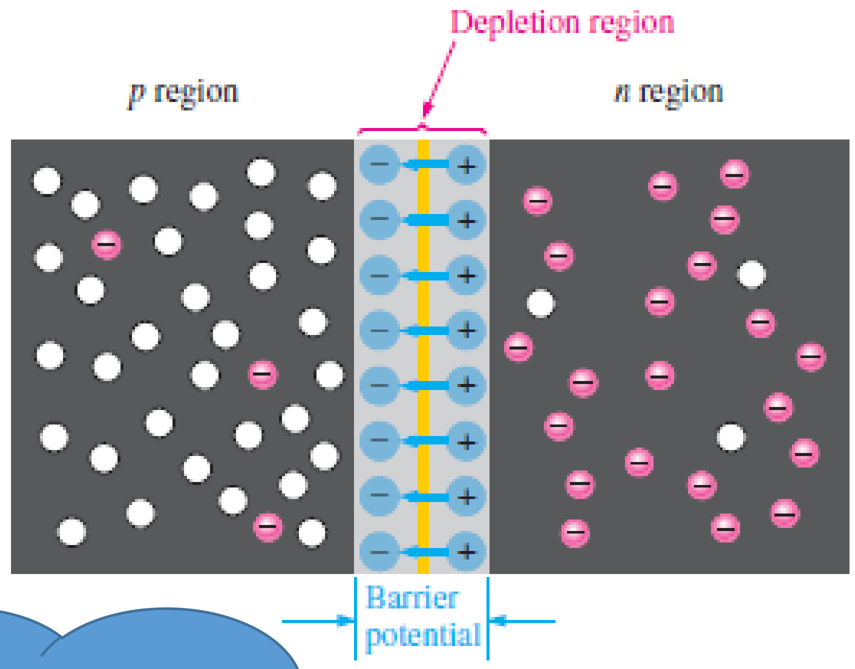


# PN Junction Diode (Zero Bias or No Bias)

For every electron that diffuses across the junction and combines with a hole, a positive charge is left in the *n region* and a negative charge is created in the *p region, forming a* barrier potential.

This action continues until the voltage of the barrier repels further diffusion…..Barrier

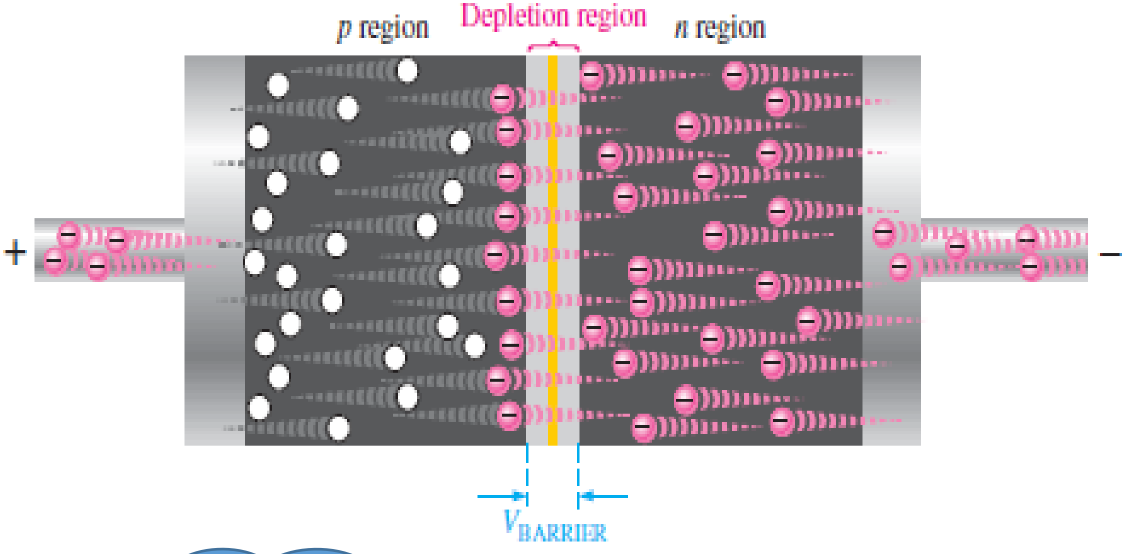
The blue arrows between the positive and negative charges in the depletion region represent the electric field.




**Key points:**
**1.Immobile carriers….Space charge or Depletion Region**
**2.Barrier Potential**
**3.Electric Field**
**4.** A net zero current flows in the circuit and the junction is said to be in **dynamic equilibrium**

# PN Junction Diode (Forward Bias)

- If a suitable positive voltage (forward bias) is applied between the two ends of the PN junction, it can supply free electrons and holes with the extra energy they require to cross the junction as the width of the depletion layer around the PN junction is decreased.




- As more electrons flow into the depletion region reducing the number of negative ions and similarly more holes move in reducing the positive ions.

What happened to minority carriers?

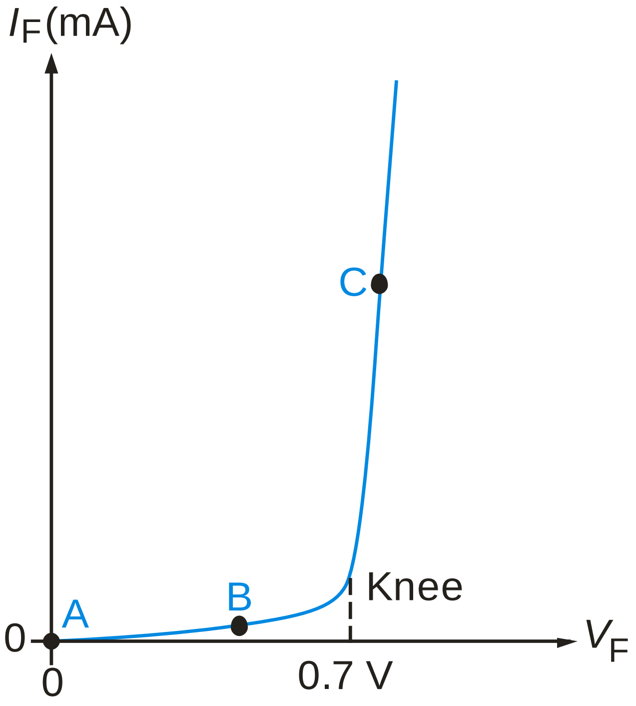
Key points:
1.Width decreases (barrier reduces)
2.Resistance decreases
3.Act as short circuit (ideal ,R=0)
4. Current conduction due to ………carriers?

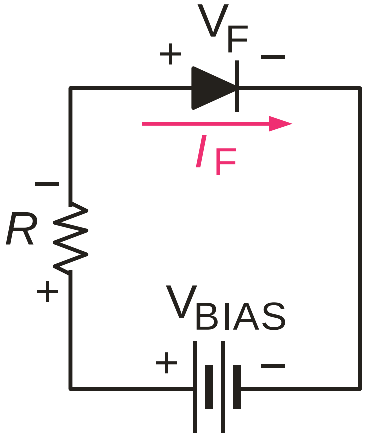
ZERO current or KNEE current.

# VI Characteristics of Diode for Forward Bias

- **VI Characteristic for forward bias.**
  - The current in forward biased called *forward current* and is designated *If.*
  - At 0V ($V_{bias}$) across the diode, there is no forward current.
  - With gradual increase of ($V_{bias}$), the forward voltage and forward current increases.
  - A resistor in series will limit the forward current in order to protect the diode from overheating and permanent damage.
  - A portion of forward-bias voltage drops across the limiting resistor.
  - Continuing increase of Vf causes rapid increase of forward current but only a gradual increase in voltage across diode.

IF= ???



# QUICK QUIZ (POLL)

A diode has forward resistance of the order of ……………

A. kΩ
B. Ω
C. MΩ
D. none of the above

# QUICK QUIZ (POLL)

**The knee voltage of a crystal diode is approximately equal to …………**

A) applied voltage

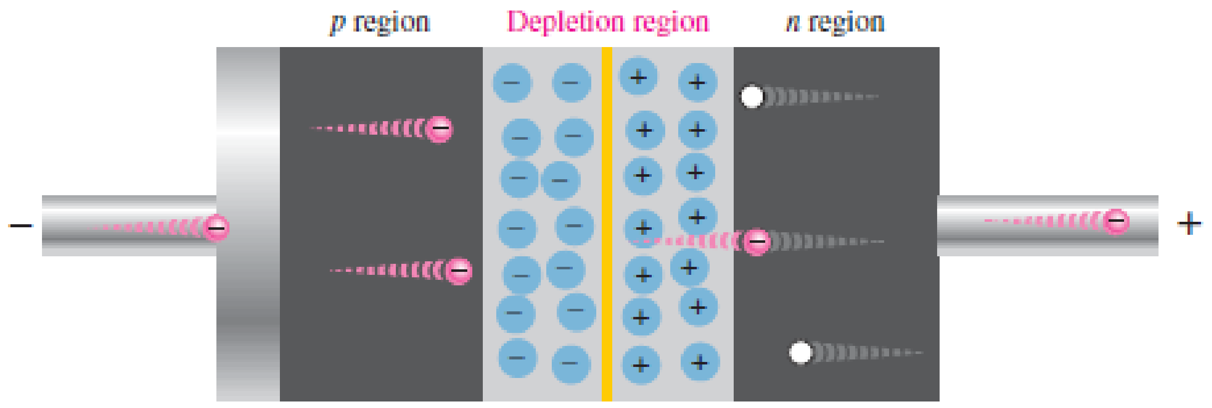
B) breakdown voltage

C) forward voltage

D) barrier potential

# PN Junction Diode (Reverse Bias)

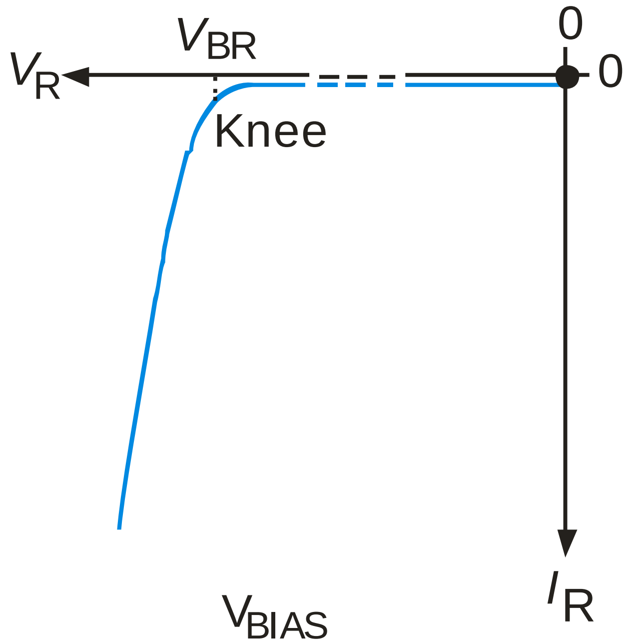
- Positive side of Vbias is connected to the n-region whereas the negative side is connected with p-region.
- By applying a negative voltage (reverse bias) results in the free charges being pulled away from the junction resulting……
    - Depletion region get wider with this configuration.
    - Effective resistance increases (high).
    - A high potential barrier is created across the junction thus preventing current from flowing through the semiconductor material.
    - Act as open switch (ideal , R=Infinite)
    - But ,A small amount current is generated due to the minority carriers in p and n regions called ……………………………………

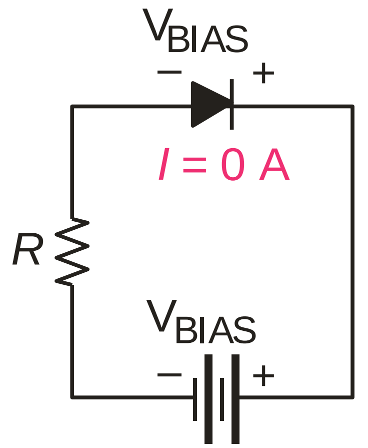


# VI Characteristics of Diode for Reverse Bias

❖**VI Characteristic for reverse bias.**

- ❖With 0V reverse voltage there is no reverse current.
- ❖There is only a small current through the junction as the reverse voltage increases.
- ❖At a point, reverse current shoots up with the break down of diode. The voltage called break down voltage. This is not normal mode of operation.
- ❖After this point the reverse voltage remains at approximately $V_{BR}$ but $I_R$ increase very rapidly.
- ❖Break down voltage depends on doping level, set by manufacturer.



# QUICK QUIZ (POLL)

A silicon diode has an external bias voltage is 12V with an external resistor of 150 ohm. What is the total forward current

a) 150mA

b) 100mA

c) 75mA

d) 12mA

# QUICK QUIZ (POLL)

- In a PN junction when the applied voltage overcomes the ........ potential, the diode current is large, which is known as ............

A) Depletion, negative bias

B) Reverse, reverse bias

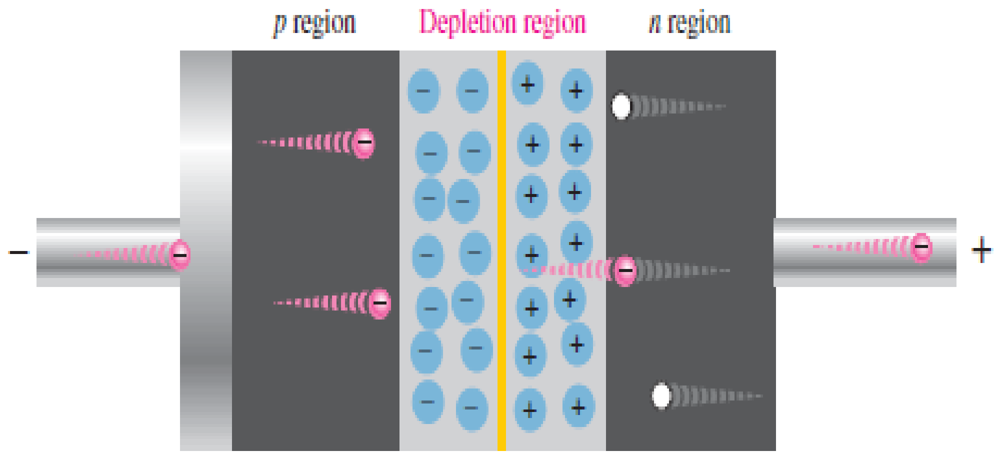
C) Resistance, reverse bias

D) Barrier, forward bias

# Avalanche breakdown

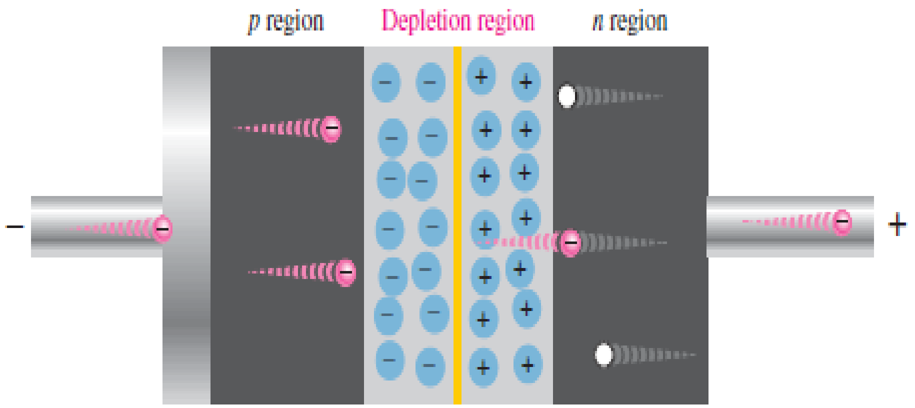
- The reverse bias increases the electrical field across the depletion region. When the high electric field exists across the depletion, the velocity of minority charge carrier crossing the depletion region increases. These carriers collide with the atoms of the crystal. Because of the violent collision, the charge carrier takes out the electrons from the atom.

- The collision increases the electron-hole pair. As the electron-hole induces in the high electric field, they are quickly separated and collide with the other atoms of the crystals. The process is continuous, and the electric field becomes so much higher then the reverse current starts flowing in the PN junction. The process is known as the **Avalanche breakdown**. After the breakdown, the junction cannot regain its original position because the diode is completely burnt off.



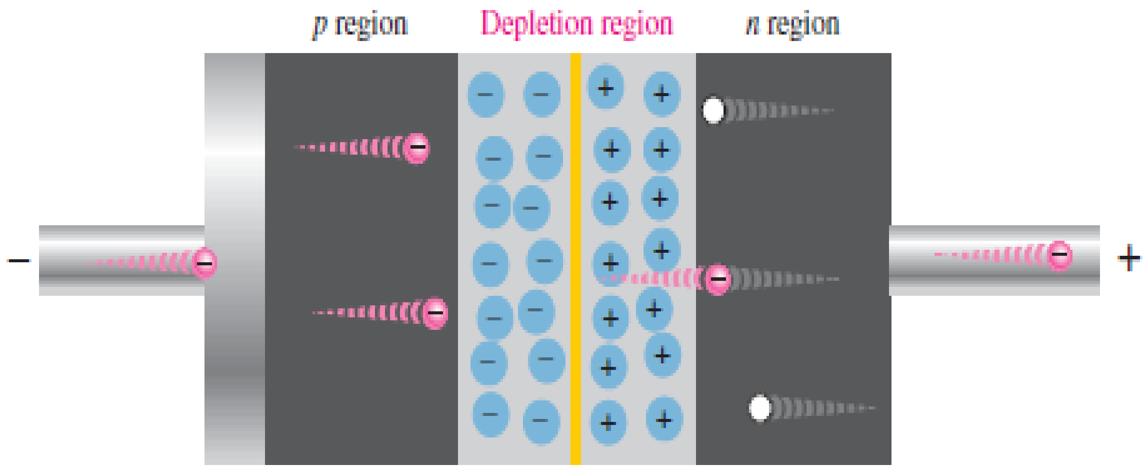
# Avalanche Breakdown Phenomenon:

- After certain reverse voltage across the junction, the minority carriers get sufficient kinetic energy due to reverse voltage and the strong electric field.
- Free electrons with sufficient kinetic energy collide with stationary ions of the depletion layer and knock out more free electrons.
- These newly created free electrons also get sufficient kinetic energy due to the same electric field, and they create more free electrons by collision cumulatively.
- As a result, very soon, **huge number of free electrons get created** in the depletion layer, and the entire diode will become conductive.
- This type of breakdown of the depletion layer is known as **avalanche breakdown.**



# Reverse Breakdown in the Reverse Bias

- If the external bias voltage is increased to a value call *breakdown voltage* the reverse current can increase drastically.
- Free minority electrons get enough energy to knock valance electron into the conduction band.
- The newly released electron can further strike with other atoms.



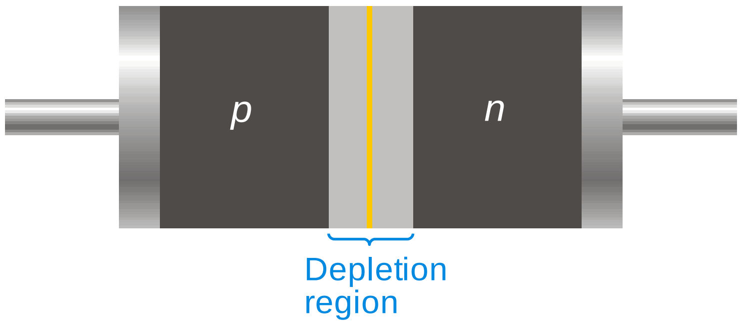
# QUICK QUIZ (POLL)

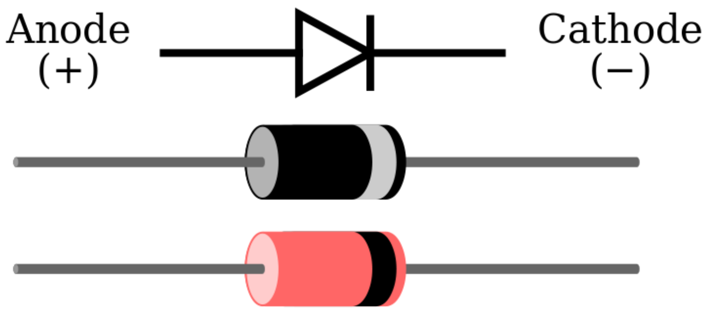
During reverse bias, a small current develops known as
a) Forward current
b) Reverse current
c) Reverse saturation current
d) Active current

# Summerize Diode

- Diode, semiconductor material, such as silicon, in which half is doped as p-region and half is doped as n-region with a PN-junction in between.

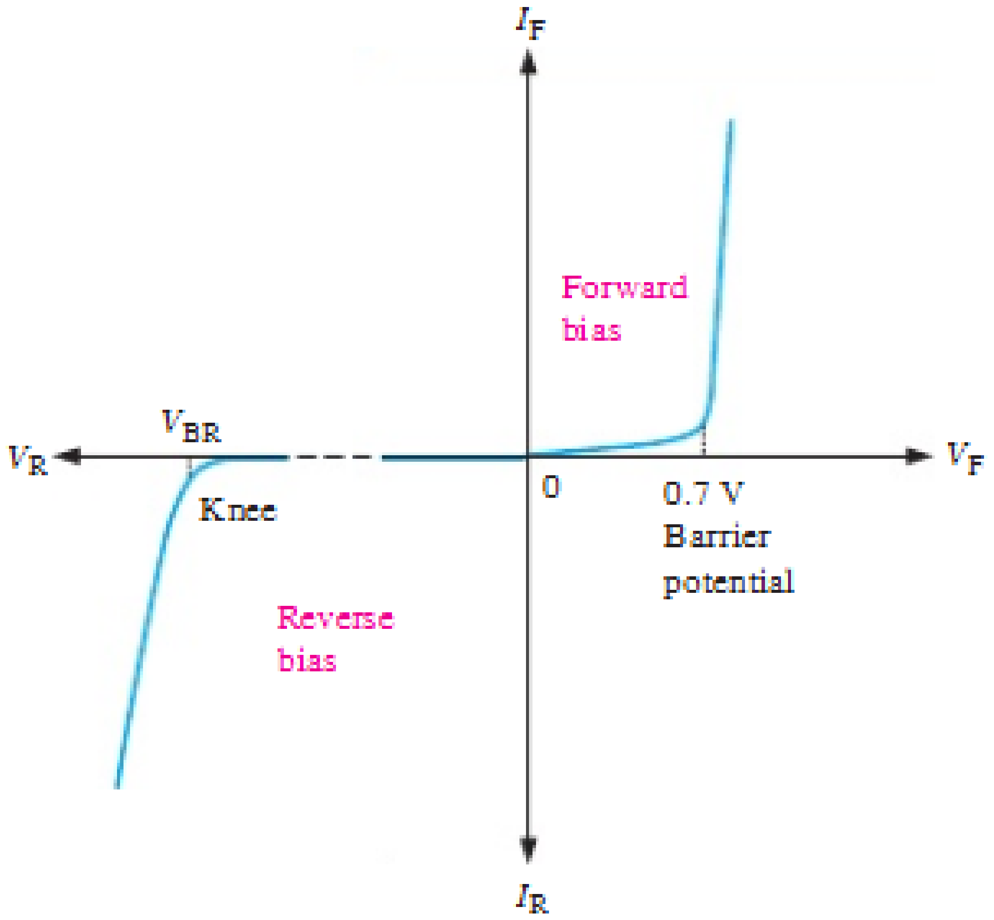
- The p region is called **anode** and n type region is called **cathode.**




- It conducts current in one direction and offers high (ideally infinite) resistance in other direction.

# Complete VI Characteristics of Diode




The complete *V-I* characteristic curve for a diode.

# QUICK QUIZ (POLL)

An ideal crystal diode is one which behaves as a perfect ……….. when forward biased.

A. conductor
B. insulator
C. resistance material
D. none of the above

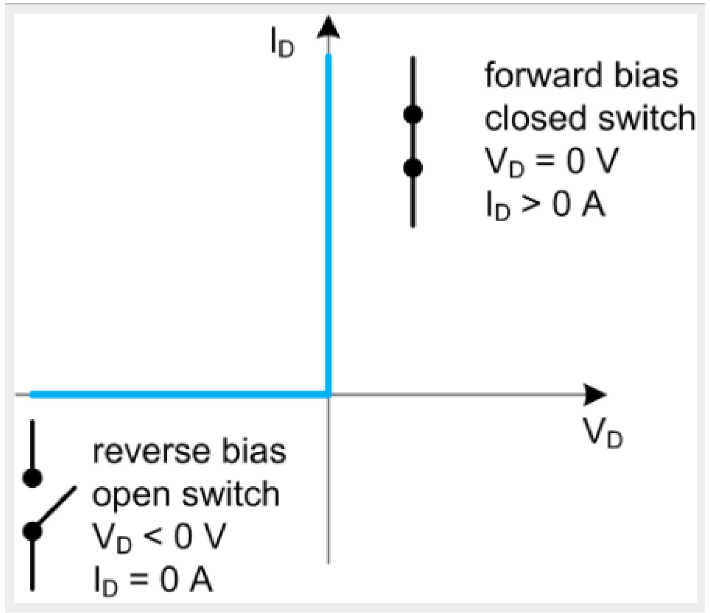
# Summary

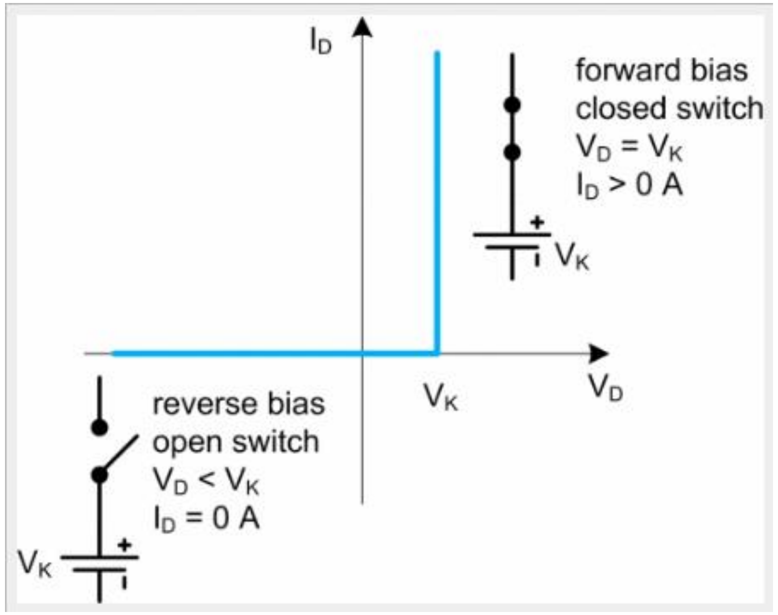
- The PN junction region of a Junction Diode has the following important characteristics:

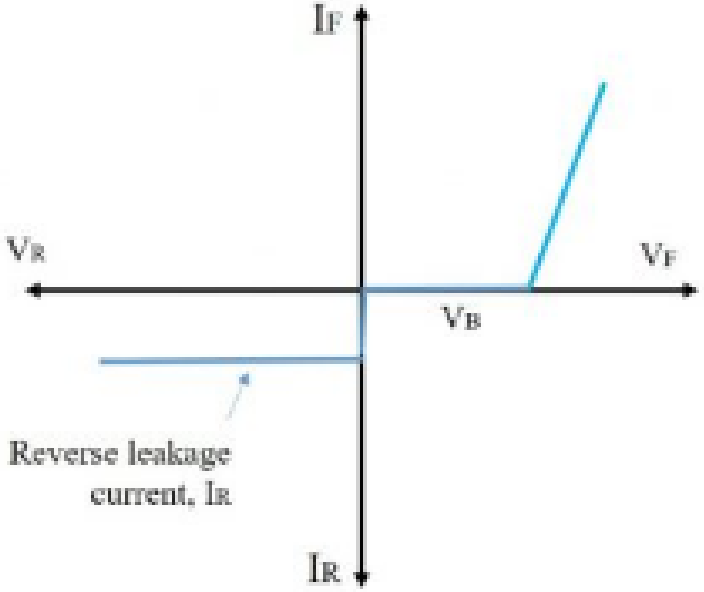
1. Semiconductors contain two types of mobile charge carriers, “Holes” and “Electrons”.
2. The holes are positively charged while the electrons negatively charged.
3. A semiconductor may be doped with donor impurities such as Antimony (N-type doping), so that it contains mobile charges which are primarily electrons.
4. A semiconductor may be doped with acceptor impurities such as Boron (P-type doping), so that it contains mobile charges which are mainly holes.
5. The junction region itself has no charge carriers and is known as the depletion region.
6. The junction (depletion) region has a physical thickness that varies with the applied voltage.
7. When a diode is Zero Biased no external energy source is applied and a natural Potential Barrier is developed across a depletion layer which is approximately 0.5 to 0.7v for silicon diodes and approximately 0.3 of a volt for germanium diodes.
8. When a junction diode is Forward Biased the thickness of the depletion region reduces and the diode acts like a short circuit allowing full circuit current to flow.
9. When a junction diode is Reverse Biased the thickness of the depletion region increases and the diode acts like an open circuit blocking any current flow, (only a very small leakage current will flow).

# Diode Model

- Ideal Diode
- Practical Diode



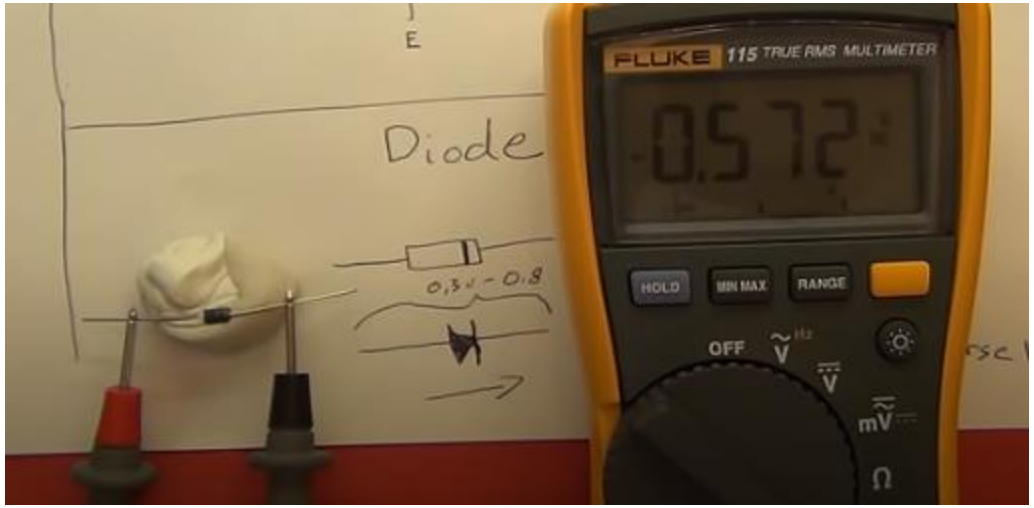



# Applications of a Diode

1. Rectifiers
   - ❑ Half Wave Rectifier
   - ❑ Full Wave Rectifier
2. Clipper
3. Clamper

# Testing of diode





https://www.youtube.com/watch?v=8LGD5LdOzEM

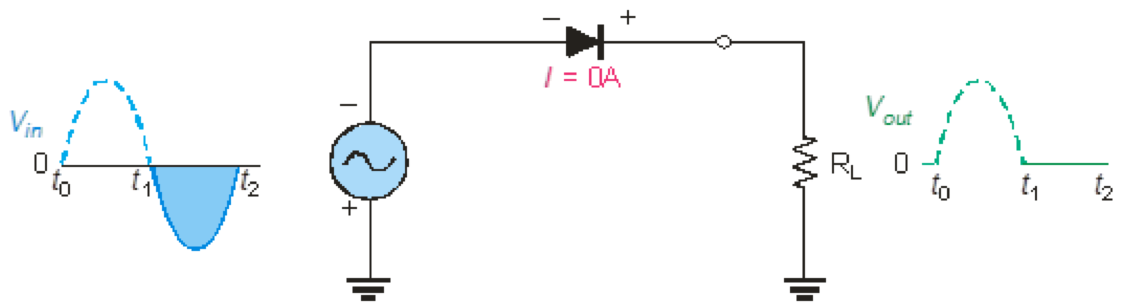
# Half wave Rectifiers

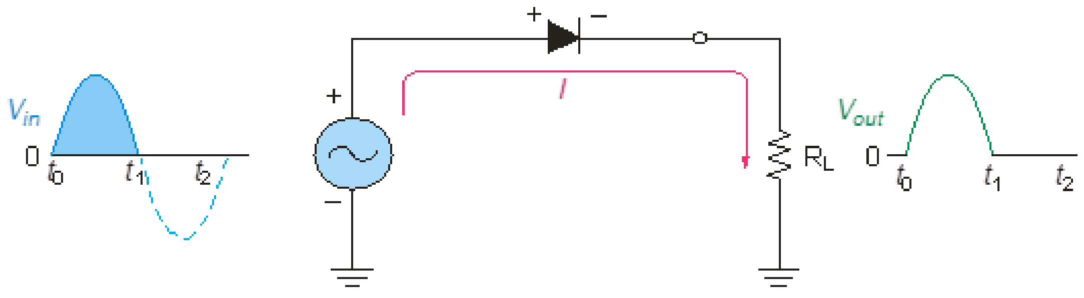
❖As diodes conduct current in one direction and block in other.

❖When connected with ac voltage, diode only allows half cycle passing through it and hence convert ac into dc.

❖As the half of the wave get rectified, the process called half wave rectification.

- A diode is connected to an ac source and a load resistor forming a half wave rectifier.
- Positive half cycle causes current through diode, that causes voltage drop across resistor.



# Explanation Slide