

Semiconductor Devices

Unit I

Quick Revision Guide



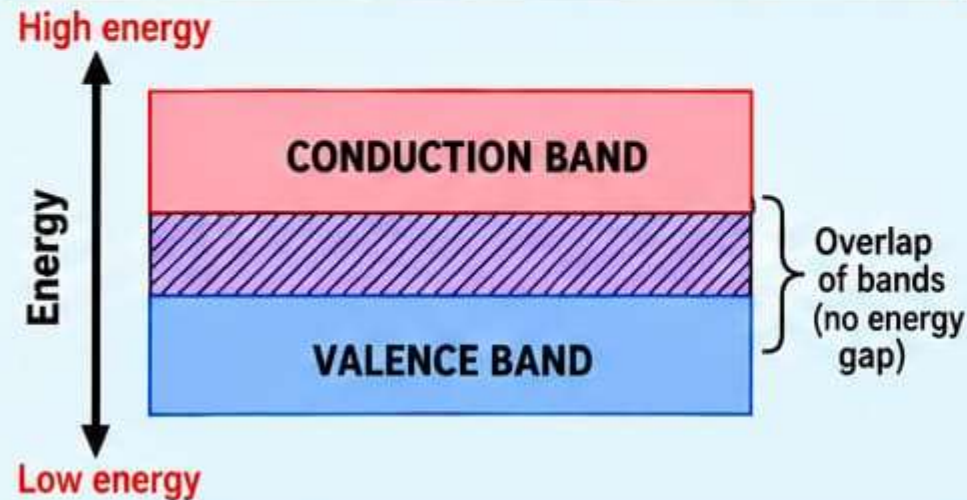
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Energy Band Diagrams of Solids (Conductor, Semiconductor and Insulator)

In a **solid**, the **energy levels** of atoms split into a large number of closely spaced levels forming **energy bands**.
The two important bands are: **Valence Band** (contains valence electrons) and **Conduction Band** (allows free movement of electrons).

1. CONDUCTOR (e.g., Copper, Aluminium, Silver)

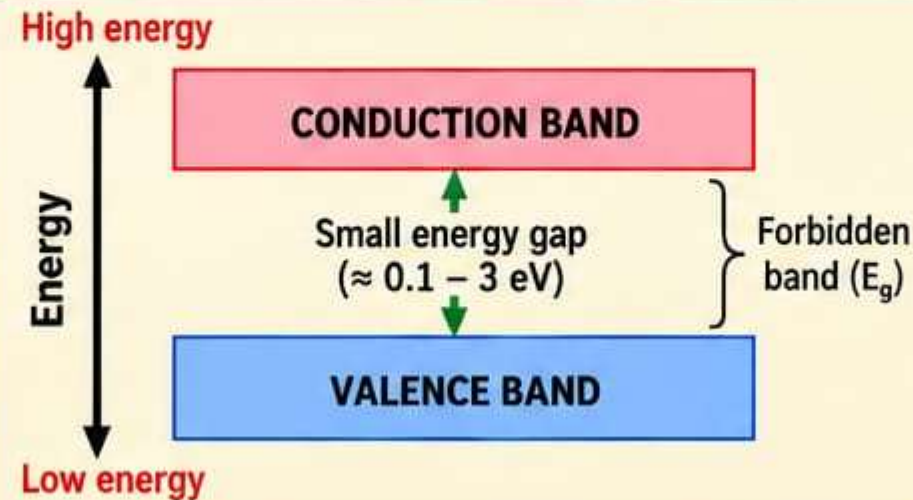


Valence band and conduction band overlap (or there is no forbidden energy gap).

Key Points

- No forbidden energy gap.
- Valence and conduction bands overlap.
- Large number of free electrons are available.
- Hence, conductors have high electrical conductivity.
- **Examples:** Copper (Cu), Aluminium (Al), Silver (Ag), etc.

2. SEMICONDUCTOR (e.g., Si, Ge, GaAs)

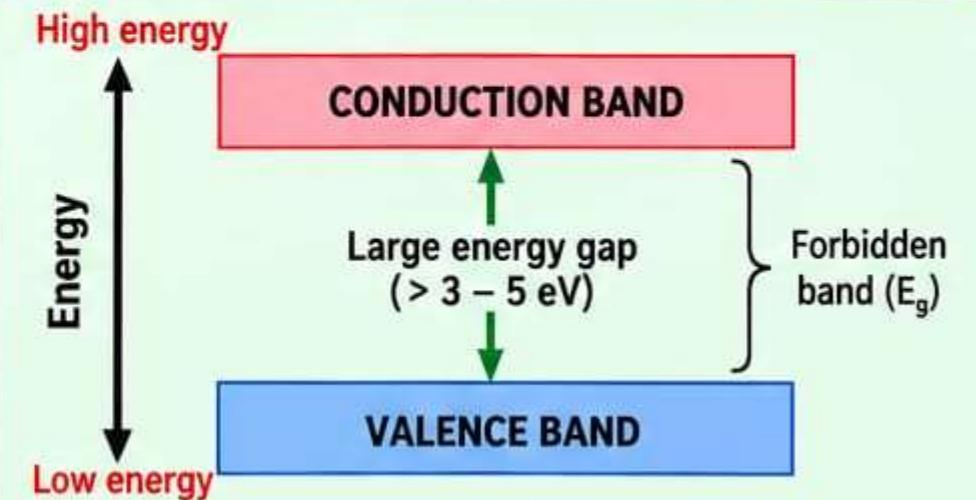


Valence band and conduction band are separated by a small energy gap ($\approx 0.1 - 3$ eV).

Key Points

- Small forbidden energy gap.
- At absolute zero, electrons are in the valence band.
- At room temperature, some electrons gain enough energy to cross the small gap and move to conduction band.
- Hence, semiconductors have moderate conductivity.
- **Examples:** Silicon (Si) – 1.1 eV, Germanium (Ge) – 0.7 eV, Gallium Arsenide (GaAs) – 1.4 eV.

3. INSULATOR (e.g., Diamond, Glass, Wood)



Valence band and conduction band are separated by a large energy gap ($> 3 - 5$ eV).

Key Points

- Large forbidden energy gap.
- Very few electrons can cross the gap even at high temperature.
- Hence, they have very low conductivity (almost no current).
- **Examples:** Diamond (≈ 5.5 eV), Glass (≈ 9 eV), Wood, Rubber, Mica, etc.

Comparison of Energy Gaps and Conductivity

Property	Conductor	Semiconductor	Insulator
Energy gap (E_g)	≈ 0 eV (bands overlap)	$\approx 0.1 - 3$ eV	$> 3 - 5$ eV
Band arrangement	Overlap	Small gap	Large gap
Number of free electrons	Very large	Moderate	Very few
Electrical conductivity	High	Moderate	Very low (almost zero)
Examples	Cu, Al, Ag	Si, Ge, GaAs	Diamond, Glass, Wood

Important Takeaway



Smaller the energy gap, easier it is for electrons to move from valence band to conduction band, so the electrical conductivity increases!

Intrinsic and Extrinsic Semiconductors

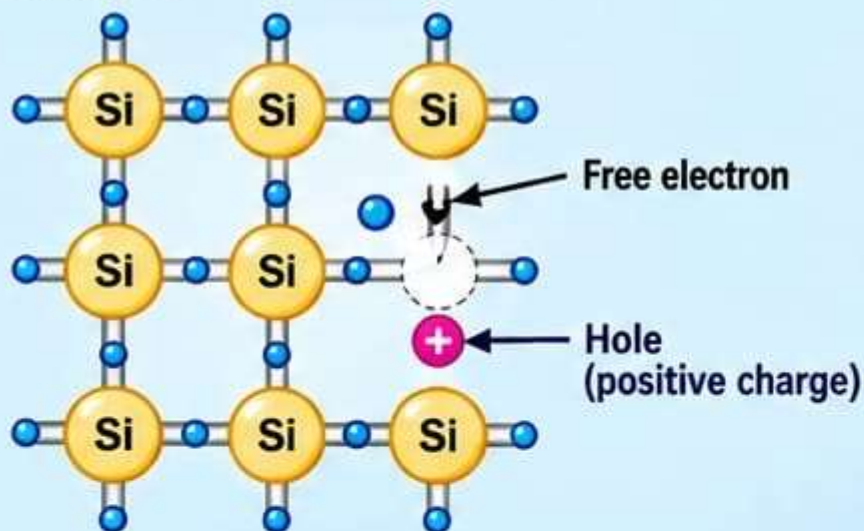
Intrinsic Semiconductor

A semiconductor in an extremely pure form (is free from impurities) is called an **intrinsic semiconductor**.

- Examples: Pure Silicon (Si) or Germanium (Ge)
- At room temperature, some covalent bonds break due to thermal energy and electron-hole pairs are generated.
- Number of free electrons (n) = Number of holes (p)

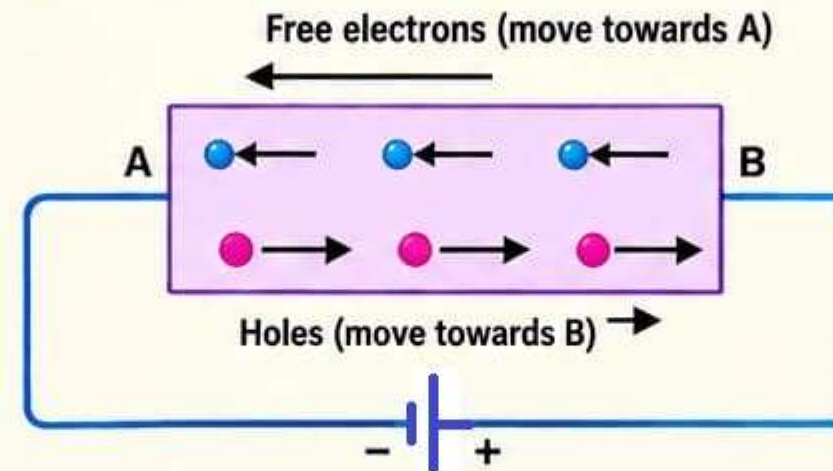
$$n = p = n_i$$

- Both electrons and holes contribute to current conduction.



In an intrinsic semiconductor, electron-hole pairs are created due to breaking of covalent bonds by thermal energy.

Current conduction in intrinsic semiconductor



When a voltage is applied, free electrons move towards the positive terminal (A) and holes move towards the negative terminal (B). Hence, the total current is the sum of electron current and hole current.

Extrinsic Semiconductor

A semiconductor with a small amount of suitable impurities added to increase its conductivity is called an **extrinsic semiconductor**.

- Obtained by adding impurities to a pure semiconductor (known as doping).
- The amount and type of impurity are carefully controlled.
- Extrinsic semiconductors are of two types:

n-type semiconductor

p-type semiconductor

n-type Semiconductor

- Formed by adding a small amount of pentavalent impurity (5 valence electrons) such as Phosphorus (P), Arsenic (As) or Antimony (Sb).
- Four electrons form covalent bonds and the fifth electron is loosely held and becomes a free electron.
- Electrons are majority carriers and holes are minority carriers.

Majority carriers – electrons
Minority carriers – holes

p-type Semiconductor

- Formed by adding a small amount of trivalent impurity (3 valence electrons) such as Boron (B), Aluminium (Al) or Gallium (Ga).
- Only three electrons take part in covalent bonds, leaving one vacant bond (hole).
- Holes are majority carriers and electrons are minority carriers.

Majority carriers – holes
Minority carriers – electrons

Key Points

- ✓ Intrinsic semiconductor is pure; extrinsic is doped with impurities.
- ✓ Intrinsic: $n = p = n_i$ (both electrons and holes conduct).
- ✓ **n-type**: pentavalent impurity, electrons are majority carriers.

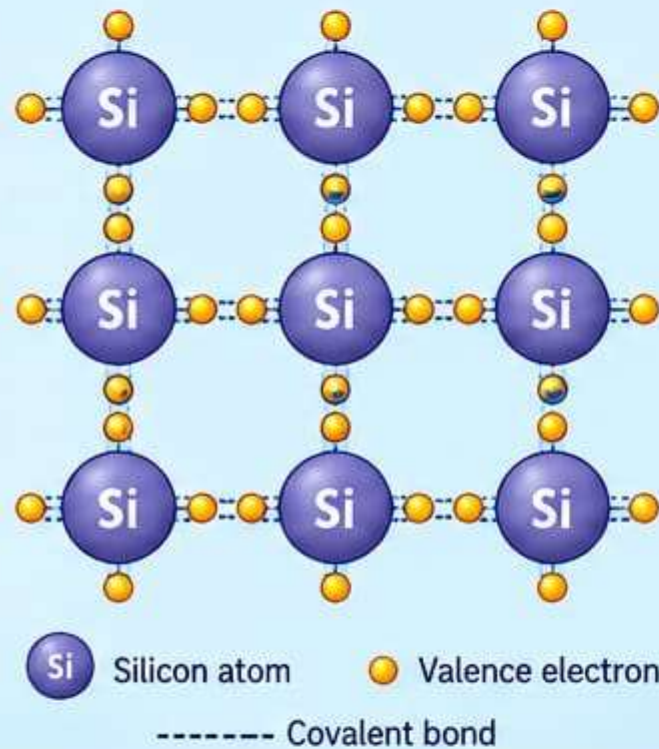
- ✓ **p-type**: trivalent impurity, holes are majority carriers.
- ✓ Doping greatly increases the conductivity of a semiconductor.

DOPING PROCESS IN SEMICONDUCTORS

Doping is the intentional addition of a small amount of impurity atoms into a pure semiconductor to change its electrical properties.

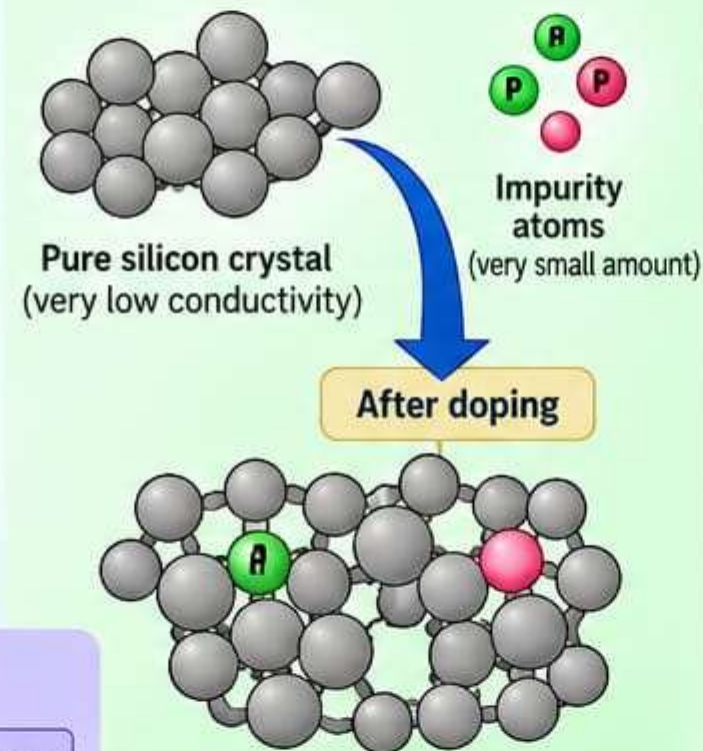
1 Pure (Intrinsic) Semiconductor

- Made of pure silicon (Si) or germanium (Ge).
- Each atom has 4 valence electrons.
- All electrons are involved in covalent bonds.
- Very few free charge carriers → low conductivity.



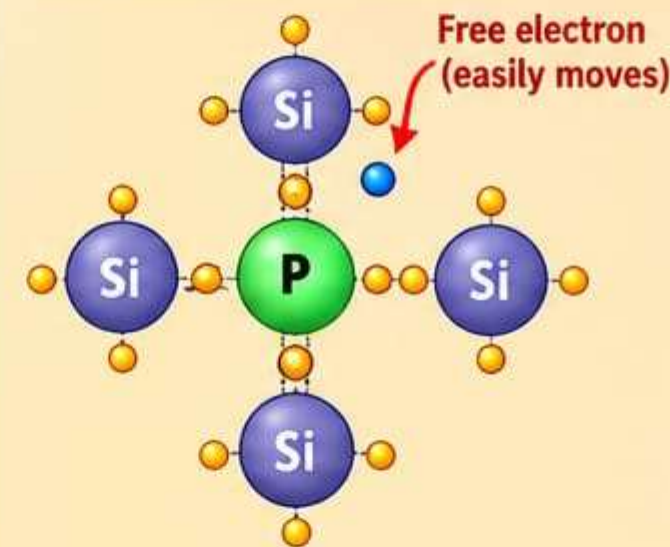
2 Doping Process

- A small amount of impurity atoms are added to pure semiconductor.
- The impurity atoms replace some of the silicon atoms in the crystal lattice.
- This process is called doping.
- Even a very small amount (about 1 in 10^6 to 10^8 atoms) is enough to change the conductivity.



3 n-type Semiconductor

- Doped with pentavalent (Group V) impurity atoms such as Phosphorus (P), Arsenic (As) or Antimony (Sb).
- Impurity atom has 5 valence electrons.
- Four electrons form bonds with neighbouring Si atoms.
- The 5th electron is loosely bound and becomes a free electron.
- Electrons are the majority carriers and holes are minority carriers.

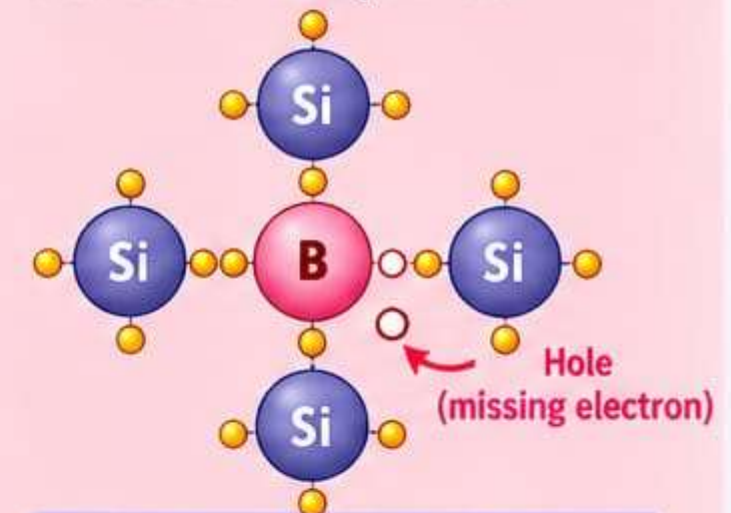


n-type semiconductor

Majority carriers : Electrons
Minority carriers : Holes

4 p-type Semiconductor

- Doped with trivalent (Group III) impurity atoms such as Boron (B), Aluminium (Al) or Gallium (Ga).
- Impurity atom has 3 valence electrons.
- It can form only three bonds with neighbouring Si atoms.
- One bond is incomplete, creating a hole (positive charge).
- Holes are the majority carriers and electrons are minority carriers.



p-type semiconductor

Majority carriers : Holes
Minority carriers : Electrons

Common Dopant Elements

Type	Dopant elements	Valence electrons
n-type (Group V)	Phosphorus (P) Arsenic (As) Antimony (Sb)	5
p-type (Group III)	Boron (B) Aluminium (Al) Gallium (Ga)	3



Key Points

- Doping increases the electrical conductivity of the semiconductor.
- Only a small amount of impurity (1 ppm to 100 ppm) is required.
- n-type → extra electrons (negative charge carriers).
- p-type → holes (positive charge carriers).
- Doped semiconductors are used to make diodes, transistors, ICs and other electronic devices.



Applications

- Diodes, transistors and integrated circuits
- Solar cells
- Sensors
- LEDs and other optoelectronic devices



A SMALL CHANGE MAKES A BIG DIFFERENCE – DOPING TURNS A POOR CONDUCTOR INTO A USEFUL SEMICONDUCTOR!

N - Type Semiconductor

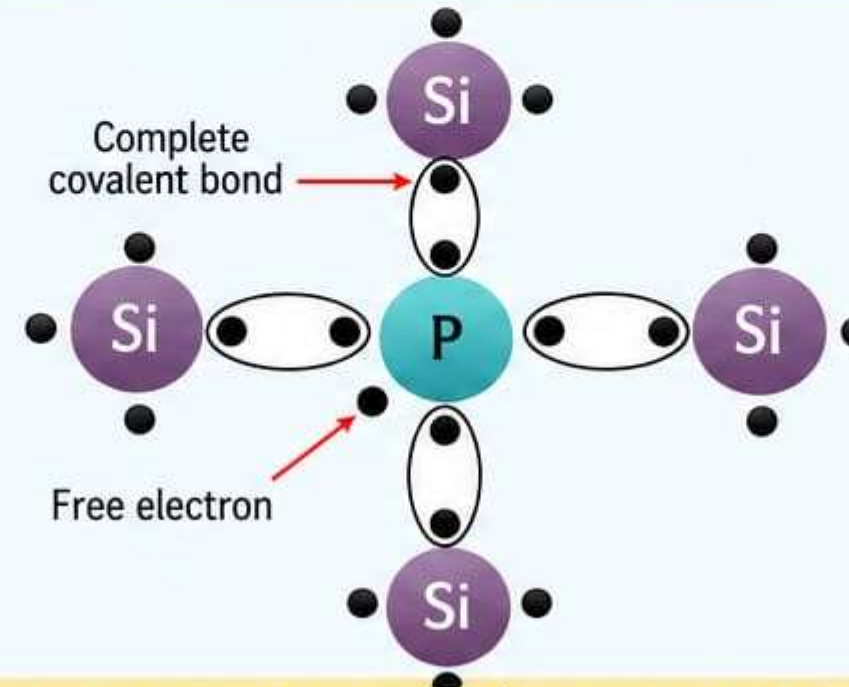
Formed by **donor doping** – Electrons are the majority charge carriers

“N” stands for **Negative** because electrons are the majority carriers.

1 What is an N - type semiconductor?

- An N-type semiconductor is obtained by doping an intrinsic semiconductor (like silicon) with a **pentavalent impurity (donor)** such as **Phosphorus (P)**, **Arsenic (As)** or **Antimony (Sb)**.
- The impurity atom has 5 valence electrons, so after forming four covalent bonds with neighbouring silicon atoms, **one electron remains free**.
- This free electron is loosely bound and can easily move in the crystal.
- Thus, electrons become the majority charge carriers and holes are the minority charge carriers.

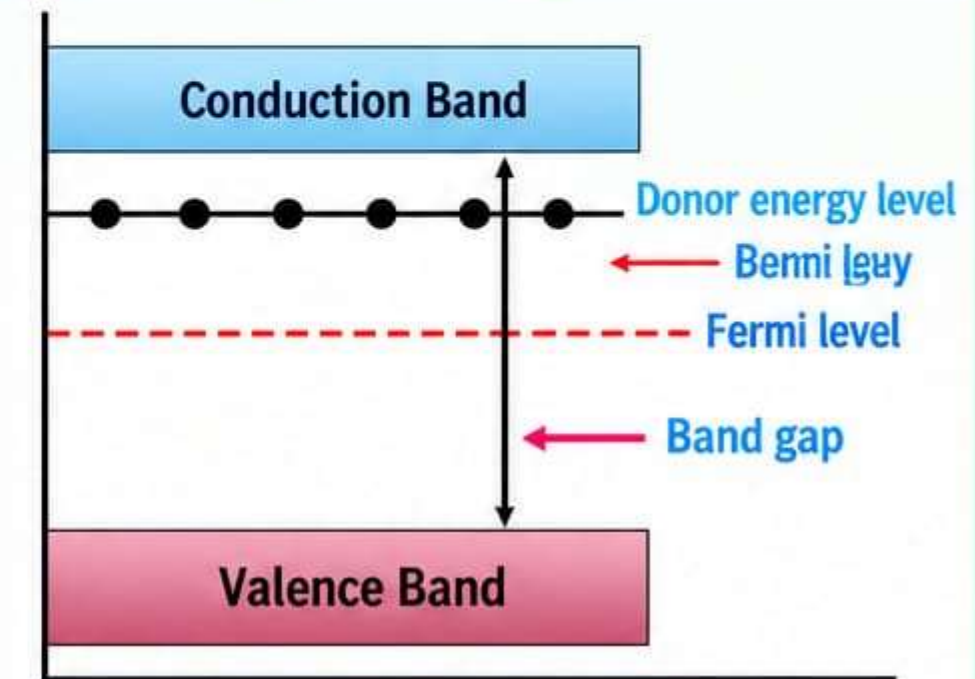
2 Formation of N - type semiconductor



N type semiconductor (Si doped with P)

Si = Intrinsic semiconductor atom
P = Pentavalent impurity atom (Donor)

3 Energy level diagram



Energy level diagram of N type semiconductor

4 Why free electron is formed?

- Each Si atom has 4 valence electrons and forms 4 covalent bonds.
- Phosphorus (P) has 5 valence electrons.
- When P replaces a Si atom, it forms 4 covalent bonds with 4 neighbouring Si atoms.
- The fifth electron is not required for bonding and remains as a free electron (loosely bound).
- This free electron can easily move through the crystal and contributes to conduction.

5 Majority and minority carriers

- Majority carriers :** **Electrons**
- Minority carriers :** **Holes**
- Conduction in n-type semiconductor is mainly due to the movement of electrons.
- Electrons are treated as negative charge carriers.
- At room temperature, the number of electrons is much larger than the number of holes.

6 Examples of donor impurities

Impurity	Symbol	Valence electrons
Phosphorus	P	5
Arsenic	As	5
Antimony	Sb	5

These are pentavalent elements from Group V of the periodic table. So, they are called **donor impurities** because they donate an extra electron.

7 Important points

- Formed by doping intrinsic semiconductor with pentavalent impurity.
- Four covalent bonds are complete and one extra electron is free.
- Electrons are the majority carriers.
- Holes are the minority carriers.
- Donor energy level is very close to the conduction band.
- Fermi level is near the conduction band.
- Examples: Si doped with P, As, Sb.

N - type semiconductor → Formed by donor doping → Electrons are the majority charge carriers → Fermi level near conduction band

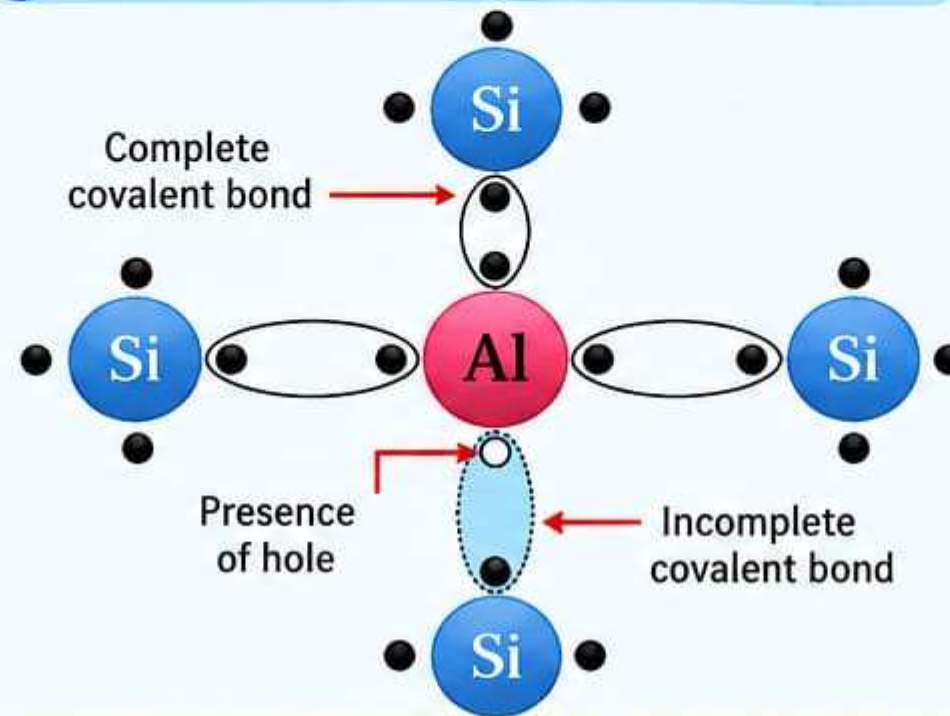
P - Type Semiconductor

Formed by acceptor doping – Holes are the majority charge carriers

1 What is a P - type semiconductor?

- A p-type semiconductor is obtained by doping an intrinsic semiconductor (like silicon) with a **trivalent impurity (acceptor)** such as **Aluminium (Al)**, **Boron (B)**, **Gallium (Ga)** or **Indium (In)**.
- The impurity has only 3 valence electrons, so one covalent bond remains incomplete.
- This creates a vacancy called a **hole**.
- Thus, holes become the majority charge carriers and electrons are the minority charge carriers.

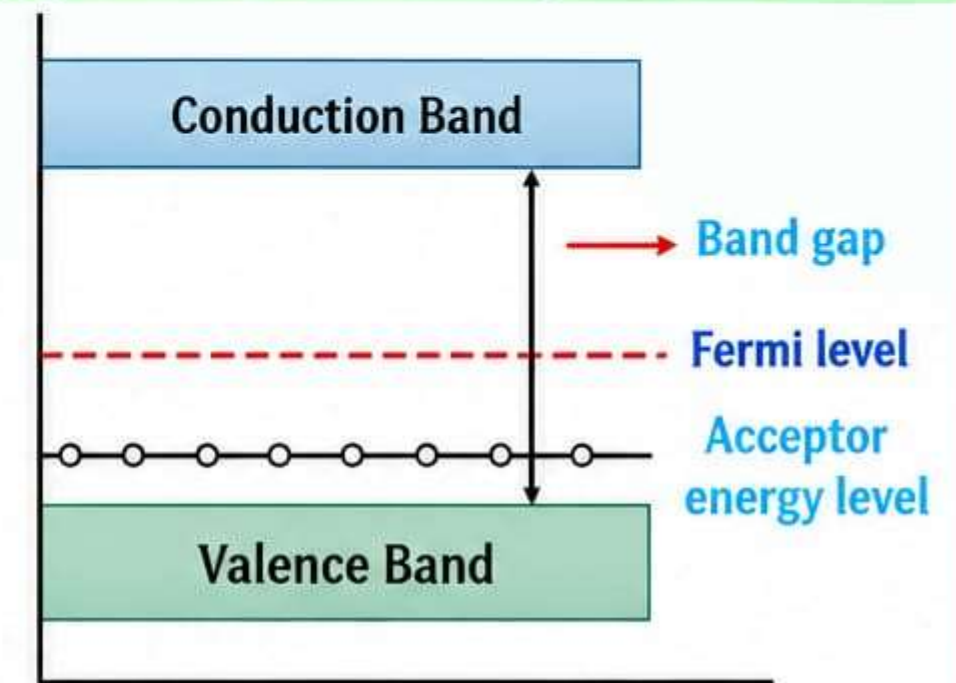
2 Formation of P - type semiconductor



P type semiconductor (Si doped with Al)

Si = Intrinsic semiconductor atom
Al = Trivalent impurity atom (Acceptor)

3 Energy level diagram



Energy level diagram of P type semiconductor

4 Why hole is formed?

- Each Si atom has 4 valence electrons and forms 4 covalent bonds.
- Aluminium (Al) has only 3 valence electrons.
- When Al replaces a Si atom, it can form only 3 covalent bonds.
- The fourth bond is incomplete and a vacancy (hole) is created.
- This hole can accept an electron from a neighbouring atom, making the hole move through the crystal.

5 Majority and minority carriers

- Majority carriers** : **Holes**
- Minority carriers** : **Electrons**
- Conduction in p-type semiconductor is mainly due to the movement of holes.
- Holes are treated as positive charge carriers.
- At room temperature, the number of holes is much larger than the number of electrons.

6 Examples of acceptor impurities

Impurity	Symbol	Valence electrons
Boron	B	3
Aluminium	Al	3
Gallium	Ga	3
Indium	In	3

These are trivalent elements from Group III of the periodic table. So, they are called **acceptor impurities** because they accept an electron.

7 Important points

- Formed by doping intrinsic semiconductor with trivalent impurity.
- One covalent bond remains incomplete.
- Creates a hole in the crystal.
- Holes are majority carriers.
- Electrons are minority carriers.
- Fermi level is closer to the valence band.
- Conduction takes place mainly due to holes.
- Examples: Si doped with B, Al, Ga, In.

P - type semiconductor → Formed by acceptor doping → Holes are the majority charge carriers → Fermi level near valence band

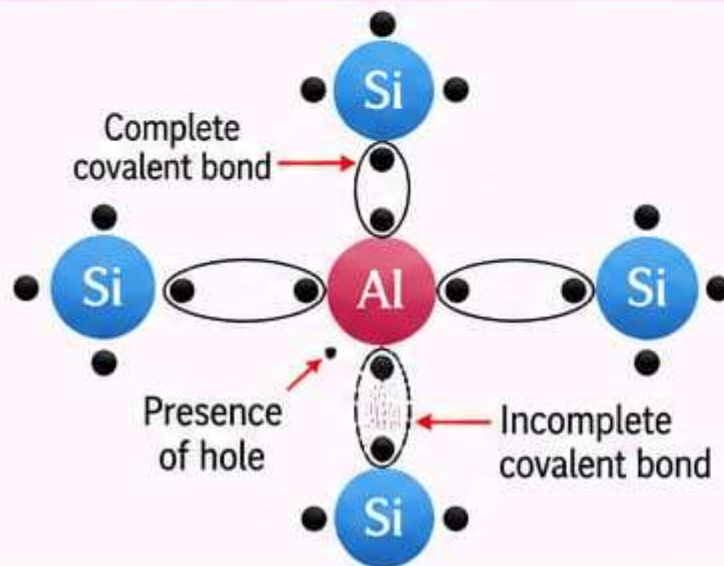
Comparison of P Type and N Type Semiconductors

Both are extrinsic semiconductors formed by doping an intrinsic semiconductor.

P - Type Semiconductor

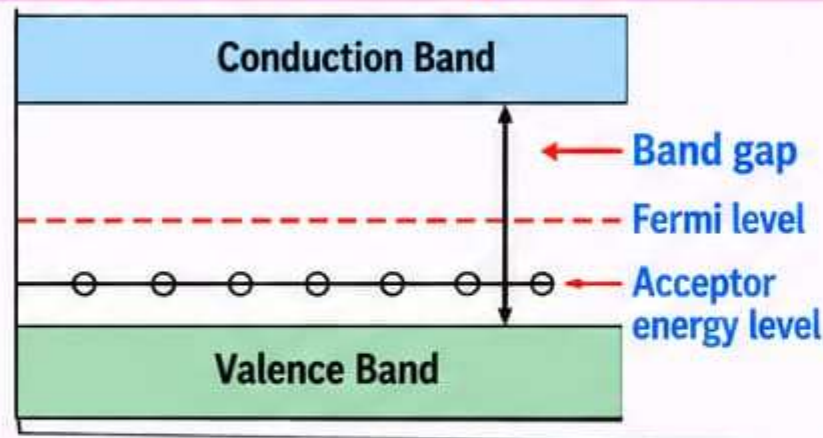
Formed by acceptor doping – Holes are the majority carriers

Formation of P type semiconductor



Si = Intrinsic semiconductor atom
Al = Trivalent impurity atom (Acceptor)

Energy level diagram of P type semiconductor

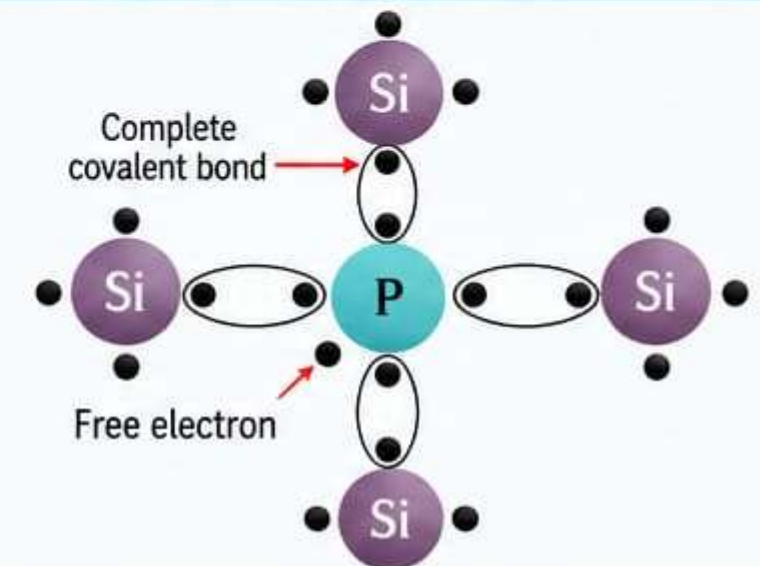


Feature

N - Type Semiconductor

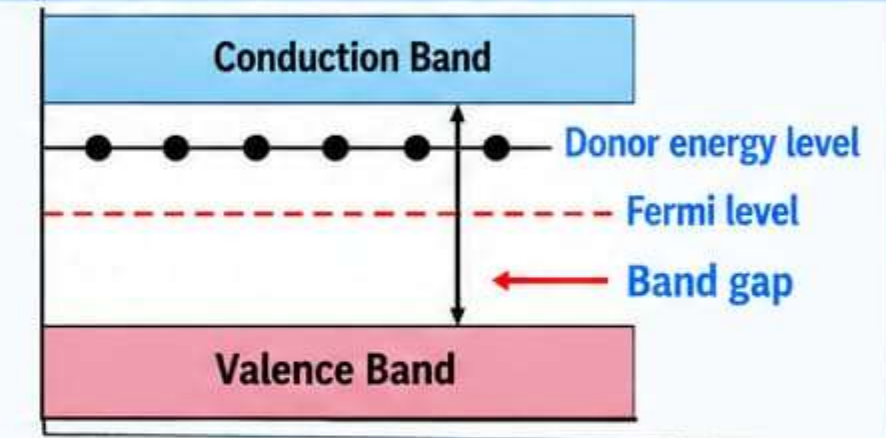
Formed by donor doping – Electrons are the majority carriers

Formation of P type semiconductor



Si = Intrinsic semiconductor atom
P = Pentavalent impurity atom (Donor)

Energy level diagram of N type semiconductor



Trivalent (Acceptor)	Type of impurity	Pentavalent (Donor)
Aluminium (Al), Boron (B), Gallium (Ga), Indium (In)	Examples	Phosphorus (P), Arsenic (As), Antimony (Sb)
3	Valence electrons of impurity atom	5
Creates a hole (vacancy of electron)	Effect on crystal	Provides an extra electron
Holes	Majority charge carriers	Electrons
Electrons	Minority charge carriers	Holes
Near valence band	Position of Fermi level	Near conduction band
Acceptor level (slightly above valence band)	Impurity energy level	Donor level (slightly below conduction band)
Due to movement of holes	Conductivity	Due to movement of electrons



P type and N type semiconductors are opposite in nature – one has holes as majority carriers, the other has electrons.
Both are widely used to form PN junction diodes, transistors and other semiconductor devices.

Doping converts an intrinsic semiconductor into a useful device material.

Charge Carriers in Semiconductors

In semiconductors, current is carried by two types of charge carriers:

Electrons and **Holes**

1. What are Charge Carriers?

- In a semiconductor, current flows due to movement of charge carriers.
- There are two charge carriers:
 - Electrons** – negatively charged particles
 - Holes** – positively charged vacancies
- Both electrons and holes are created in a pure (intrinsic) semiconductor in equal numbers at room temperature.

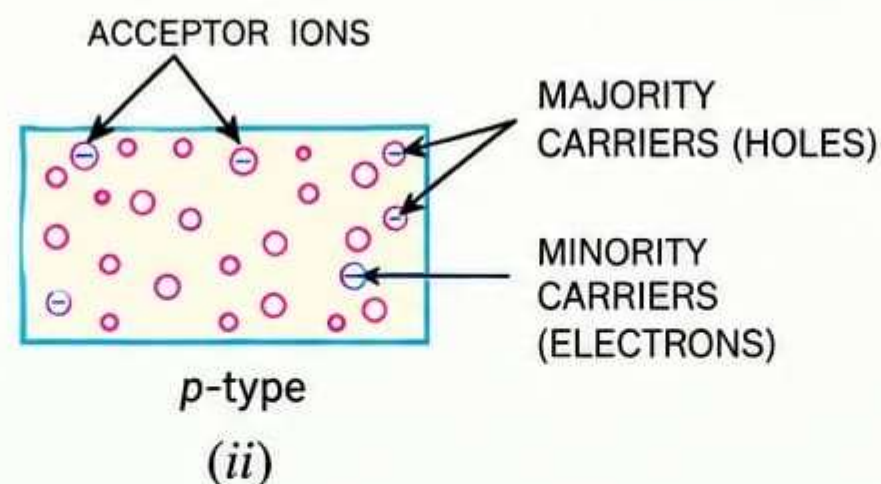
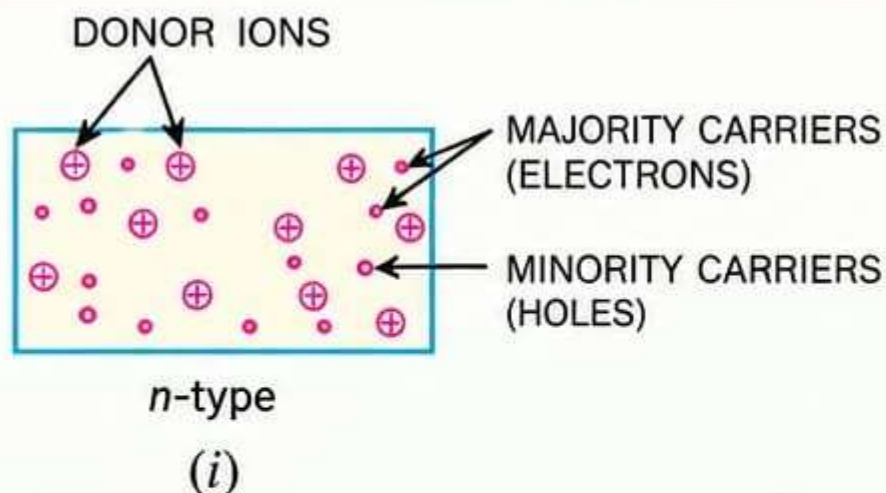
2. n-type Semiconductor

- Formed by adding **donor** (pentavalent) impurities such as P, As or Sb.
- Each donor atom contributes one extra electron.
- These extra electrons are free electrons and increase the conductivity.
- Electrons are the **majority carriers** and holes are the **minority carriers**.
- The semiconductor as a whole remains electrically neutral.

3. p-type Semiconductor

- Formed by adding **acceptor** (trivalent) impurities such as B, Al, Ga or In.
- Each acceptor atom creates a hole by accepting an electron from a covalent bond.
- Holes are the **majority carriers** and electrons are the **minority carriers**.
- Holes behave as positively charged carriers.
- The semiconductor as a whole remains electrically neutral.

4. Diagrams of Charge Carriers



5. Key Points to Remember

- ✓ **n-type** semiconductor has a large number of free electrons (**majority carriers**).
- ✓ **p-type** semiconductor has a large number of holes (**majority carriers**).
- ✓ Minority carriers are due to thermal generation of electron-hole pairs.
- ✓ Donor impurities give extra electrons.
- ✓ Acceptor impurities create holes.
- ✓ Both *n*-type and *p*-type semiconductors are electrically neutral overall.

Conclusion:

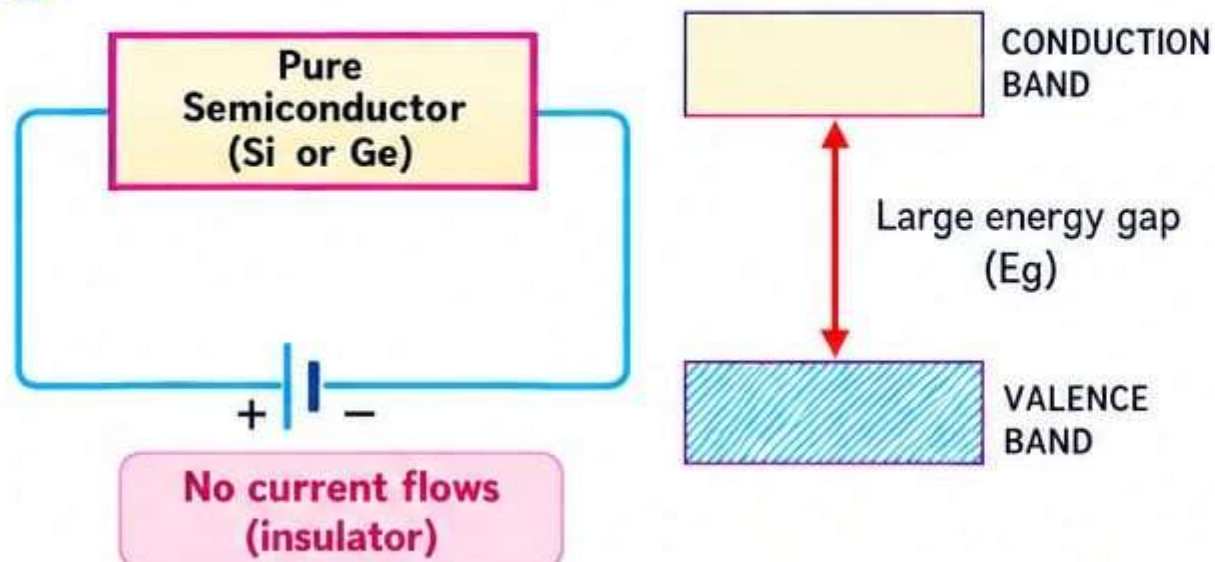
In semiconductors, current is carried by electrons and holes. *n*-type has **electrons as majority carriers**, whereas *p*-type has **holes as majority carriers**. Both are electrically neutral.

Electrons and holes together make semiconductors useful!

Effect of Temperature on Semiconductors

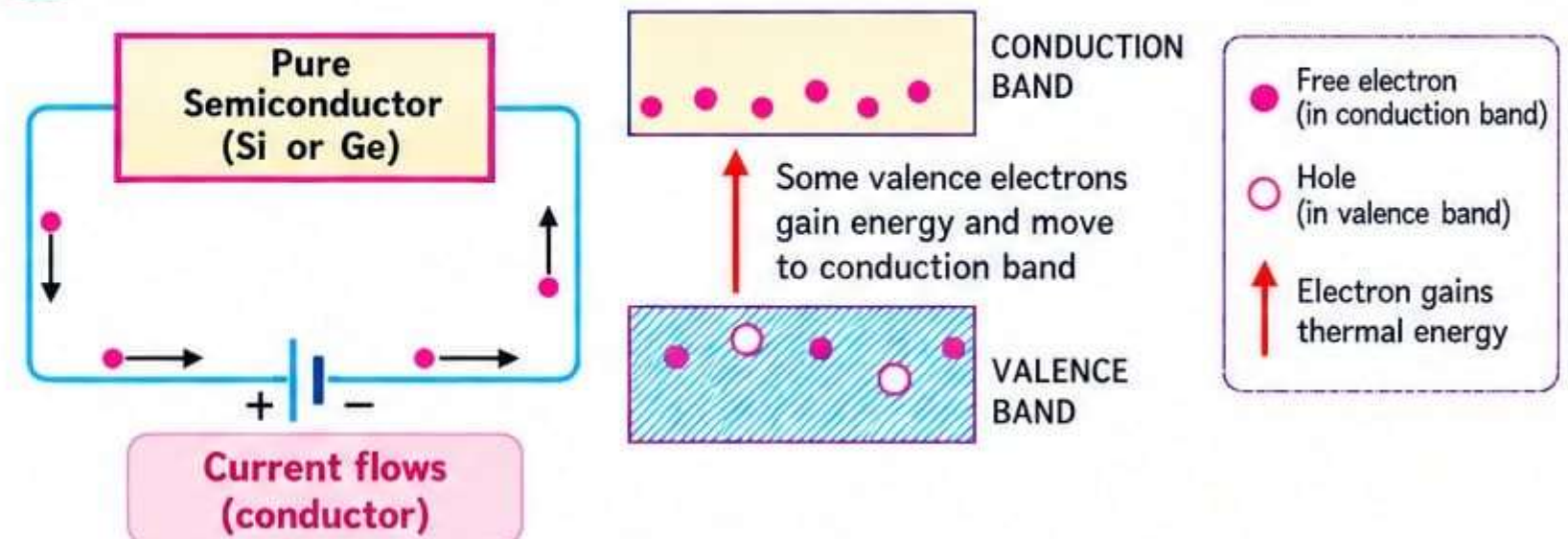
As temperature increases, a semiconductor conducts more current.

1 At Absolute Zero Temperature (0 K)



- At 0 K, all electrons are tightly held in covalent bonds.
- Valence band is completely filled and conduction band is empty.
- Hence, no free electrons are available and the semiconductor behaves as an **insulator**.

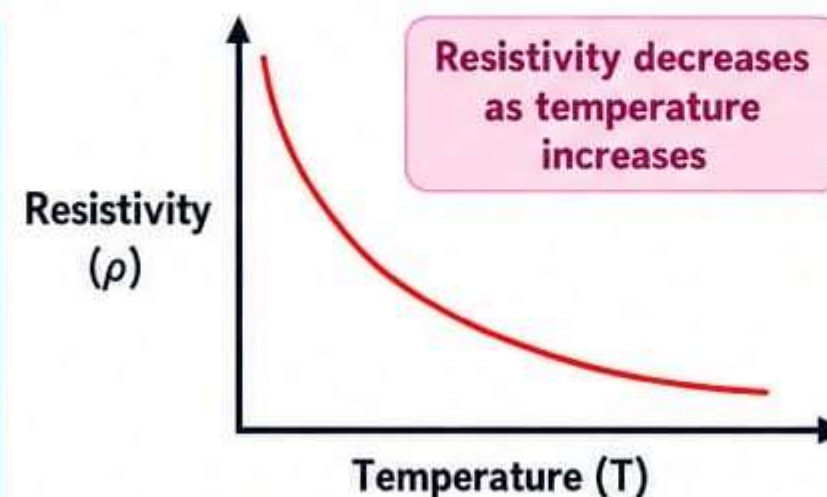
2 At Higher Temperature (Room Temperature and above)



- When temperature is raised, some valence electrons gain thermal energy and break free from covalent bonds.
- These electrons move to the conduction band and become free electrons.
- Each time an electron leaves a covalent bond, a **hole** is created in the valence band.
- Both **free electrons and holes contribute to current** in a semiconductor.

3 Effect on Electrical Conductivity

- As temperature increases, number of free electrons and holes increases.
- Hence electrical conductivity increases and resistivity decreases.
- The semiconductor has a **negative temperature coefficient of resistance (NTC)**.



Key Takeaways

- At 0 K, semiconductor behaves as an insulator.
- Increase in temperature breaks some covalent bonds.
- More free electrons and holes are generated.
- Electrical conductivity increases and resistivity decreases.
- Semiconductors have a **negative temperature coefficient of resistance (NTC)**.

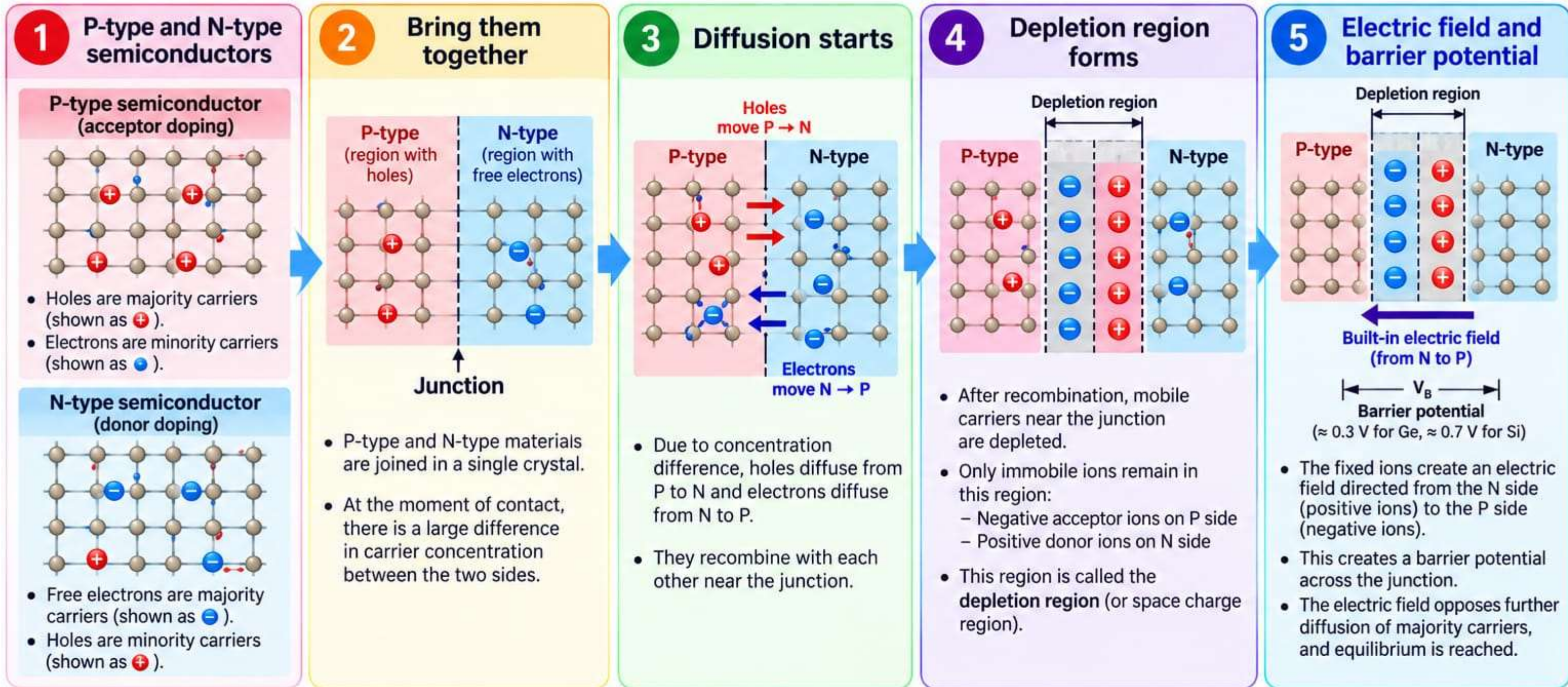


Real Life Example

Devices like thermistors use the temperature dependence of semiconductor resistance for temperature sensing.

FORMATION OF PN JUNCTION

A p-n junction is formed by joining p-type and n-type semiconductors in a single crystal.

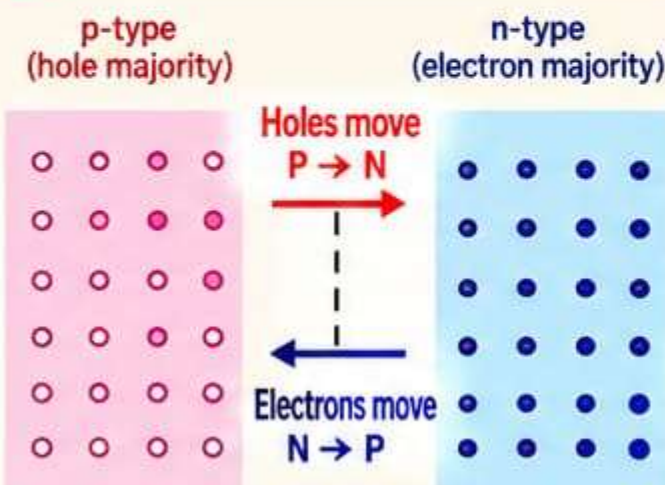


Thus, when p-type and n-type semiconductors are joined, diffusion and recombination of carriers create a depletion region, an internal electric field and a barrier potential at the junction.

DEPLETION REGION AND BARRIER POTENTIAL in a $p-n$ Junction

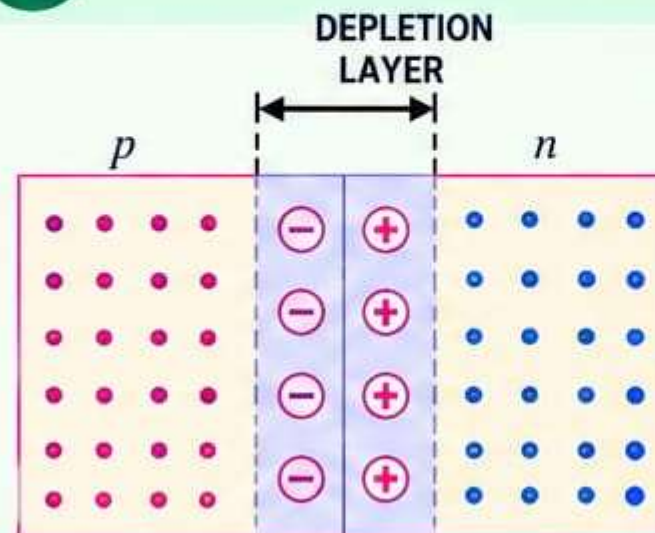
When a p -type and n -type semiconductor are joined, carriers diffuse across the junction and create a depletion region and a potential barrier.

1 Diffusion of carriers



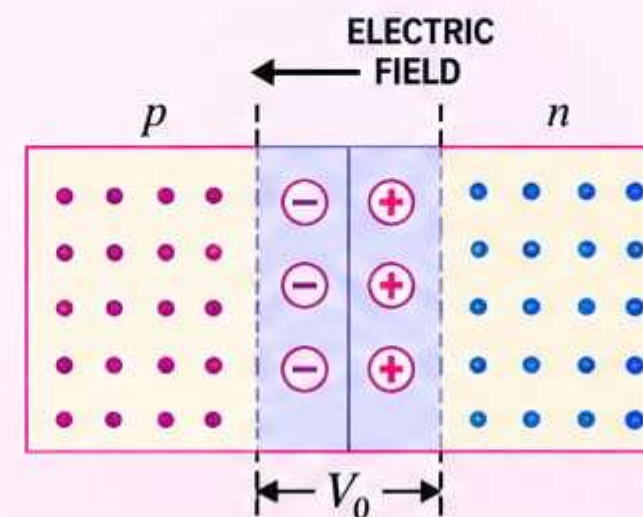
- Due to concentration difference, holes diffuse from p to n and electrons diffuse from n to p .
- They recombine with each other near the junction.

2 Formation of depletion region



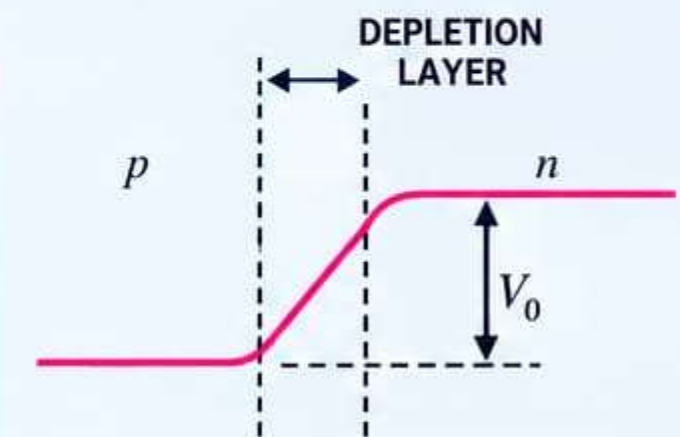
- After recombination, mobile carriers disappear near the junction.
- Only immobile ions remain:
 - Negative acceptor ions on the p side
 - Positive donor ions on the n side
- This region with no free charge carriers is called the **depletion region**.

3 Electric field across the junction



- The fixed ions create an electric field directed from the n side (positive ions) to the p side (negative ions).
- This electric field opposes further diffusion of majority carriers.
- An equilibrium is reached when the drift due to this field balances the diffusion.

4 Potential (Voltage) across the junction

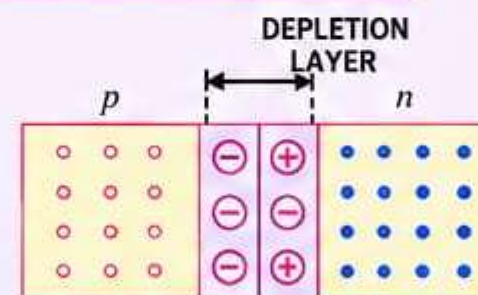


- The potential difference across the depletion region is called the **barrier potential** (V_0).
- It is the minimum voltage required to overcome the potential barrier and allow large current flow.
- Typical values (at room temperature):
 - Silicon (Si): $V_0 \approx 0.7$ V
 - Germanium (Ge): $V_0 \approx 0.3$ V

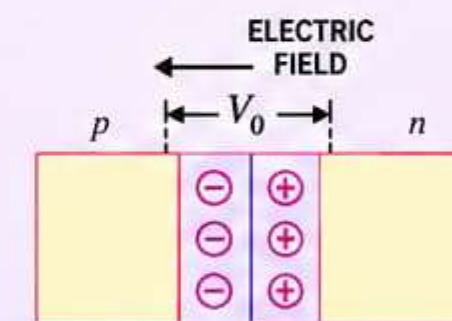
Key Points

- ✓ Depletion region is free from mobile charge carriers.
- ✓ It contains immobile ions (negative on p side, positive on n side).
- ✓ An electric field is set up from n to p .
- ✓ The potential difference across this region is the **barrier potential**.
- ✓ Barrier potential depends on the material and temperature.

Typical Diagrams



Charge distribution across a $p-n$ junction



Electric field and barrier potential

The depletion region is very thin in practice (only a few micrometres). For clarity, the width is shown exaggerated in the diagrams.

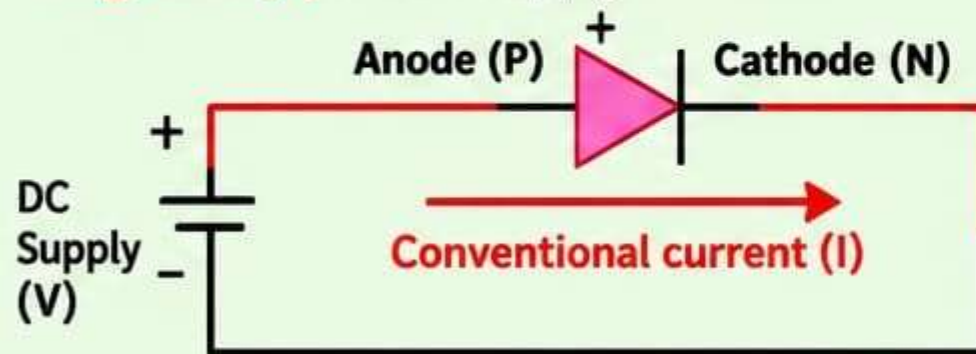
Thus, the depletion region and barrier potential prevent further diffusion of carriers and keep the $p-n$ junction in equilibrium.

Forward Biasing and Reverse Biasing of a PN Junction Diode

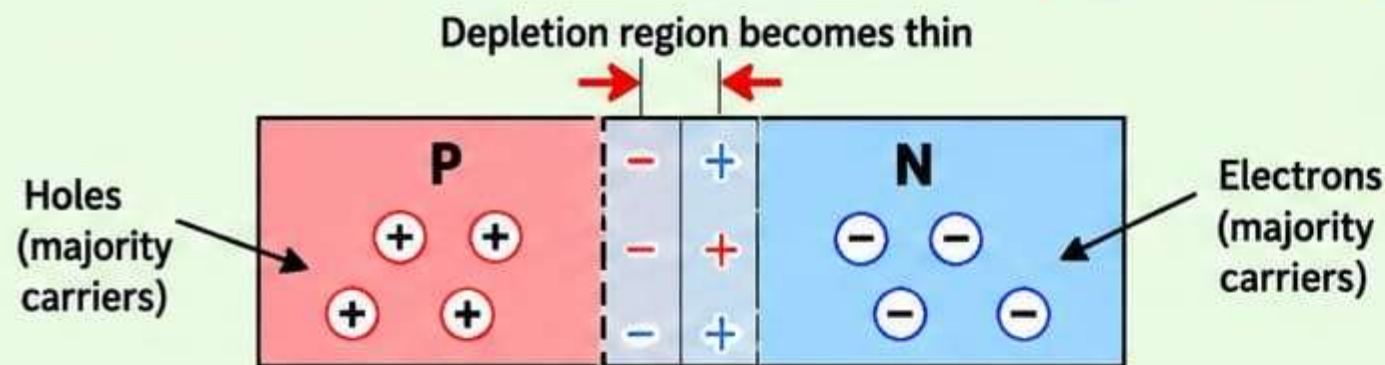
A diode allows current in one direction only!

Forward Biasing (Forward Bias)

P-side connected to **positive (+)** and N-side connected to **negative (-)** of the supply.



Diode is **FORWARD BIASED** and **conducts current**.

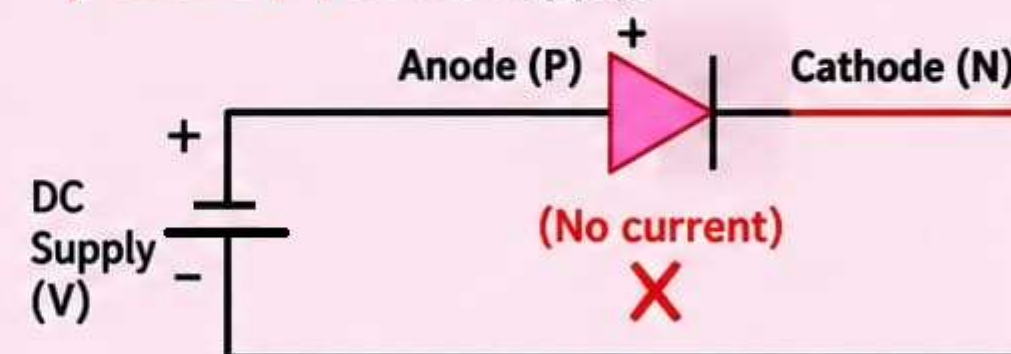


Key Points (Forward Bias)

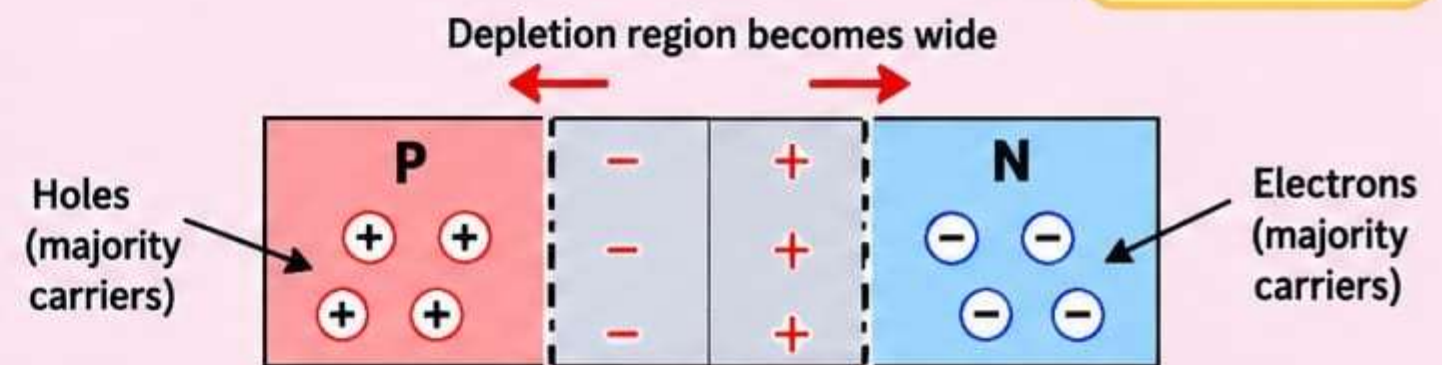
- P-side to positive, N-side to negative.
- Depletion region width decreases (becomes thin).
- Barrier potential is reduced.
- Diode offers low resistance and allows current to flow.
- Conventional current flows from P to N.

Reverse Biasing (Reverse Bias)

P-side connected to **negative (-)** and N-side connected to **positive (+)** of the supply.



Diode is **REVERSE BIASED** and **blocks current (ideally)**.



Key Points (Reverse Bias)

- P-side to negative, N-side to positive.
- Depletion region width increases (becomes wide).
- Barrier potential is increased.
- Diode offers very high resistance and blocks current (only a very small leakage current flows).
- Ideally no current flows.

Conclusion

- ✓ **Forward bias** → Diode conducts (low resistance).
- ✓ **Reverse bias** → Diode blocks (high resistance).

A PN junction diode acts like a **one-way valve for current**!

V – I CHARACTERISTICS OF A PN JUNCTION DIODE

The V–I characteristic of a *pn* junction diode is the curve between the voltage across the junction (V) and the current through the diode (I).
Voltage is taken along the X-axis and current along the Y-axis.

Circuit arrangement

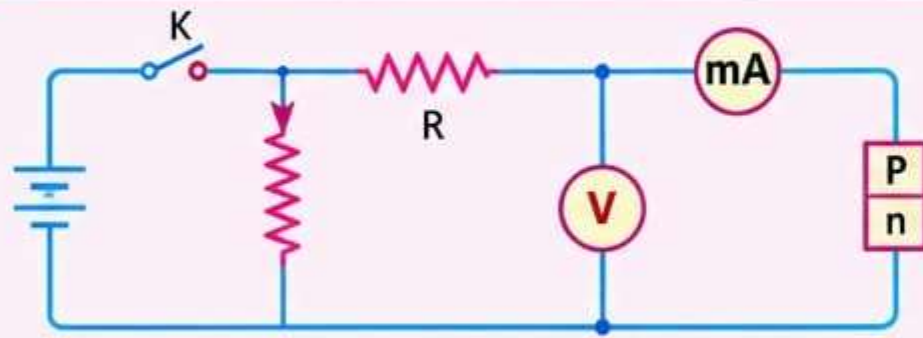


Fig.

R is the current limiting resistance. It prevents the forward current from exceeding the permitted value.

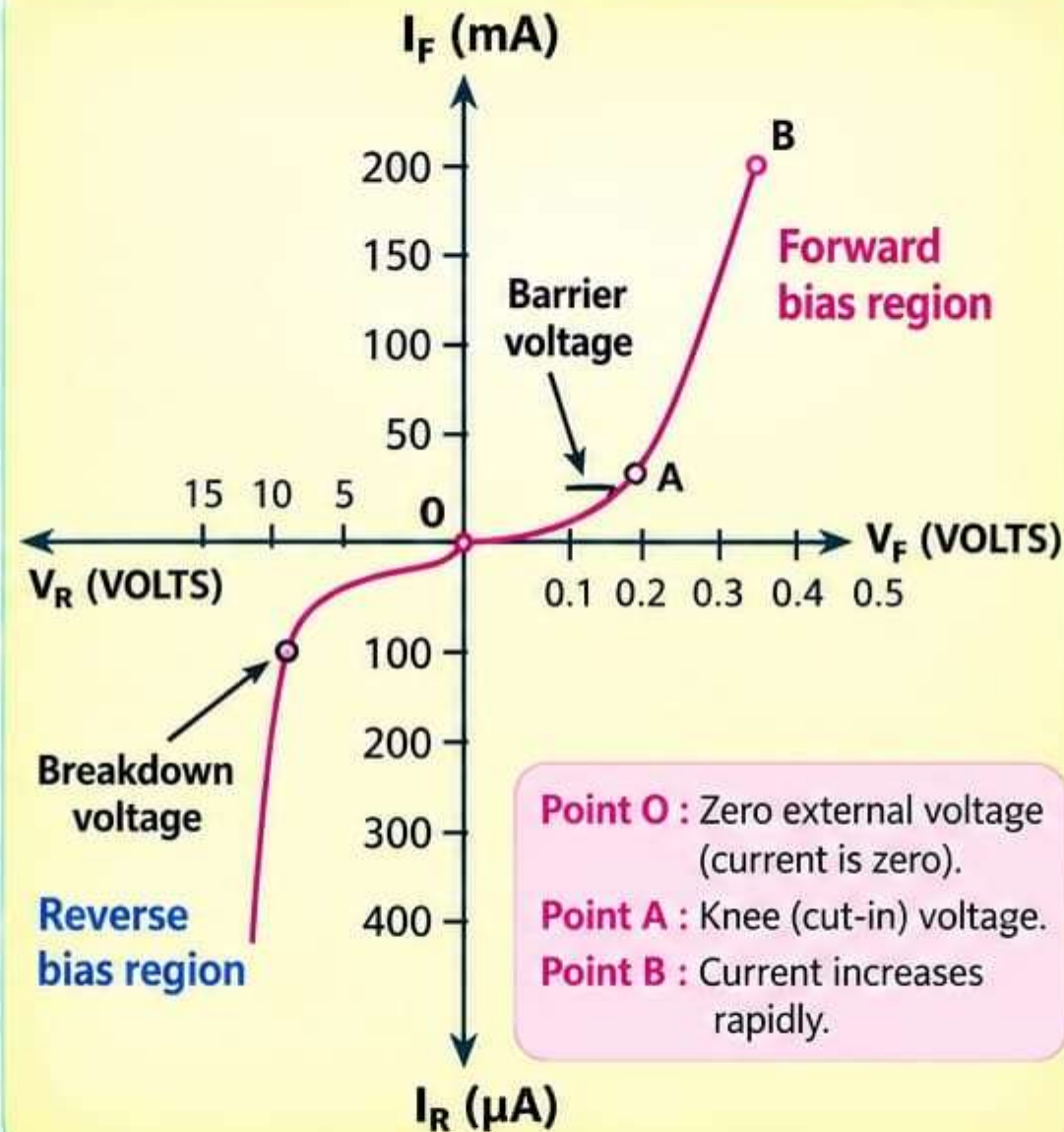
How to obtain the characteristics

- 1 Connect the circuit as shown in Fig.
- 2 For forward characteristic, connect *p*-side to positive and *n*-side to negative. Vary the supply voltage and note the ammeter and voltmeter readings.
- 3 For reverse characteristic, reverse the supply connections (*p*-side to negative and *n*-side to positive) and note the readings.
- 4 Plot the graph between diode voltage (X-axis) and current (Y-axis).

Important Points

- ✓ At zero external voltage, current is zero (point O).
- ✓ Forward current is in mA range, reverse current is in μA range.
- ✓ A current limiting resistor (R) is used to prevent excessive forward current.
- ✓ Reverse current is due to minority carriers.
- ✓ Reverse voltage at which the current suddenly increases is called **breakdown voltage**.

V – I Characteristic Curve



Forward Bias (First quadrant: OA and AB)

- *p*-side is connected to positive terminal and *n*-side to negative terminal.
- The potential barrier is reduced. At a certain voltage, called **knee (cut-in) voltage**, current starts to flow.
- For silicon diode, knee voltage $\approx 0.7 \text{ V}$. For germanium diode, knee voltage $\approx 0.3 \text{ V}$.
- In region **OA**, current is very small and the curve is non-linear.
- After the knee voltage (region **AB**), current increases rapidly with a small increase in voltage and the curve becomes almost linear.

Typical knee voltage:

Silicon (Si) : 0.7 V Germanium (Ge) : 0.3 V

Reverse Bias (Third quadrant)

- *p*-side is connected to negative terminal and *n*-side to positive terminal.
- The potential barrier is increased.
- Only a very small current, called reverse saturation current (I_R), flows due to minority carriers (in the order of a few μA).
- At a high reverse voltage, the diode breaks down at the breakdown voltage, and the current increases sharply.
- This high current may damage the diode.

Key Terms

- ✓ **Knee (cut-in) voltage** : Forward voltage at which current starts increasing rapidly (Si – 0.7 V, Ge – 0.3 V).
- ✓ **Reverse saturation current** : Small current in reverse bias due to minority carriers (μA).
- ✓ **Breakdown voltage** : Reverse voltage at which the diode current increases sharply.
- ✓ **Barrier voltage** : Internal potential barrier at the junction ($\approx 0.7 \text{ V}$ for Si, 0.3 V for Ge).

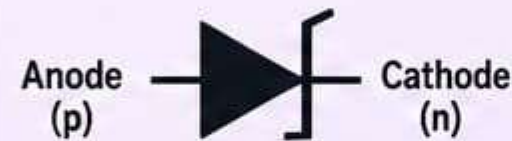
What is a Zener Diode?

- A Zener diode is a heavily doped p-n junction diode.
- It is designed to operate in the reverse breakdown region.
- It maintains an almost constant voltage (called Zener voltage, V_Z) across it when operated in reverse bias.
- It is mainly used for voltage regulation.

Zener Diode

Designed to work in reverse breakdown region

Symbol



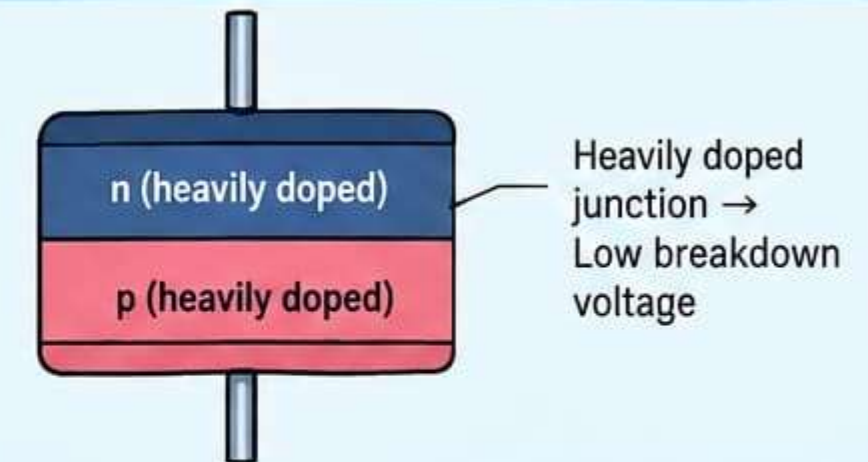
Zener Diode Symbol

Actual Appearance

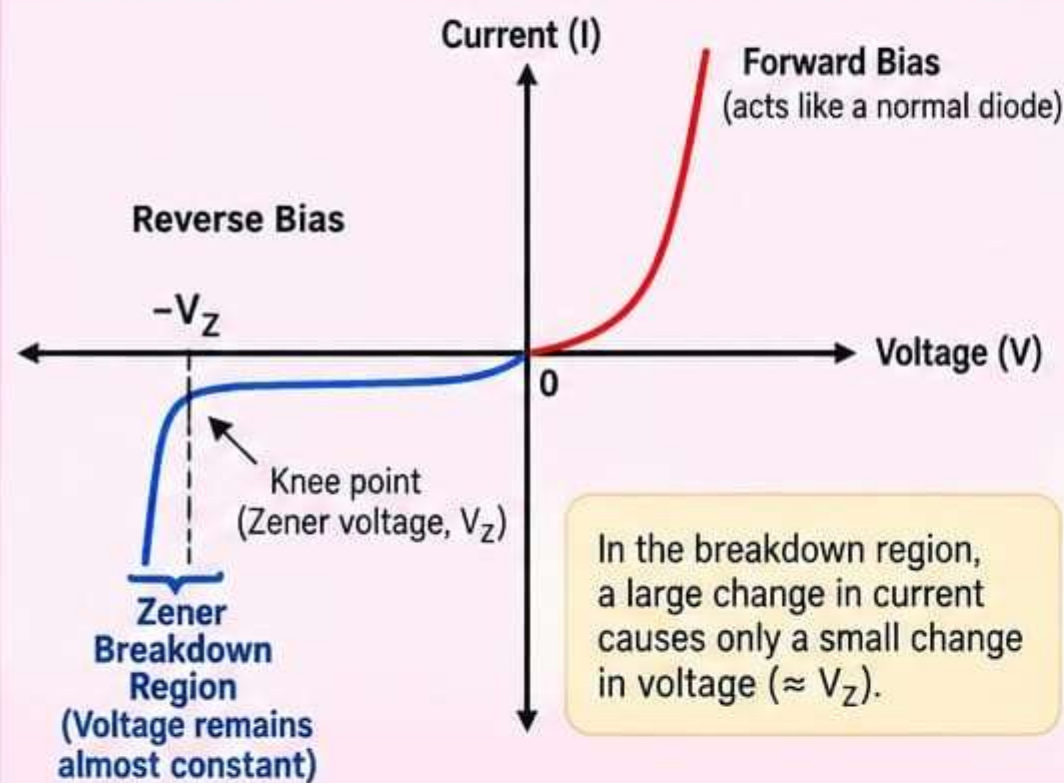


Typical Zener Diode

Construction



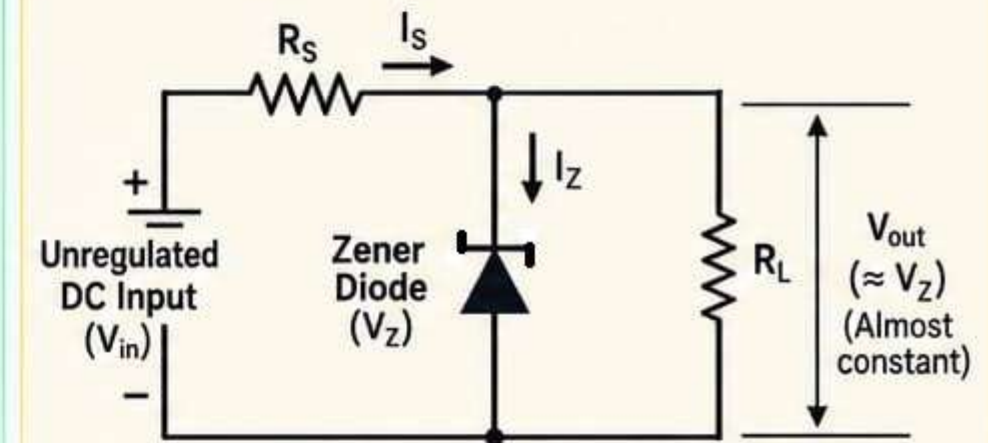
V-I Characteristics of Zener Diode



Working of Zener Diode (Reverse Bias)

- 1 Reverse Bias Applied**
The p-side is connected to negative and n-side to positive supply.
- 2 Small Reverse Current**
Initially, only a very small reverse current flows (leakage current).
- 3 At Breakdown Voltage (V_Z)**
When the reverse voltage reaches V_Z , the diode enters breakdown region (Zener breakdown).
- 4 Voltage Remains Constant**
In this region, even if the current changes largely, the voltage across the diode remains almost constant at V_Z .
- 5 Safe Operation**
A series resistor is always used to limit the current to a safe value.

Zener Diode as a Voltage Regulator



The Zener diode maintains a constant output voltage (V_Z) despite changes in input voltage or load current.

Key Points to Remember

- Operated in reverse bias.
- Heavily doped p-n junction.
- Works in breakdown region.
- Maintains nearly constant voltage (V_Z) across it.
- Series resistor is essential to limit current.
- Used for voltage regulation and reference voltage.

Applications of Zener Diode



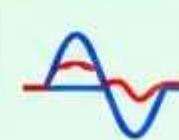
Voltage Regulation



Reference Voltage Source



Waveform Clipping



Waveform Clamping



Overvoltage Protection

Real-Life Example

Used in power supplies to provide a stable output voltage for electronic circuits, even if the input voltage fluctuates.

*Small Device...
Big Stability!*

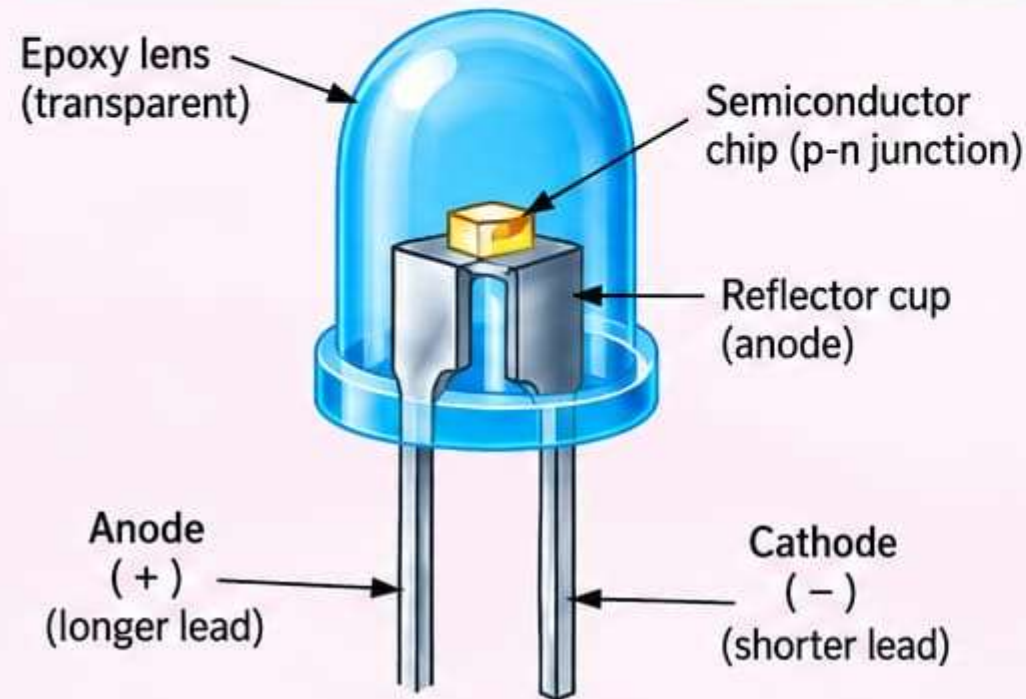


Light-Emitting Diode (LED)

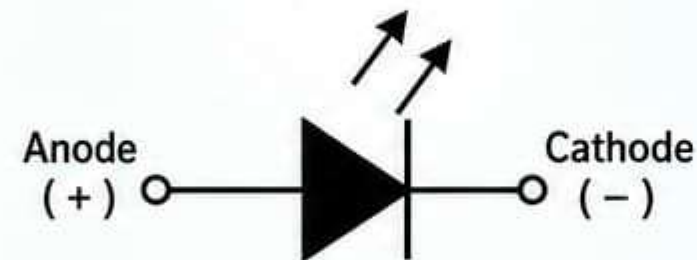
A special diode that gives off visible light when forward biased

 Converts Electrical Energy to Light Energy

Construction



Symbol



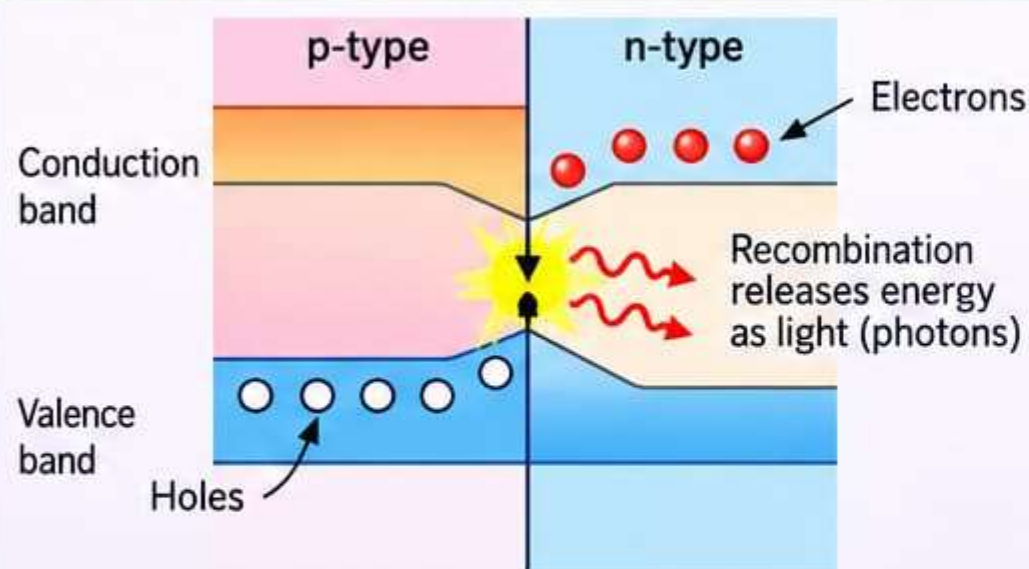
LED Symbol

Arrows pointing **away** from the diode indicate emission of light.

Working

- 1 When the LED is forward biased, electrons from the n-type region cross the p-n junction and recombine with holes in the p-type region.
- 2 During recombination, the electrons drop from a higher energy level (conduction band) to a lower energy level (valence band).
- 3 The excess energy is released in the form of photons (light).
- 4 In materials like gallium arsenide (GaAs), gallium phosphide (GaP) etc., the emitted photons produce visible light.
- 5 The intensity of light is directly proportional to the forward current through the LED.

Working Principle (Energy Band Diagram)



When electrons and holes recombine at the p-n junction, energy is released in the form of visible light.

LED Colours and Materials

Material	Emitted Colour	Example
Gallium Arsenide (GaAs)	Infrared	IR LED
Gallium Phosphide (GaP)	Red / Green	Red, Green LED
Gallium Arsenide Phosphide (GaAsP)	Red / Yellow Orange	Red, Yellow, Orange LED
Gallium Nitride (GaN)	Blue / White	Blue LED
InGaN	Green / White	Green, White LED
AlGaInP	Red / Orange	High brightness LEDs

By changing the semiconductor material, different wavelengths (colours) of light can be produced.

Applications

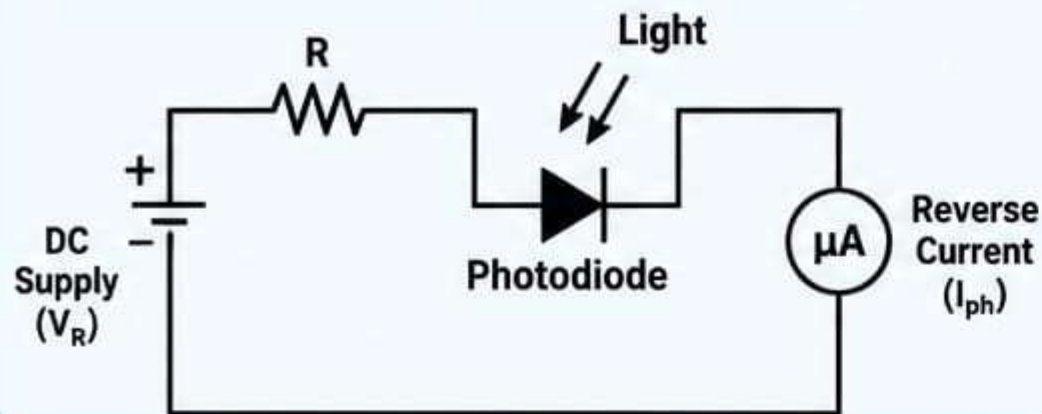
-  Indicator lights in electronic equipment
-  Seven-segment displays
-  Traffic signals
-  General lighting (LED bulbs, tube lights)
-  Mobile phones, TV and computer displays
-  Automotive lighting (brake lights, headlamps)
-  Low power and energy-efficient lighting

Brighter • Energy Efficient • Long Life

What is a Photodiode?

- A photodiode is a light sensitive semiconductor device.
- It converts incident light into an electrical current.
- It is usually a p-n junction operated in reverse bias.
- The current produced is called photocurrent and it is proportional to the intensity of light.

Circuit Diagram (Reverse Biased)

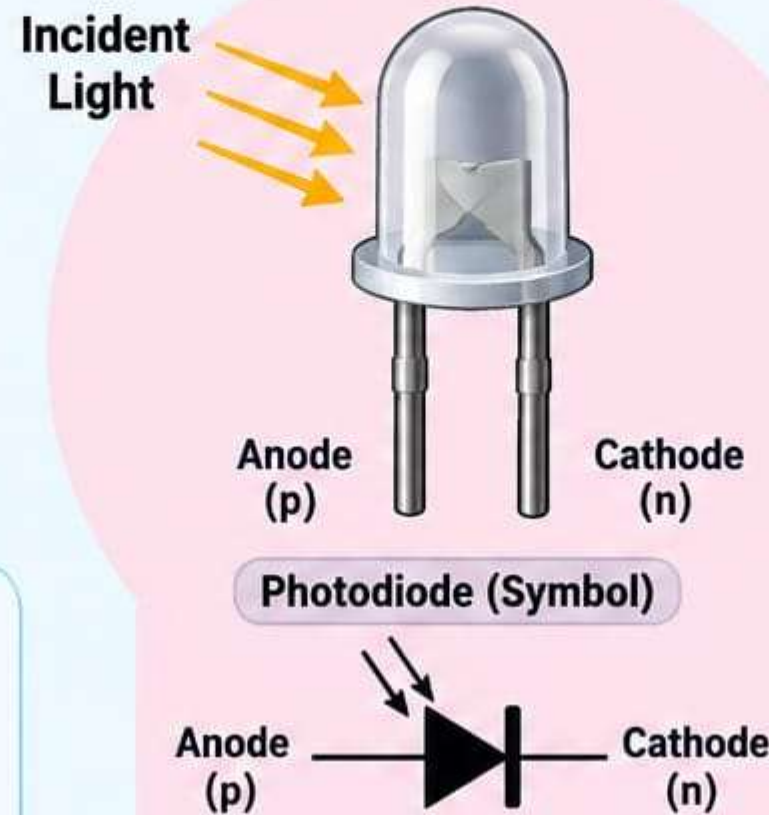


Key Points to Remember

- Operated in reverse bias.
- Produces photocurrent when light falls on it.
- Photocurrent increases with increase in light intensity.
- Faster response compared to many other light sensors.
- Used for detection and measurement of light.

Photodiode

Converts Light into Electrical Current



Working of a Photodiode

- 1 Reverse Bias Operation**
The photodiode is normally operated in reverse bias as shown in the circuit.
- 2 Light Absorption**
When light (photons) falls on the p-n junction, it creates electron-hole pairs in the depletion region.
- 3 Generation of Current**
The electric field of the depletion region separates these charge carriers, producing a reverse current called photocurrent.
- 4 Current Proportional to Light**
The magnitude of photocurrent is proportional to the intensity of the incident light.

Applications of Photodiode

Optical Communication



Used in fiber optic receivers to detect light signals.

Light Measurement



Used in light meters and camera exposure control.

Automatic Control Systems



Used in automatic street lights and security systems.

Optical Sensors



Used in object detection, position sensing and counting systems.

Consumer Electronics



Used in TV remote controls and various infrared devices.

Detects Light → Produces Electrical Signal → Used in Many Real-Life Applications

Light Today,
Smarter Tomorrow!



Light Dependent Resistor (LDR)

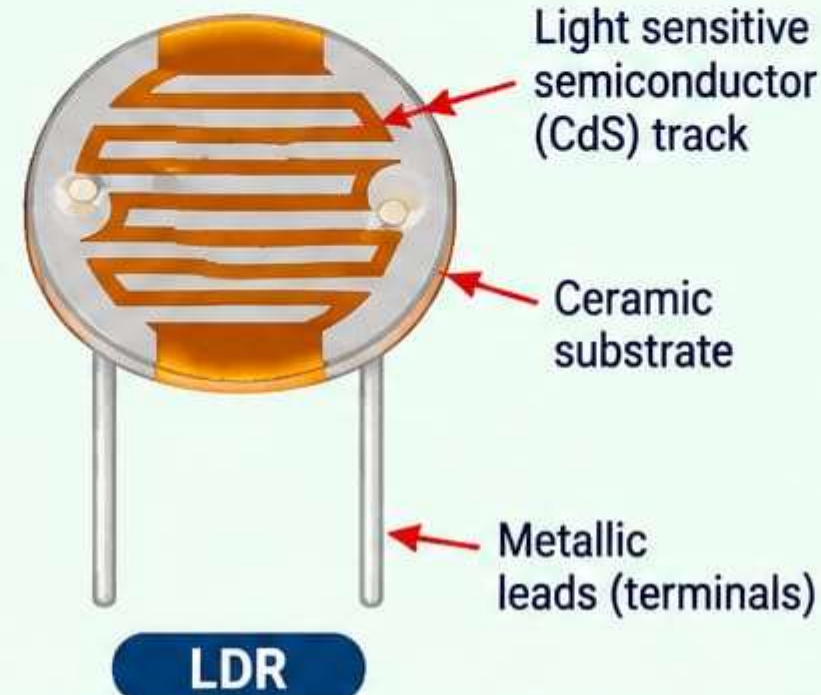
A resistor whose resistance varies with the intensity of light.

Brighter the light
Lower the resistance
Darker the light
Higher the resistance

What is LDR?

- LDR (Light Dependent Resistor) is a light sensitive resistor.
- Its resistance changes according to the amount of light falling on it.
- It is also called a photoresistor or cadmium sulphide (CdS) cell.
- It is a passive, non-polar device with two terminals.

Construction



Working Principle

- LDR is made of a semiconductor material (usually Cadmium Sulphide - CdS).
- When light falls on the surface, photons give energy to electrons, creating more charge carriers.
- As the light intensity increases, the number of charge carriers increases, so the resistance decreases.
- In dark conditions, very few charge carriers are available, so the resistance is high.

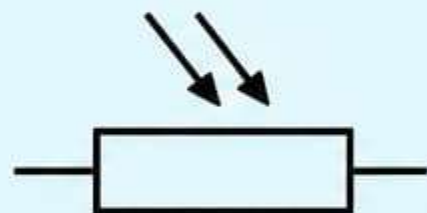


More light
→ Low resistance
(few Ω to few k Ω)



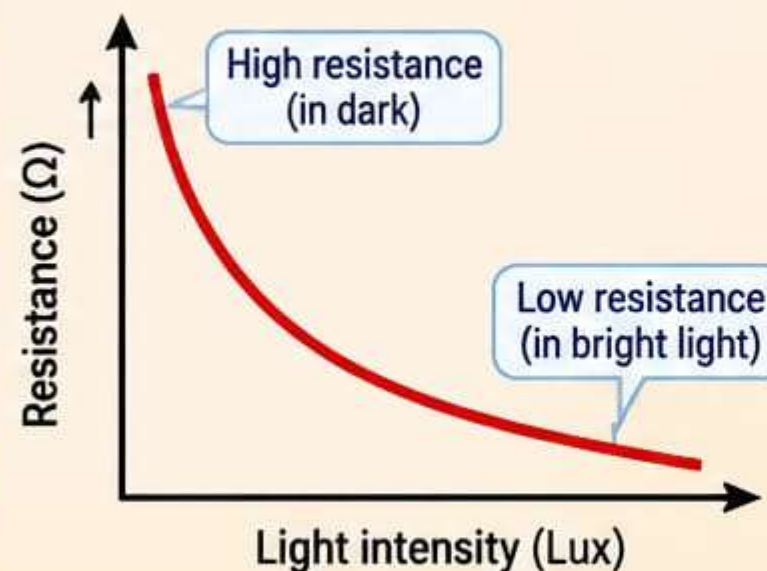
Less light (dark)
→ High resistance
(hundreds of k Ω to M Ω)

Symbol



LDR Symbol

V-I Characteristics



Typical Resistance Values

Condition	Resistance (Approx.)
In dark	0.5 M Ω – 10 M Ω
In normal indoor light	10 k Ω – 100 k Ω
In bright light (sunlight)	500 Ω – 5 k Ω

Applications



Automatic street light control



Day-night switches



Light meters in cameras



Burglar/security alarms



Automatic brightness control (TV, mobile, displays)



Used in various light sensing and counting systems

⇒ LDR converts light energy into an electrical signal by changing its resistance. ⇐