

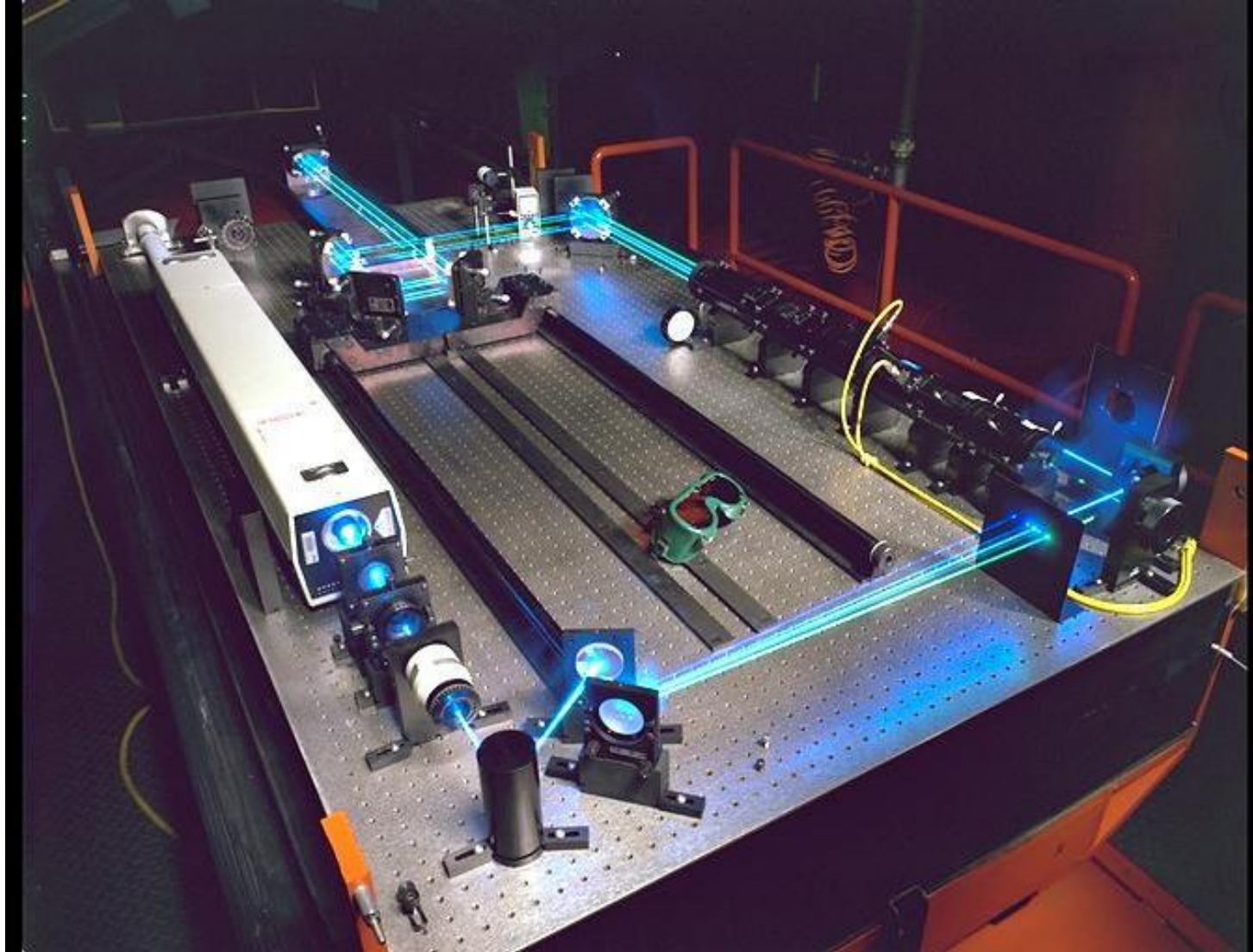
# **UNIT - V**

## **Semiconductor Devices**

## Semiconductor devices



# Semiconductor Lasers



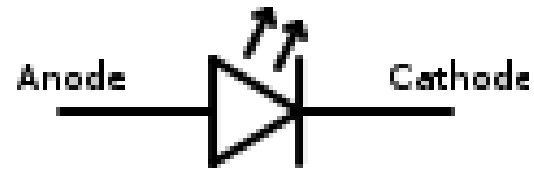
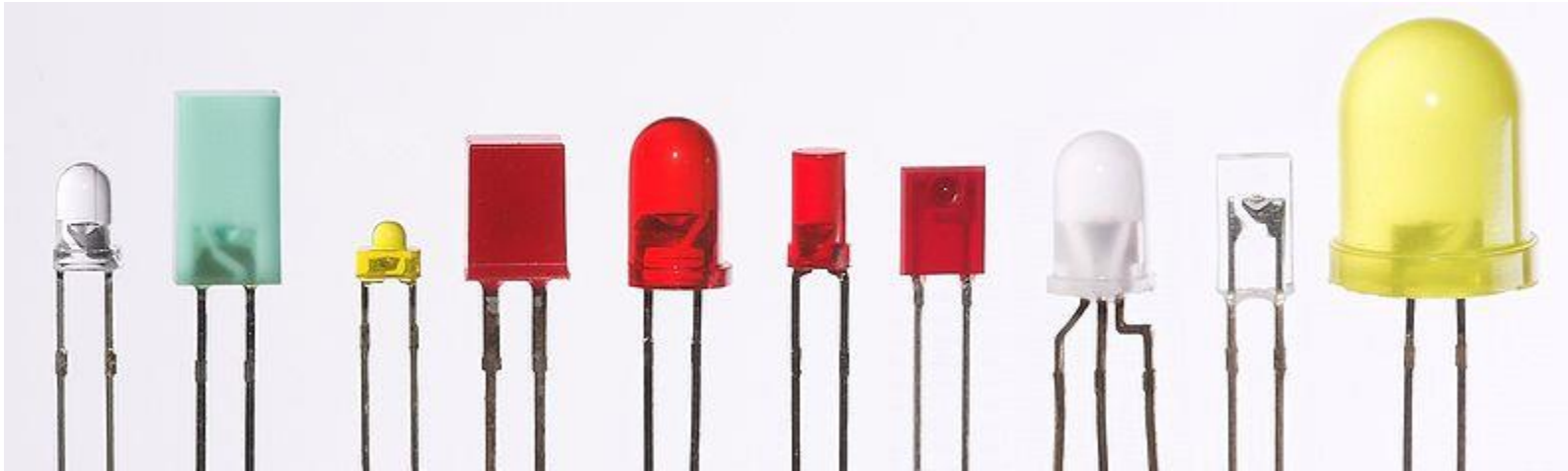


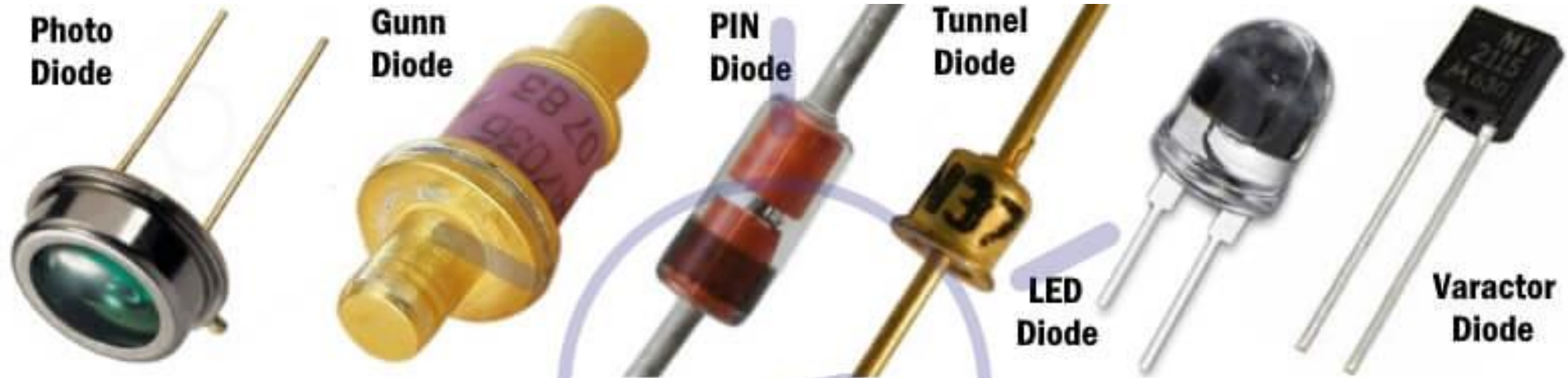
## Semiconductor devices



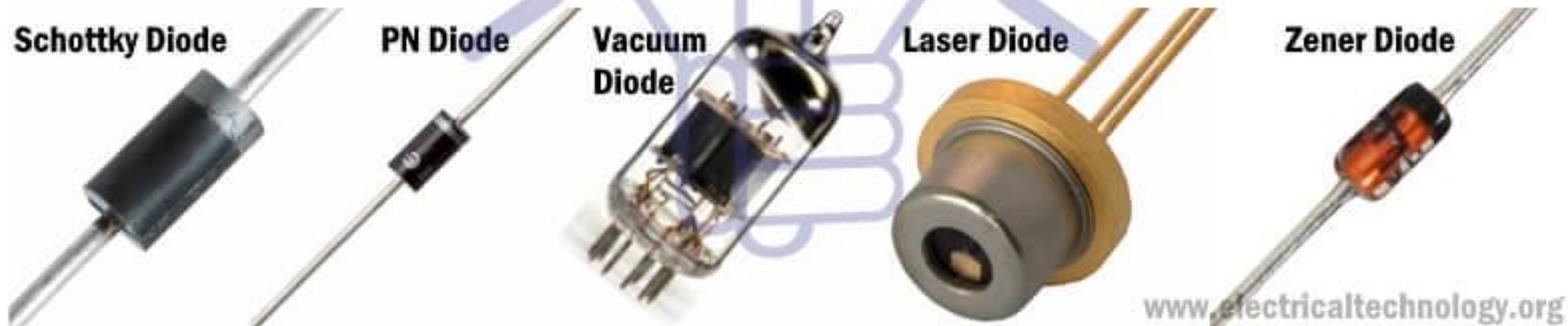
***The invention of the transistor or semiconductor was probably the most important development that lead to the personal computers amazing growth and what we know of as modern day computers.***

# Light Emitting Diodes





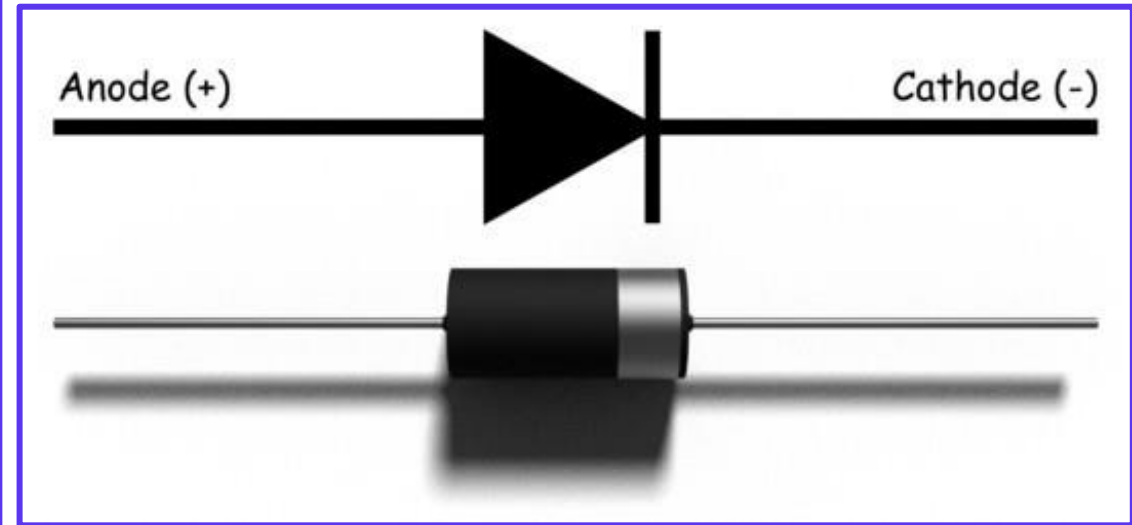
# Types of Diodes & Their Applications



## Semiconductor devices



A diode is a semiconductor device that comprises a single p-n junction. P-n junctions are usually formed by joining up of p-type and n-type semiconductor materials

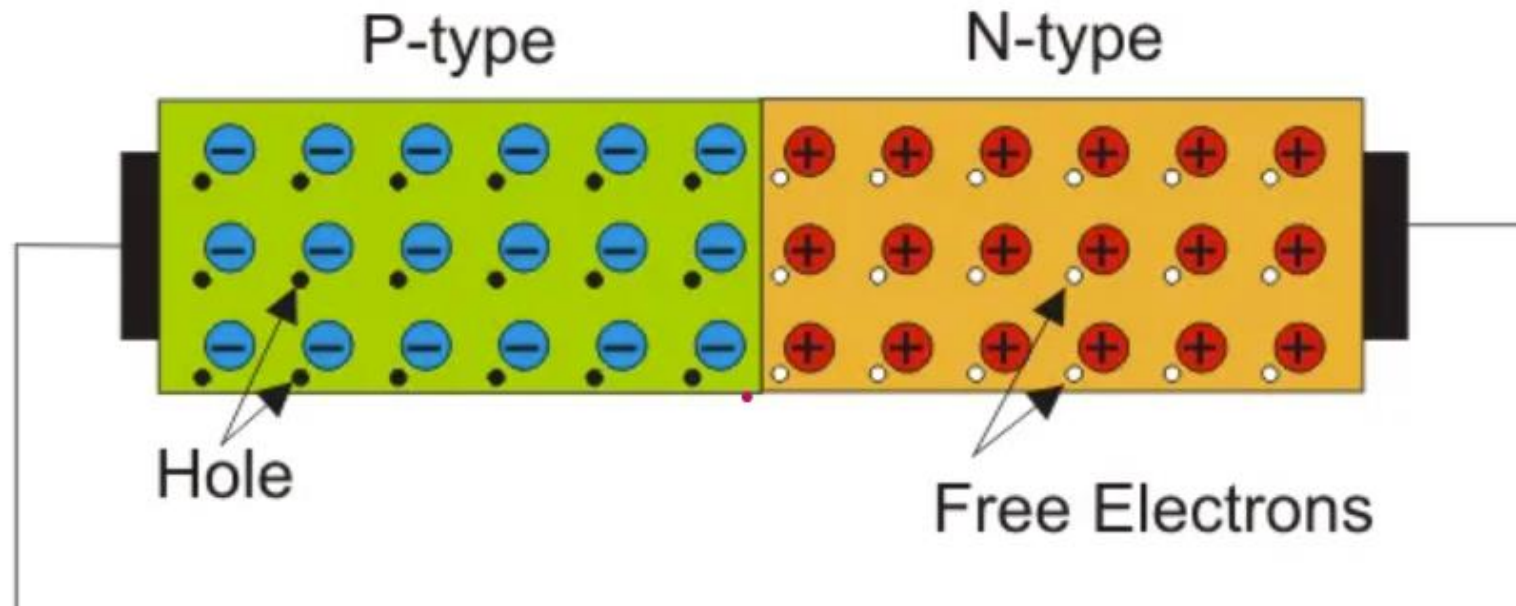


A diode is defined as a two-terminal electronic component **that only conducts current in one direction** (so long as it is operated within a specified voltage level).

An ideal diode will have **zero resistance** in one direction, and **infinite resistance** in the reverse direction.



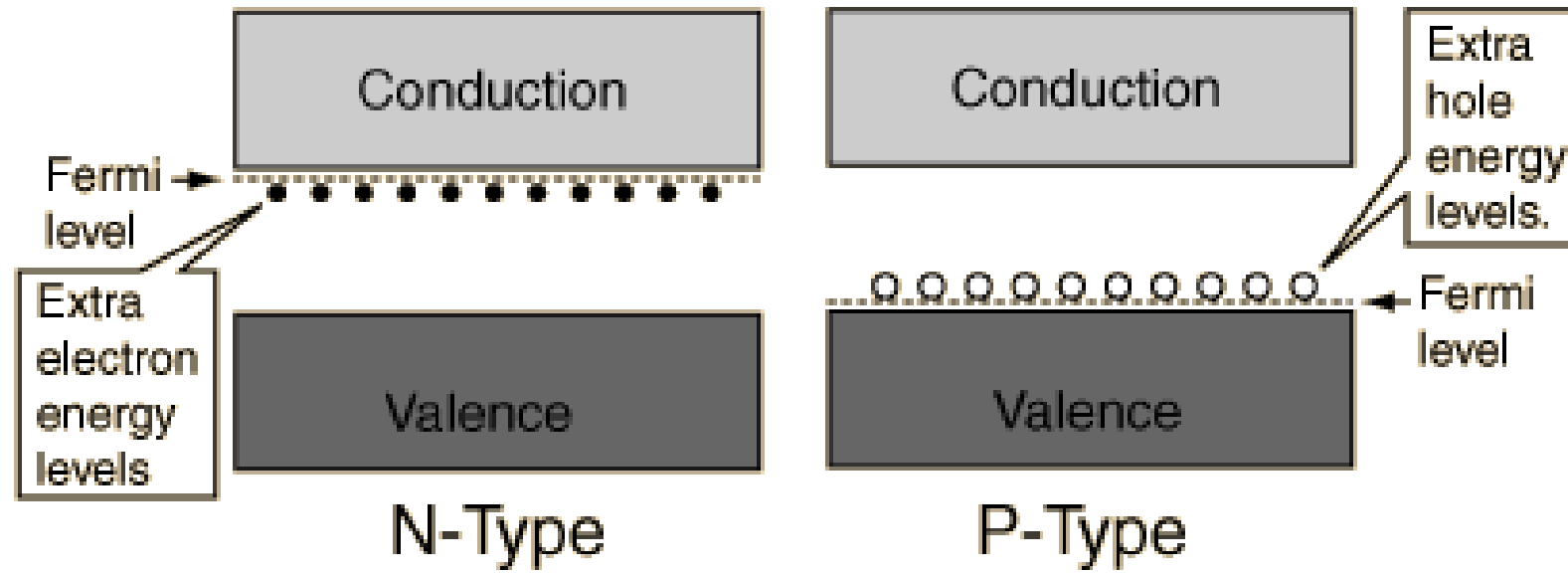
## Semiconductor devices



A diode is a semiconductor device that comprises a single p-n junction. P-n junctions are usually formed by joining up of p-type and n-type semiconductor materials



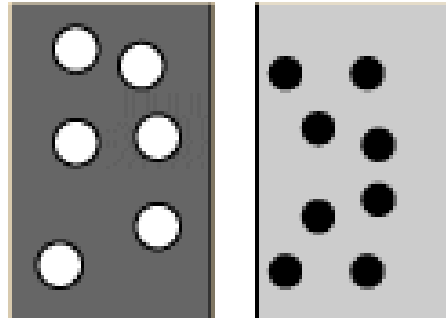
## P-N junction diode



***In the n-type region there are extra electrons and in the p-type region, there are holes from the acceptor impurities .***

# P-N Junction

*In the p-type region there are holes from the acceptor impurities and in the n-type region there are extra electrons.*



● Electron

○ Hole



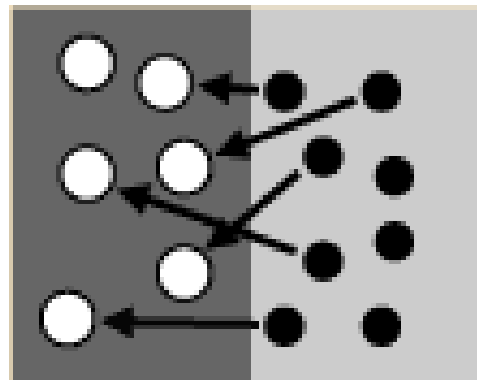
Negative ion from  
filling of p-type  
vacancy.



Positive ion from  
removal of electron  
from n-type impurity.

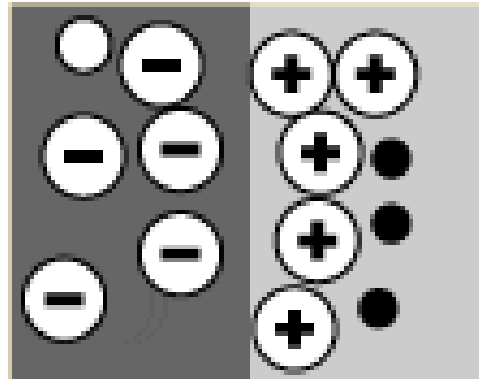
# P-N Junction

*When a p-n junction is formed, some of the electrons from the n-region which have reached the conduction band are free to diffuse across the junction and combine with holes.*



# P-N Junction

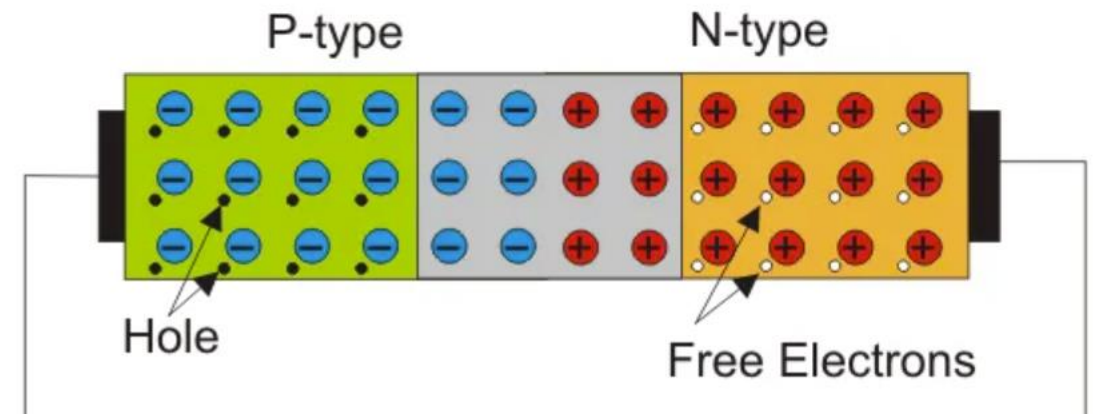
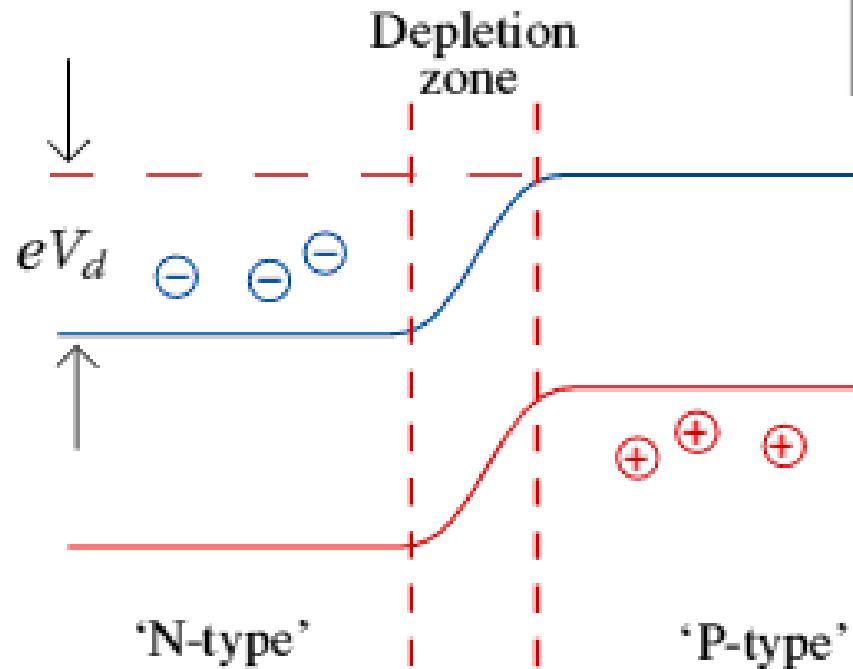
*Filling a hole makes a negative ion and leaves behind a positive ion on the n-side.*



***A space charge builds up, creating a depletion region.***



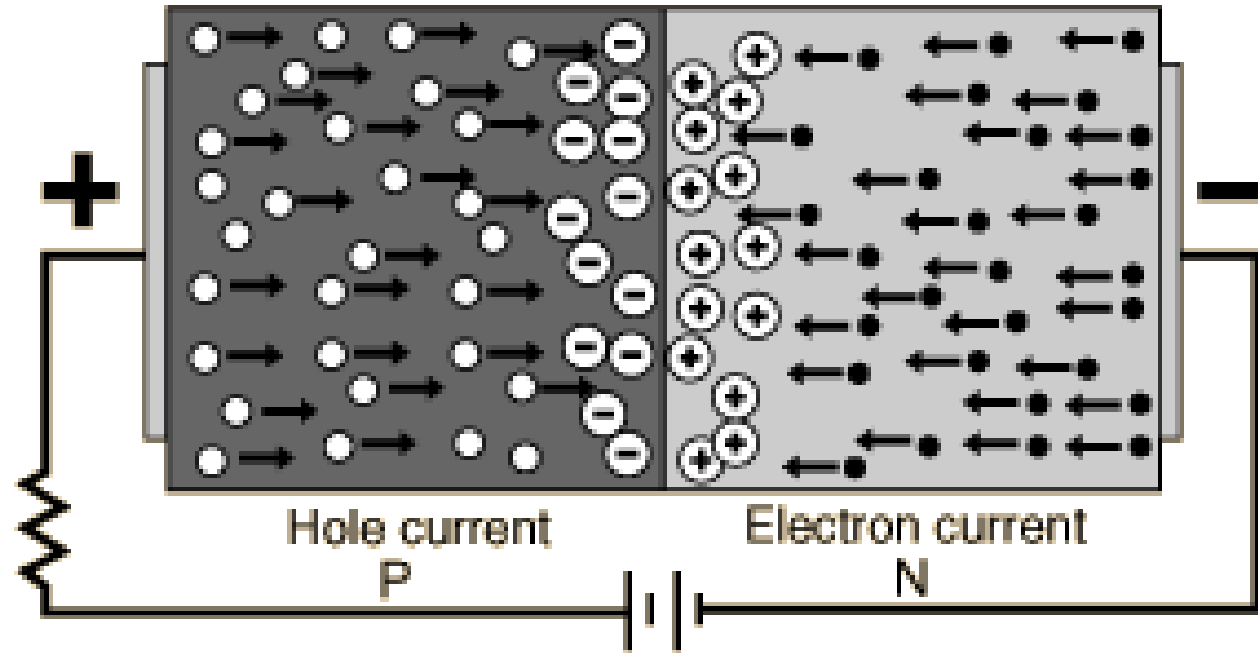
# P-N Junction



*This causes a depletion zone to form around the junction (the join) between the two materials.*

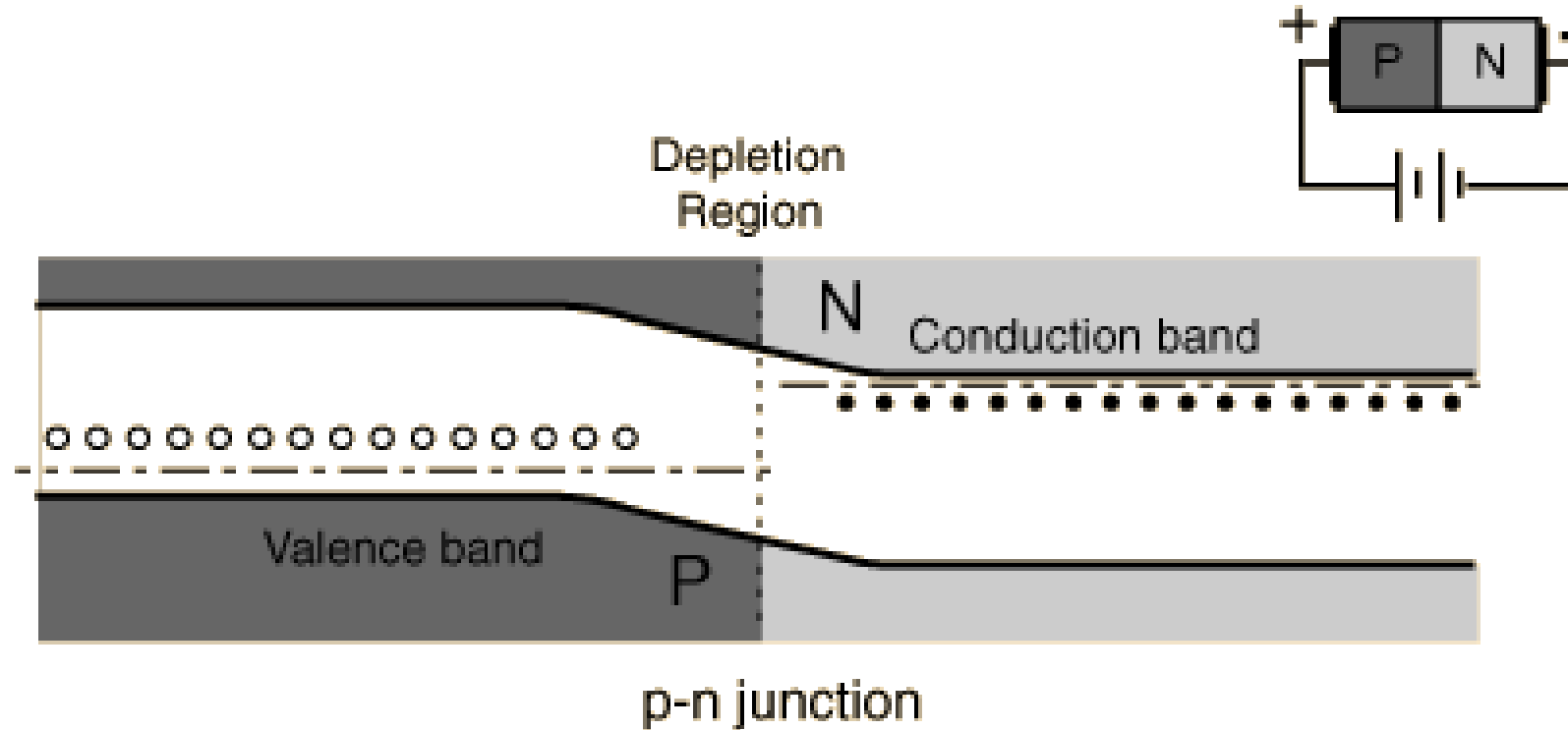
***This zone controls the behavior of the diode.***

# Forward Biasing



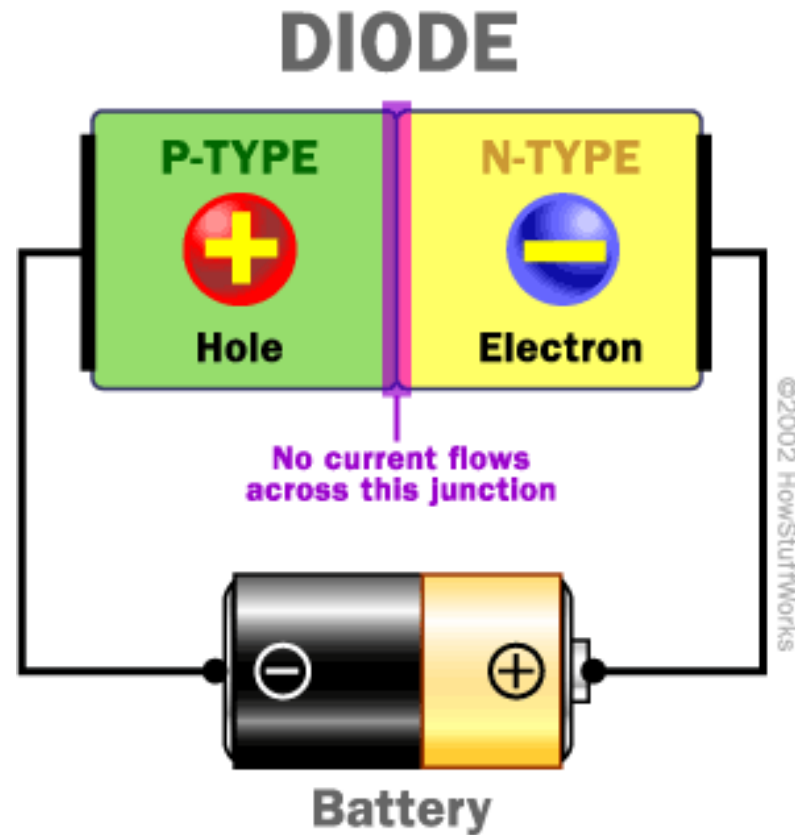
*Forward biasing the p-n junction drives holes to the junction from the p-type material and electrons to the junction from the n-type material.*

# Forward Biasing



***At the junction the electrons and holes combine so that a continuous current can be maintained.***

# Diode



***A diode is the simplest possible semiconductor device.***



# One Way Electric “Turnstile”



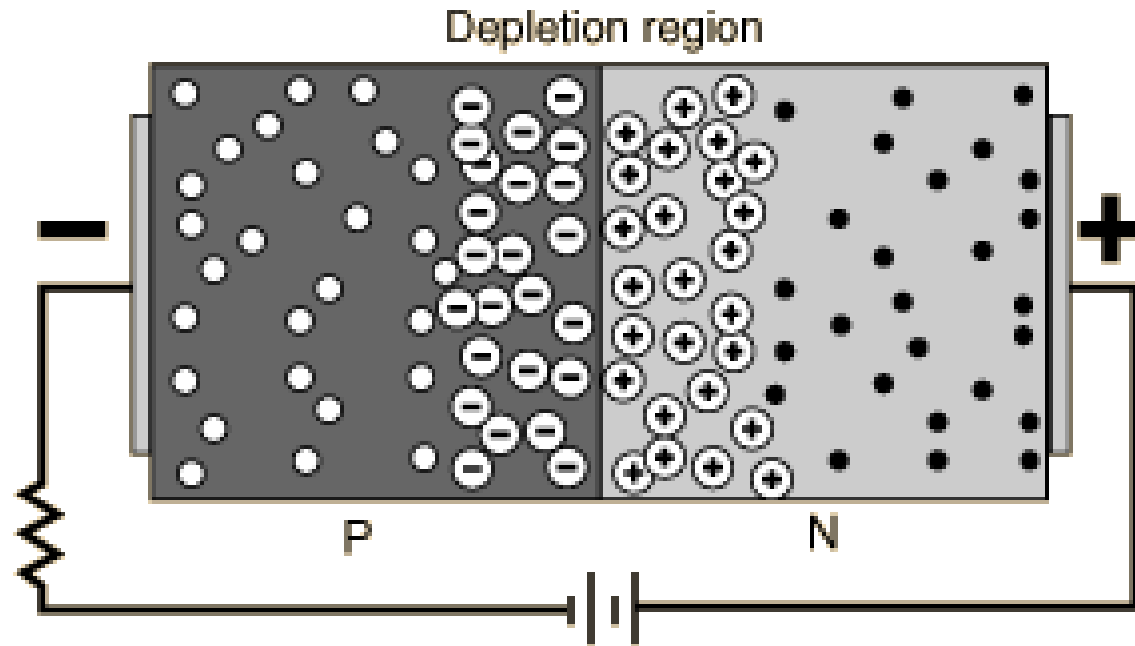
***A diode allows current to flow in one direction but not the other.***

# Jumping



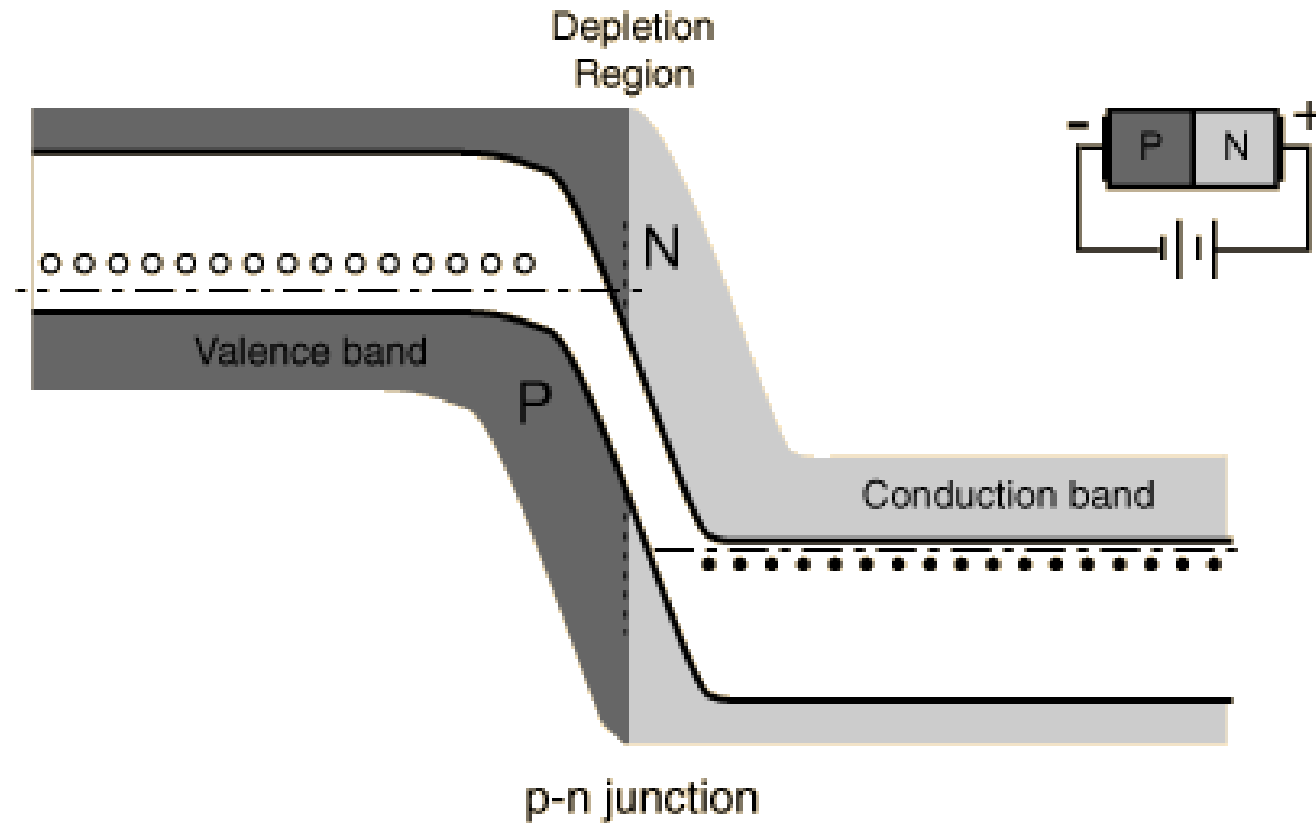
***If you apply enough reverse voltage, the junction breaks down and lets current through.***

# Reverse Biasing



***The application of a reverse voltage to the p-n junction will cause a transient current to flow as both electrons and holes are pulled away from the junction.***

# Reverse Biasing

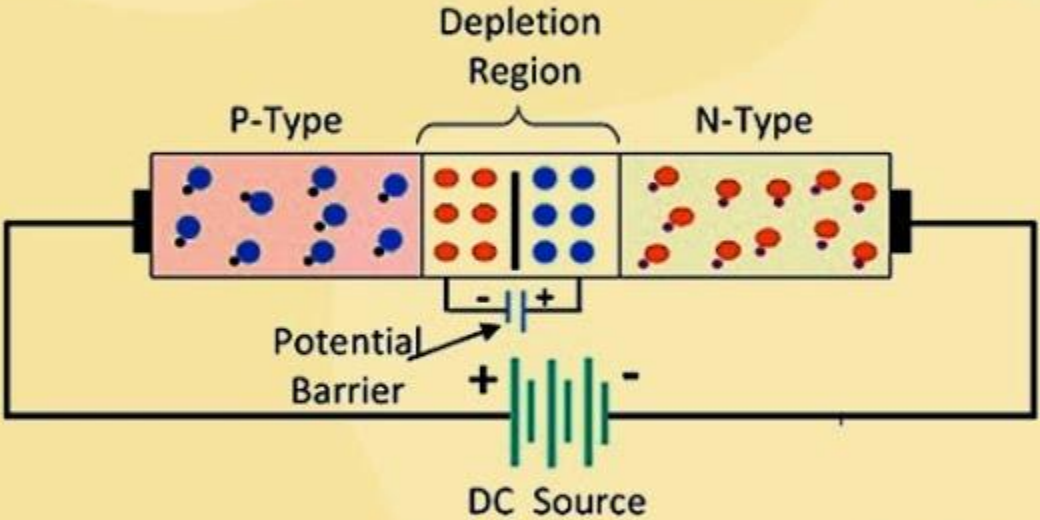


***When the potential formed by the widened depletion layer equals the applied voltage, the current will cease except for the small thermal current.***



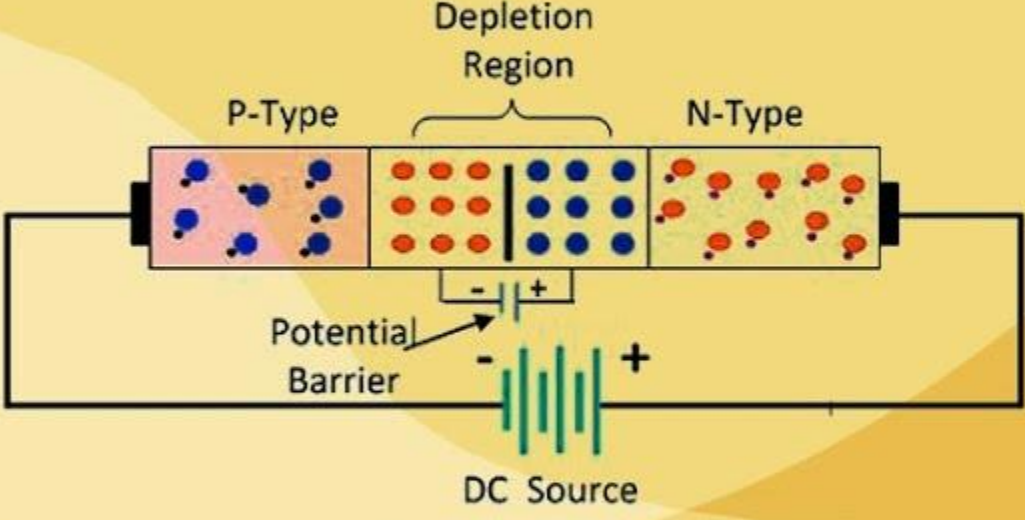
# P-N Junction diode biasing - working

## Forward Bias and Reverse Bias of PN Junction Diode



Holes •      Electrons •  
Free Electrons •      Free Holes •

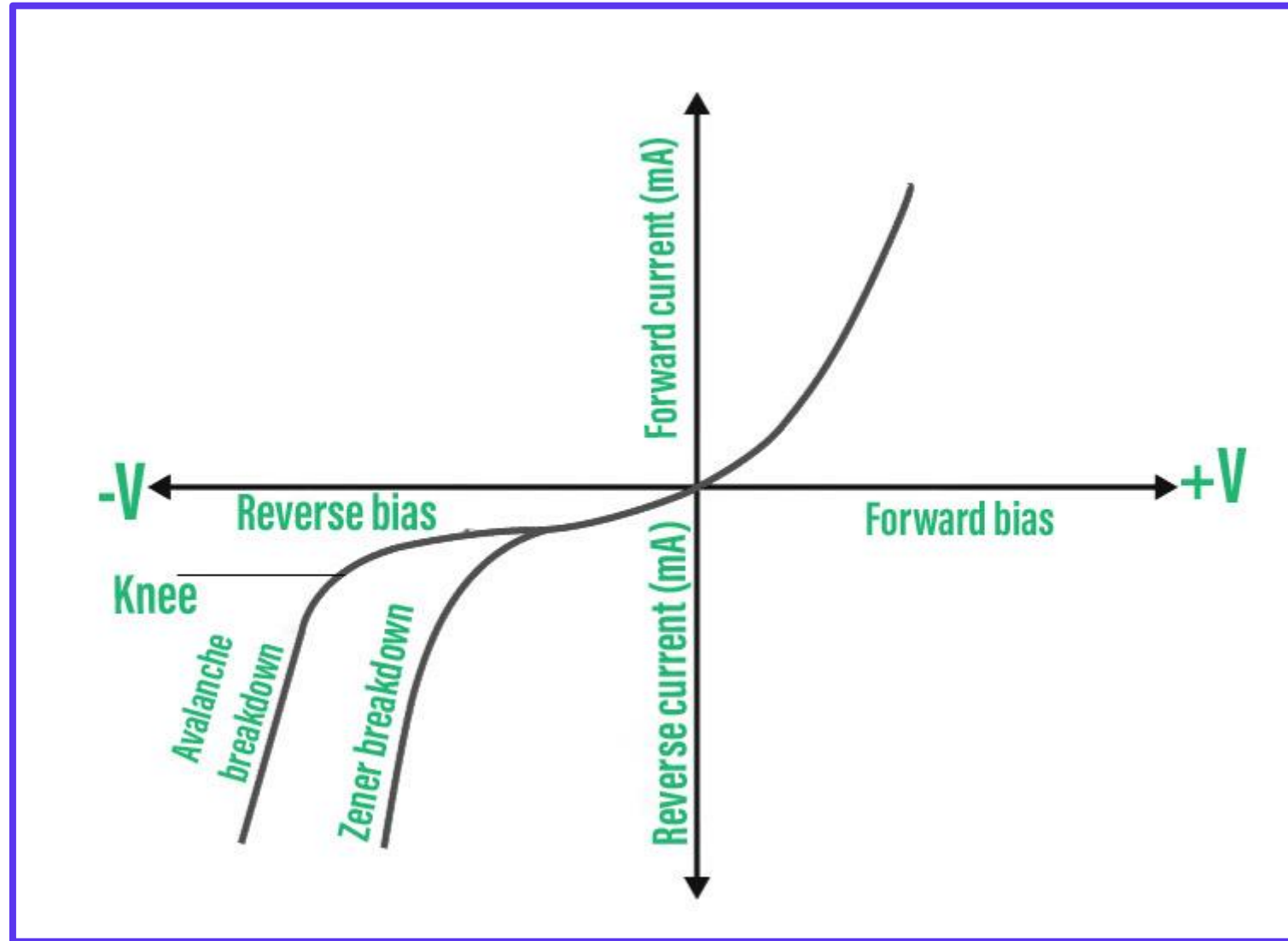
Forward Biasing



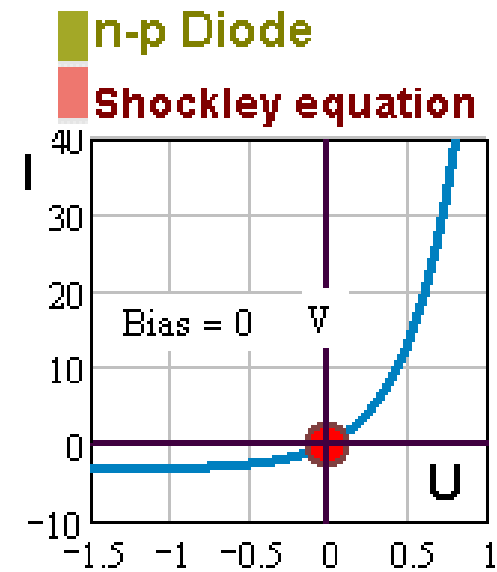
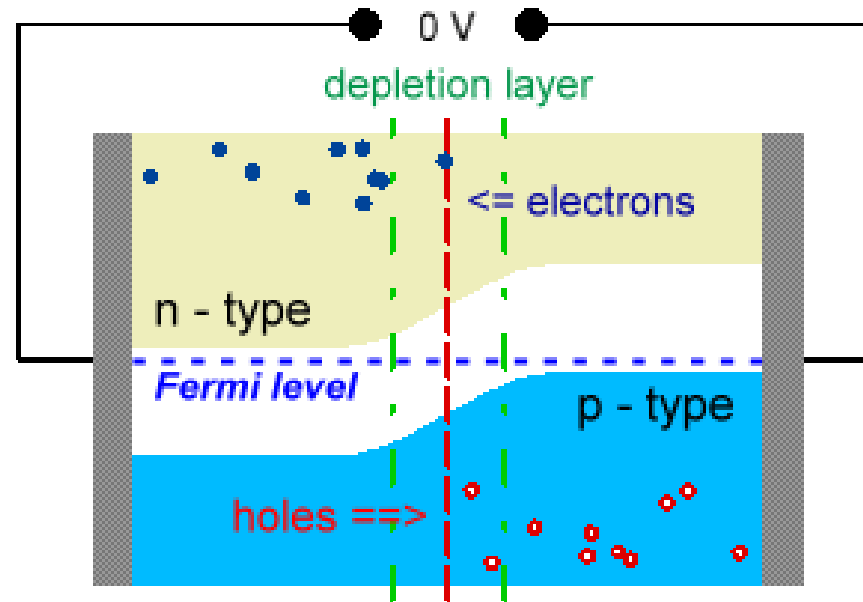
Holes •      Electrons •  
Free Electrons •      Free Holes •

Reversed Biasing

## P-N Junction diode characteristics



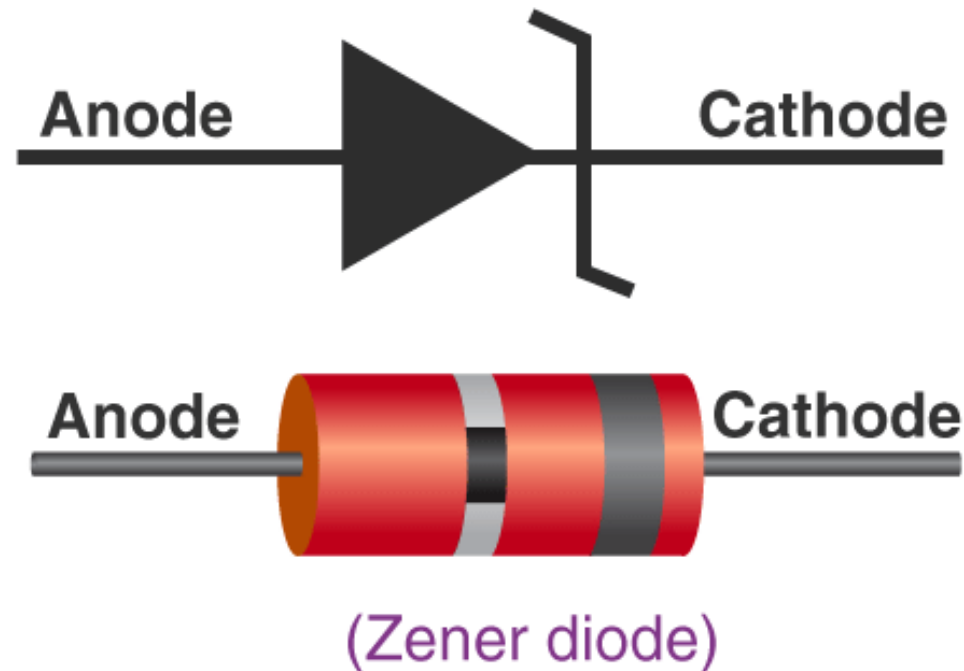
# P-N Junction



*We create a p-n junction by joining together two pieces of semiconductor, one doped n-type, the other p-type.*

# Zener diode

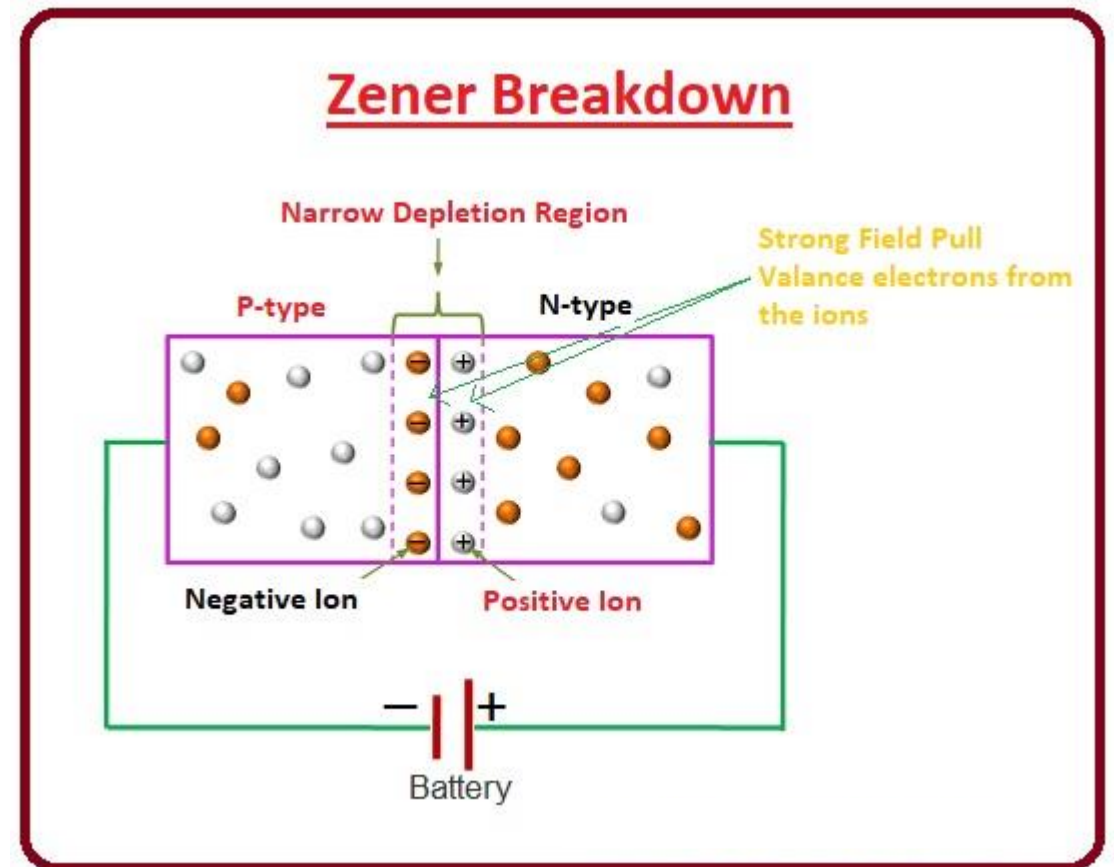
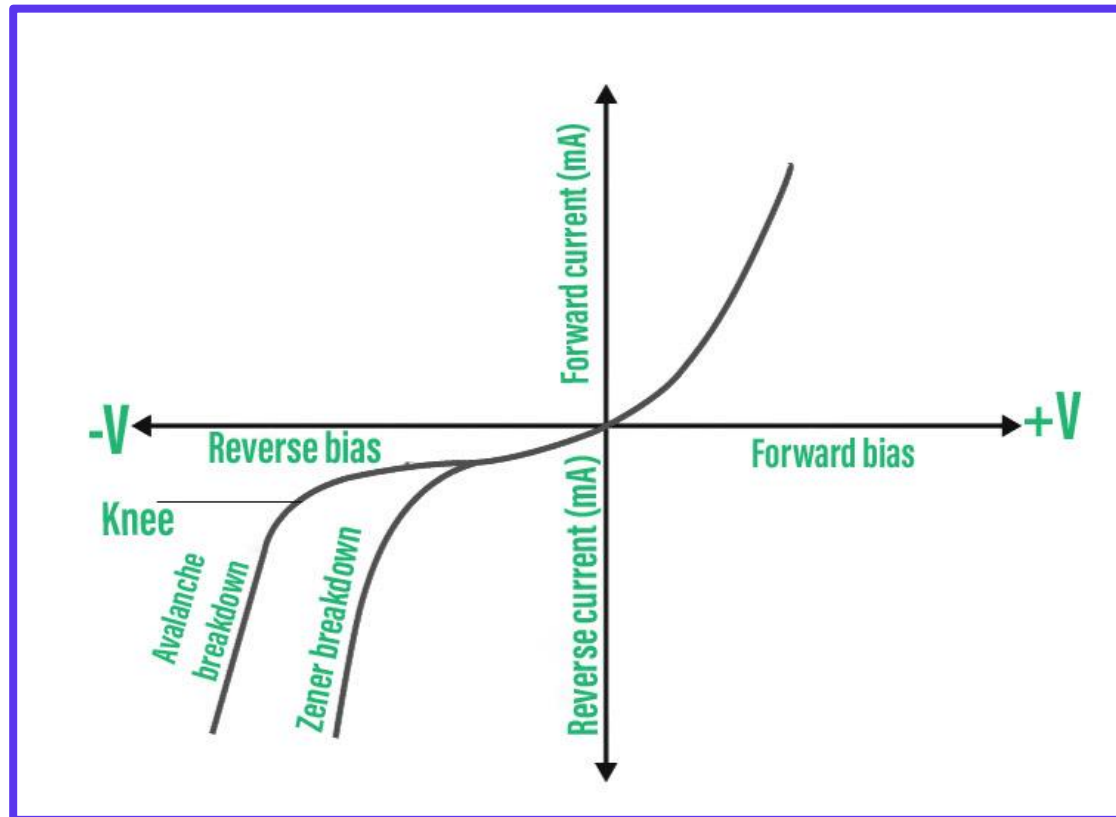
Zener diode is basically like an ordinary PN junction diode but normally operated in reverse biased condition. But ordinary PN junction diode connected in reverse biased condition is not used as Zener diode practically. A Zener diode is a specially designed, highly doped PN junction diode.





## Zener diode working and characteristics

A Zener diode operates just like a normal diode when it is forward-biased. However, when connected in reverse biased mode, a small leakage current flows through the diode. As the reverse voltage increases to the predetermined breakdown voltage ( $V_z$ ), current starts flowing through the diode. The current increases to a maximum, after which it stabilizes and remains constant over a wide range of applied voltage.



# There are two types of breakdowns for a Zener Diode:

## ❑ Avalanche Breakdown

## ❑ Zener Breakdown

### Avalanche Breakdown in Zener Diode

Avalanche breakdown occurs both in normal diode and Zener Diode at high reverse voltage. When a high value of reverse voltage is applied to the PN junction, the free electrons gain sufficient energy and accelerate at high velocities. These free electrons moving at high velocity collides other atoms and knocks off more electrons. Due to this continuous collision, a large number of free electrons are generated as a result of **electric current** in the diode rapidly increases. This sudden increase in electric current may permanently destroy the normal diode, however, a Zener diode is designed to operate under avalanche breakdown and can sustain the sudden spike of current. Avalanche breakdown occurs in Zener diodes with Zener voltage ( $V_z$ ) greater than 6V.

### Zener Breakdown in Zener Diode

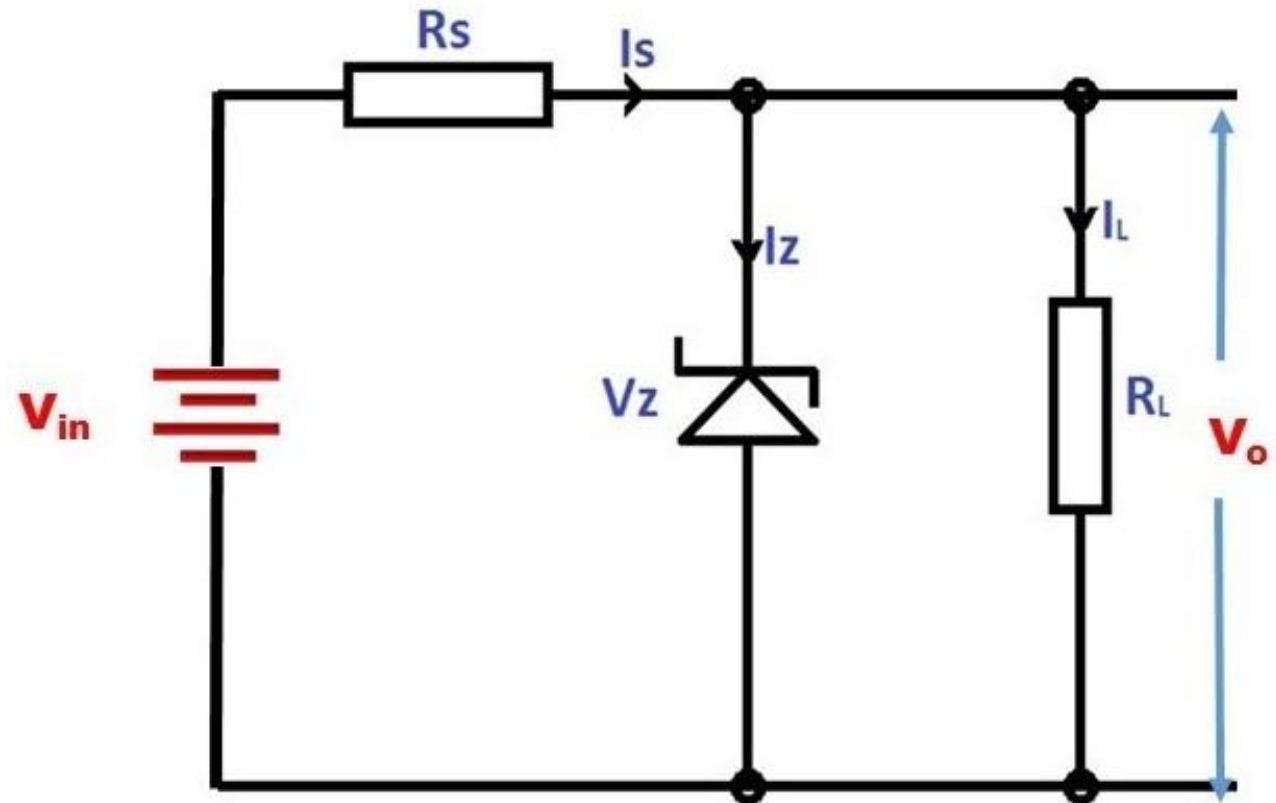
When the applied reverse bias voltage reaches closer to the Zener voltage, the electric field in the depletion region gets strong enough to pull electrons from their valence band. The valence electrons that gain sufficient energy from the strong electric field of the depletion region break free from the parent atom. At the Zener breakdown region, a small increase in the voltage results in the rapid increase of the electric current.

## Zener diode application: As a voltage regulator

Zener diode is used as a Shunt voltage regulator for regulating voltage across small loads.

The breakdown voltage of Zener diodes will be constant for a wide range of current.

Zener diode is connected parallel to the load to make it reverse bias and once the Zener diode exceeds knee voltage, the voltage across the load will become constant.



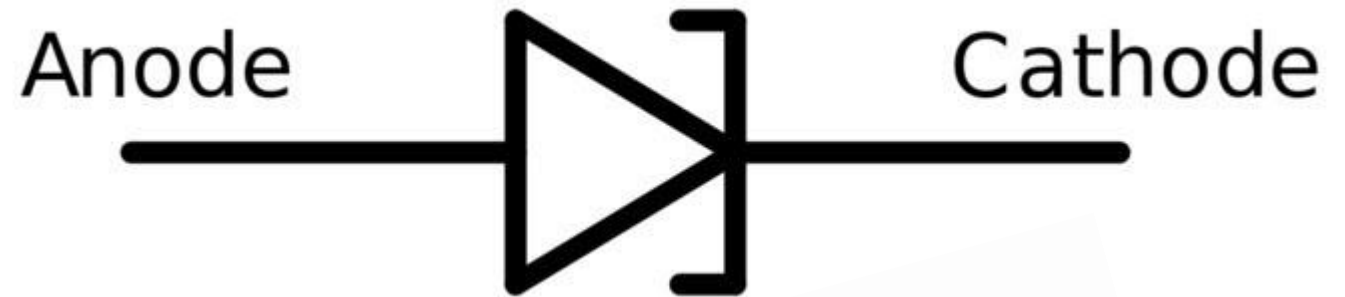
# Tunnel diode

## What is a Tunnel Diode?

A Tunnel Diode is a **heavily doped p-n junction diode**. The tunnel diode **shows negative resistance**. When voltage value increases, current flow decreases. Tunnel diode works based on Tunnel Effect.

## Tunneling Effect

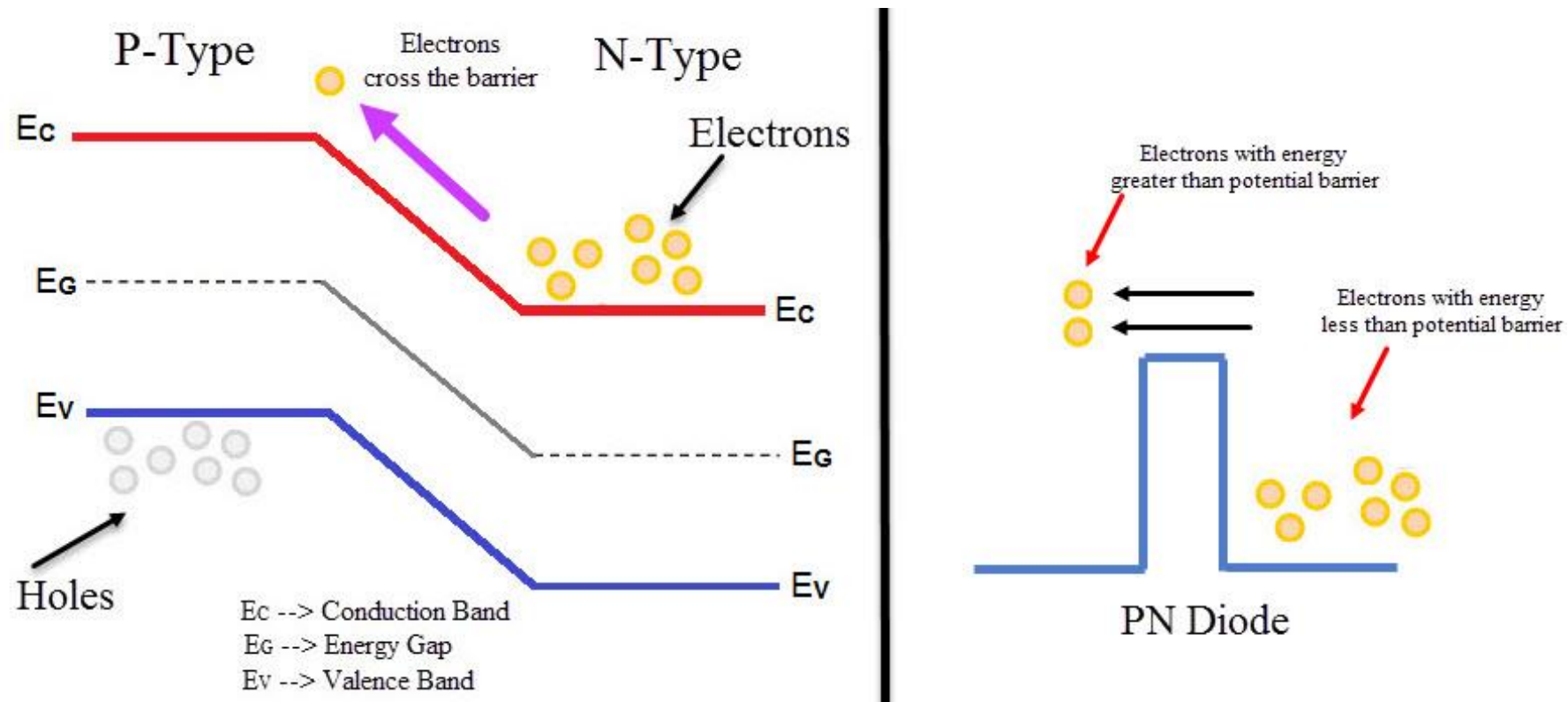
In electronics, Tunneling is known as a direct flow of electrons across the small depletion region from n-side conduction band into the p-side valence band



## Tunneling diode working - Tunneling effect

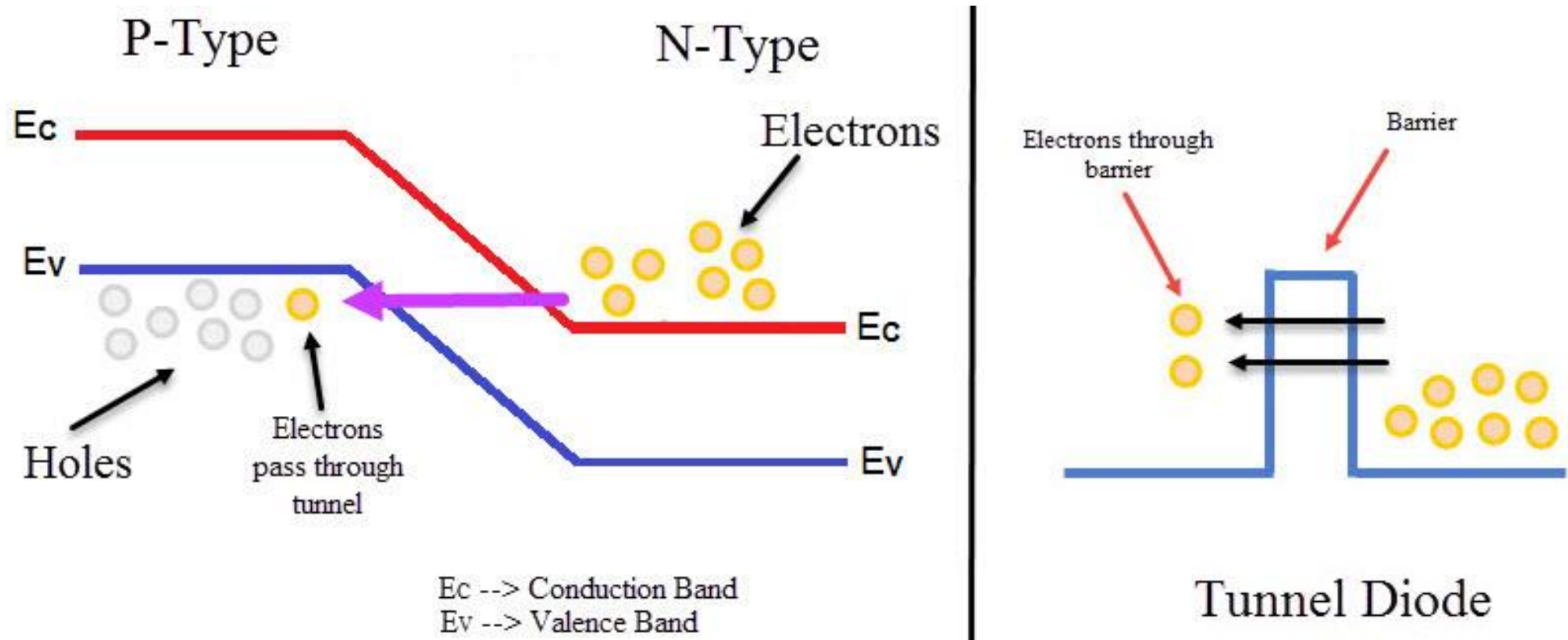
As the width of the depletion layer reduces, charge carriers can easily cross the junction. Charge carriers do not need any form of kinetic energy to move across the junction. Instead, carriers punch through junction. This effect is called Tunneling and hence the diode is called Tunnel Diode.

### Normal PN junction diode

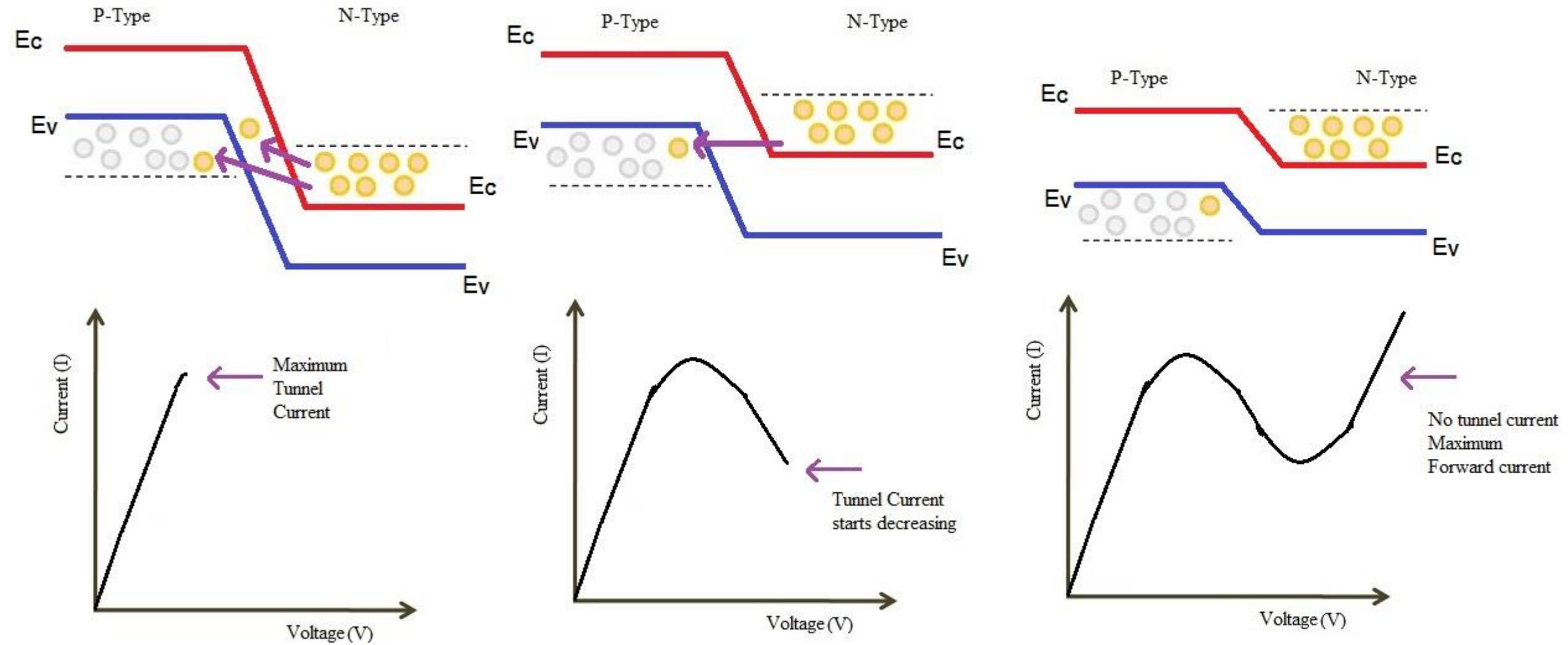


## Tunneling diode working - Tunneling effect

As the width of the depletion layer reduces, charge carriers can easily cross the junction. Charge carriers do not need any form of kinetic energy to move across the junction. Instead, carriers punch through junction. This effect is called Tunneling and hence the diode is called Tunnel Diode.

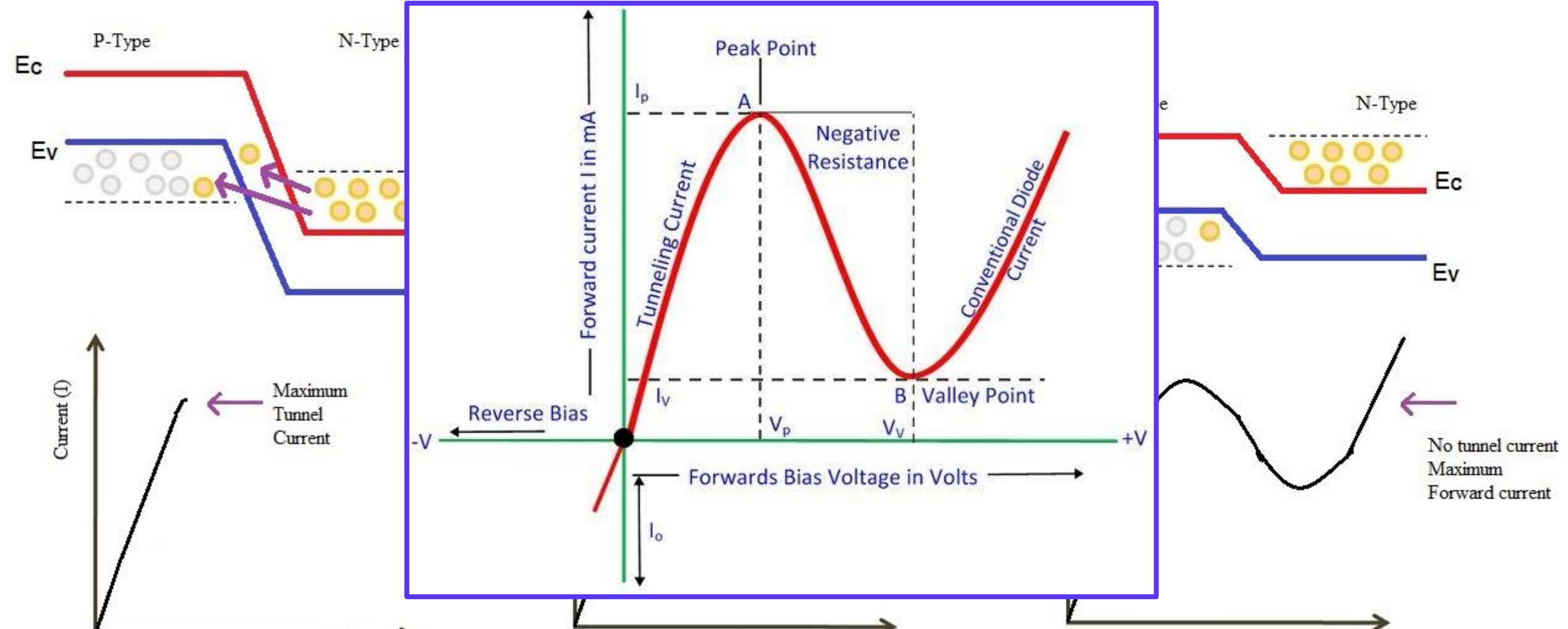


# Tunneling diode characteristics





## Tunneling diode characteristics



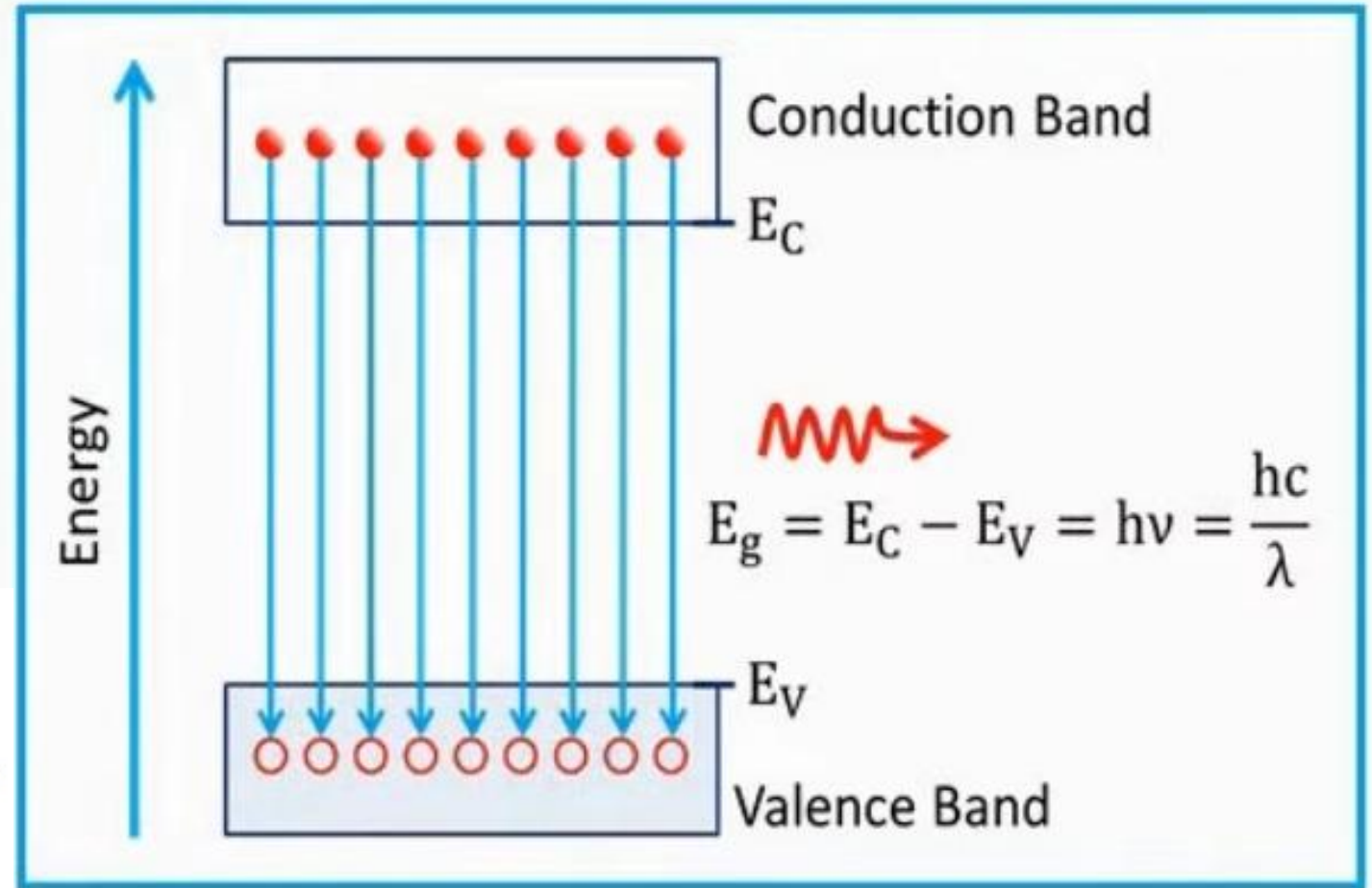
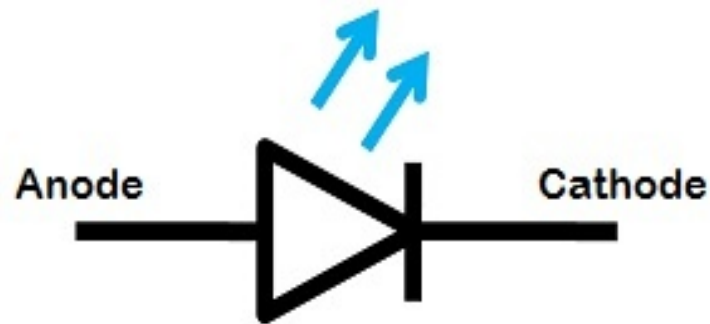
The small minimal value of current is  $I_v$ . From the above graph, it is seen that from point A to B current reduces when voltage increases. That is the negative resistance region of diode. In this region, tunnel diode produces power instead of absorbing it.

## ❑ Applications of Tunnel Diode

- ❑ Tunnel diode can be used as a switch, amplifier, and oscillator.
- ❑ Since it shows a fast response, it is used as high frequency component.
- ❑ Tunnel diode acts as logic memory storage device.
- ❑ They are used in oscillator circuits, and in FM receivers. Since it is a low current device, it is not used more.

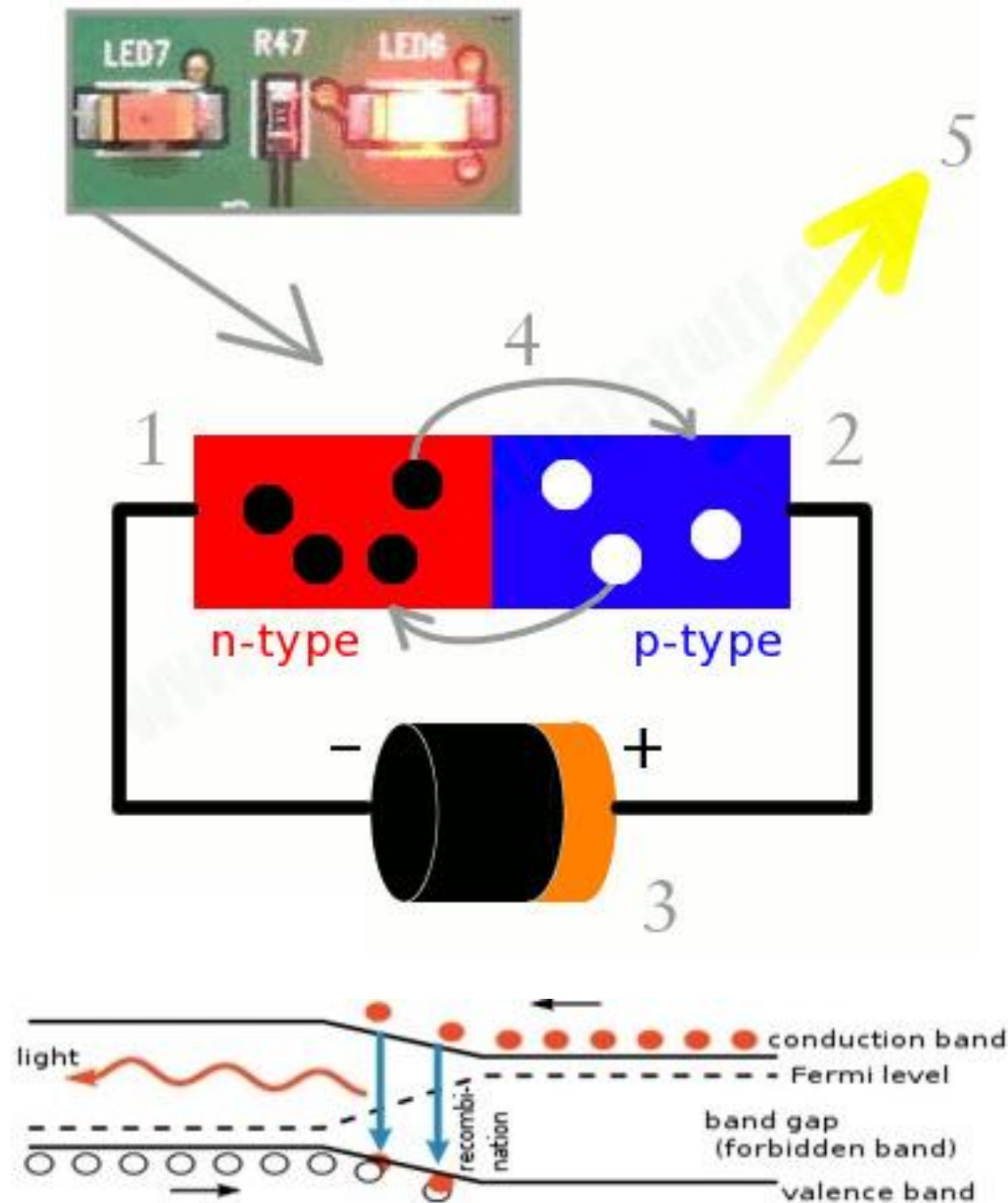
# Light Emitting Diode (LED)

- LED is a diode which emits visible light when forward biased.
- LED works on the basic principle called 'recombination'.



## Light Emitting Diode (LED) - Working

1. The N-type silicon is in red color including the electrons which are indicated by the black circles.
2. The P-type silicon is in the blue color and it contains holes, they are indicated by the white circles.
3. The power supply across the p-n junction makes the diode forward biased and pushing the electrons from n-type to p-type. Pushing the holes in the opposite direction.
4. Electron and holes at the junction are combined.
5. The photons are given off as the electrons and holes are recombined.



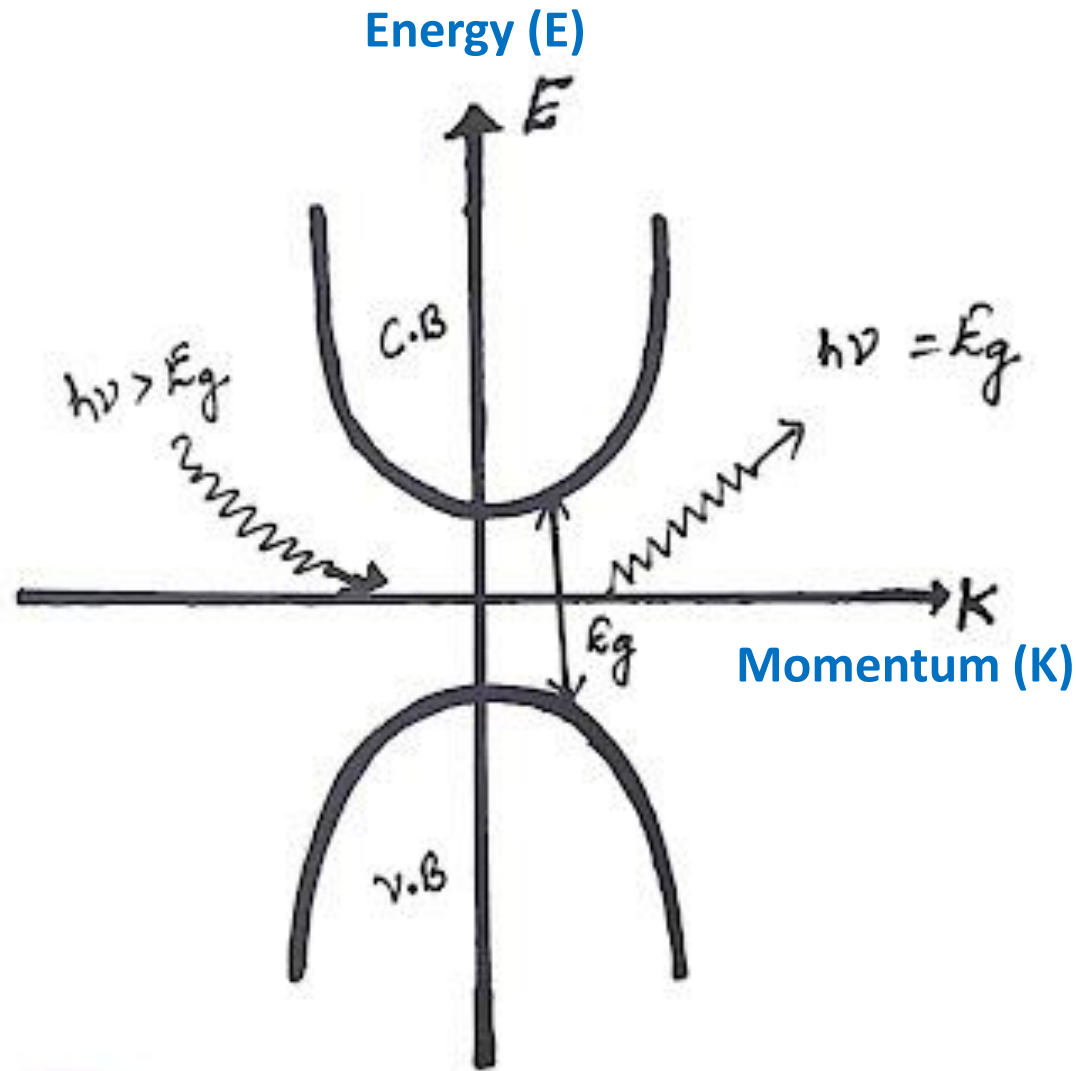
## Light Emitting Diode (LED)

- Why Silicon and Germanium diodes can not be used to as LED?
  - These are **indirect gap** semiconductors
  - Energy Gap for Si = 1.1 eV
  - Energy Gap for Ge = 0.7 eV
  - Corresponding values of wavelength do not fall in visible region.
- Which materials are used for LED?
  - GaAs, GaAsP, GaP etc. which are obtained by mixing group 3 elements with group 5 elements.
  - These are **direct gap** semiconductors and the energy gap is such that corresponding wavelength falls in the visible region

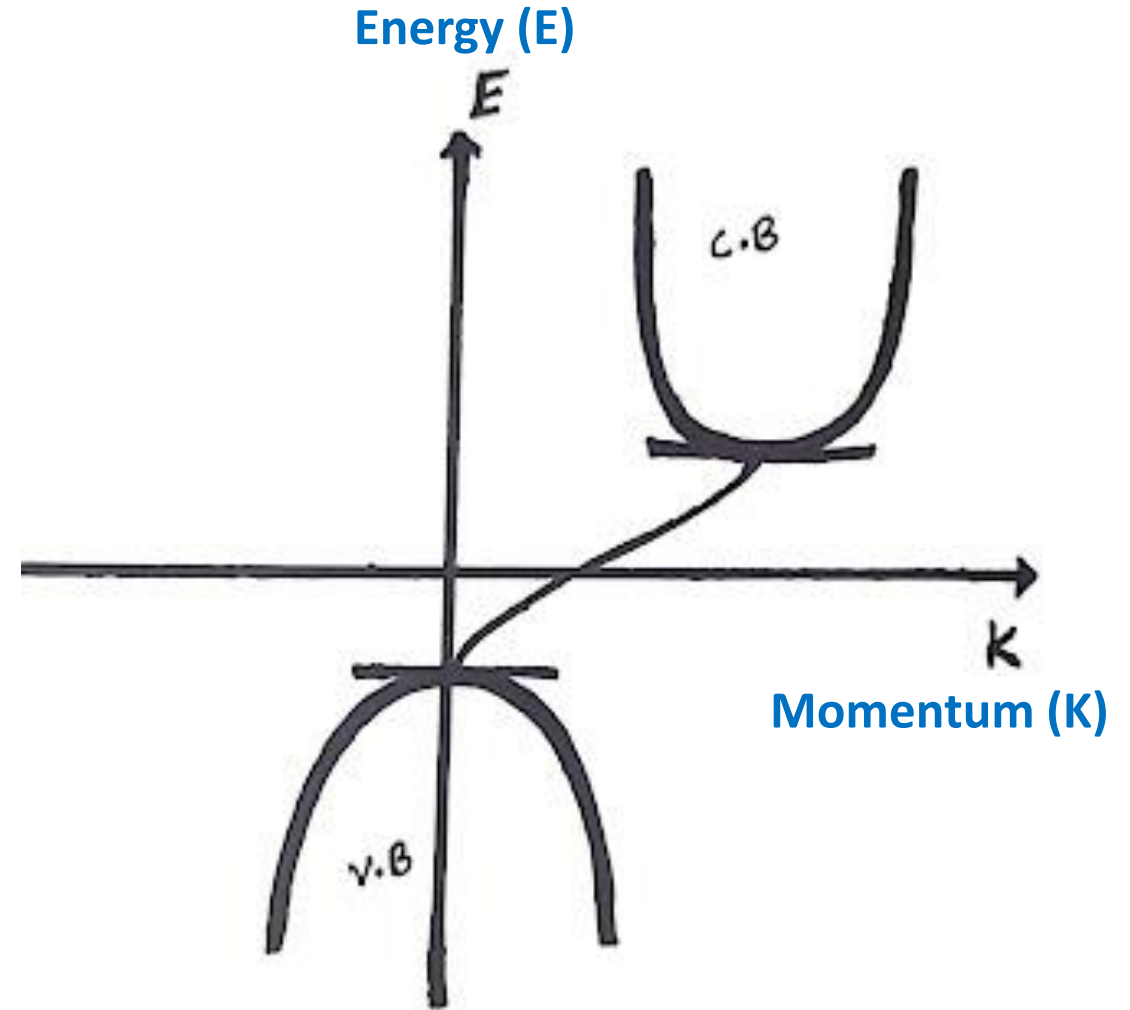
$$E_g = E_C - E_V = h\nu = \frac{hc}{\lambda}$$



## Direct and Indirect band-gap semiconductors



Direct band-gap

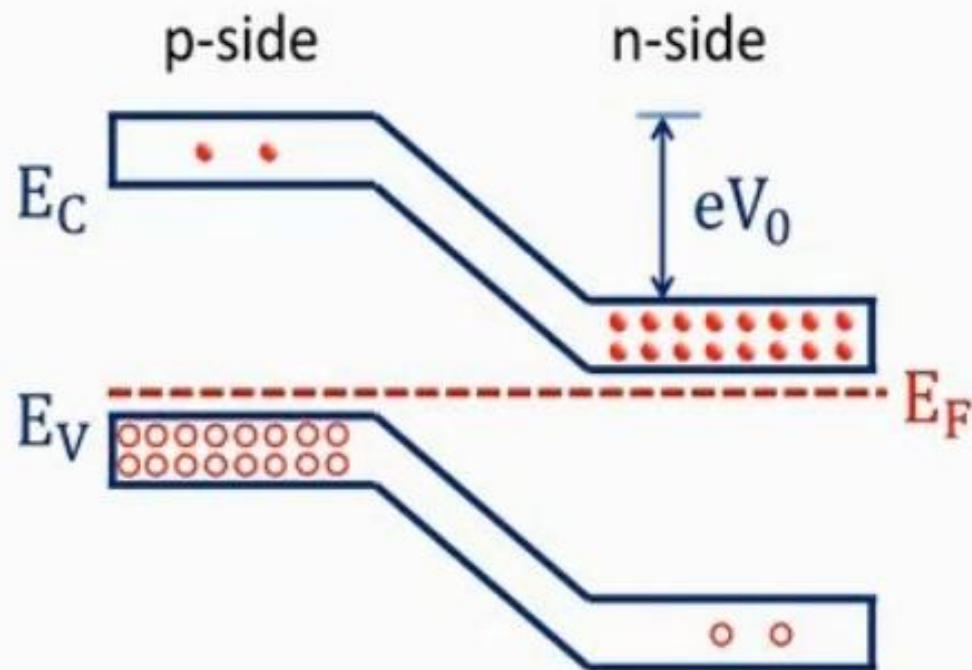


Indirect band-gap

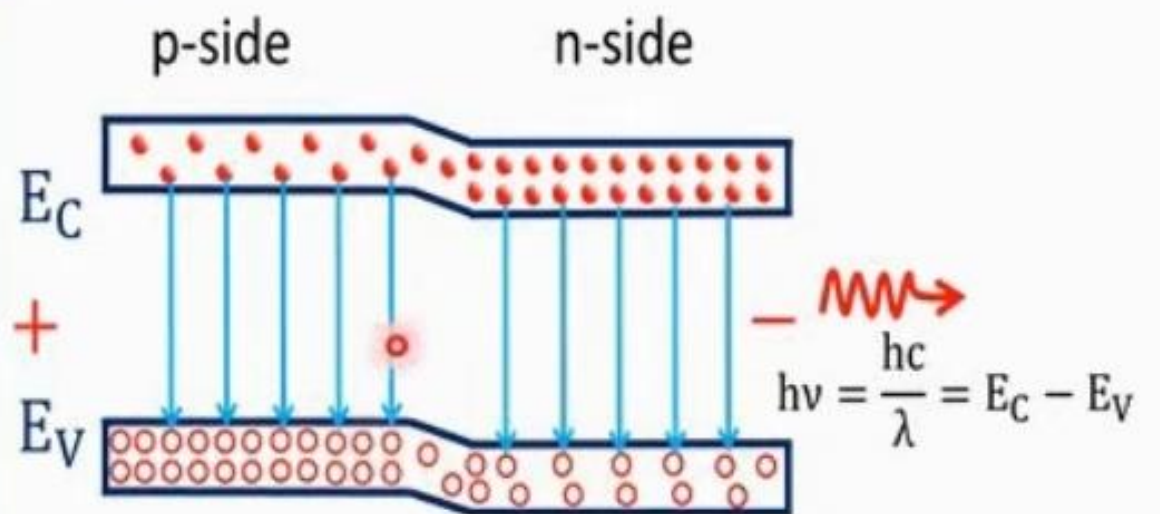
Direct band-gap semiconductor (DBG)	Indirect band-gap semiconductor (IBG)
A direct band-gap (DBG) semiconductor is one in which the maximum energy level of the valence band aligns with the minimum energy level of the conduction band with respect to momentum.	A indirect band-gap (IBG) semiconductor is one in which the maximum energy level of the valence band are misaligned with the minimum energy level of the conduction band with respect to momentum.
In a DBG semiconductor, a direct recombination takes place with the release of the energy equal to the energy difference between the recombining particles.	Due to a relative difference in the momentum, first, the momentum is conserved by release of energy and only after both the momenta align themselves, a recombination occurs accompanied with the release of energy.
The efficiency factor of a DBG semiconductor is much more than that of an IBG semiconductor.	The probability of a radiative recombination, is much less in comparison to that in case of DBG semiconductors
The most thoroughly investigated and studied DBG semiconductor material is Gallium Arsenide (GaAs).	The two well-known intrinsic semiconductors, Silicon and Germanium are both IBG semiconductors.
DBG semiconductors are always preferred over IBG for making optical sources.	The IBG semiconductors cannot be used to manufacture optical sources.

## Energy Band diagram for LED

(Why LED is used in forward bias mode?)



Energy Bands of Unbiased LED



Energy Bands aligned when forward biased



## Materials used in Light Emitting Diode (LED)

- Gallium arsenide (GaAs)
- Aluminium gallium arsenide (AlGaAs)
- Gallium arsenide phosphide (GaAsP)
- Aluminium gallium indium phosphide (AlGaInP)
- Gallium phosphide (GaP)
- Aluminium gallium phosphide (AlGaP)
- Aluminium nitride (AlN)
- Aluminium gallium nitride (AlGaN)

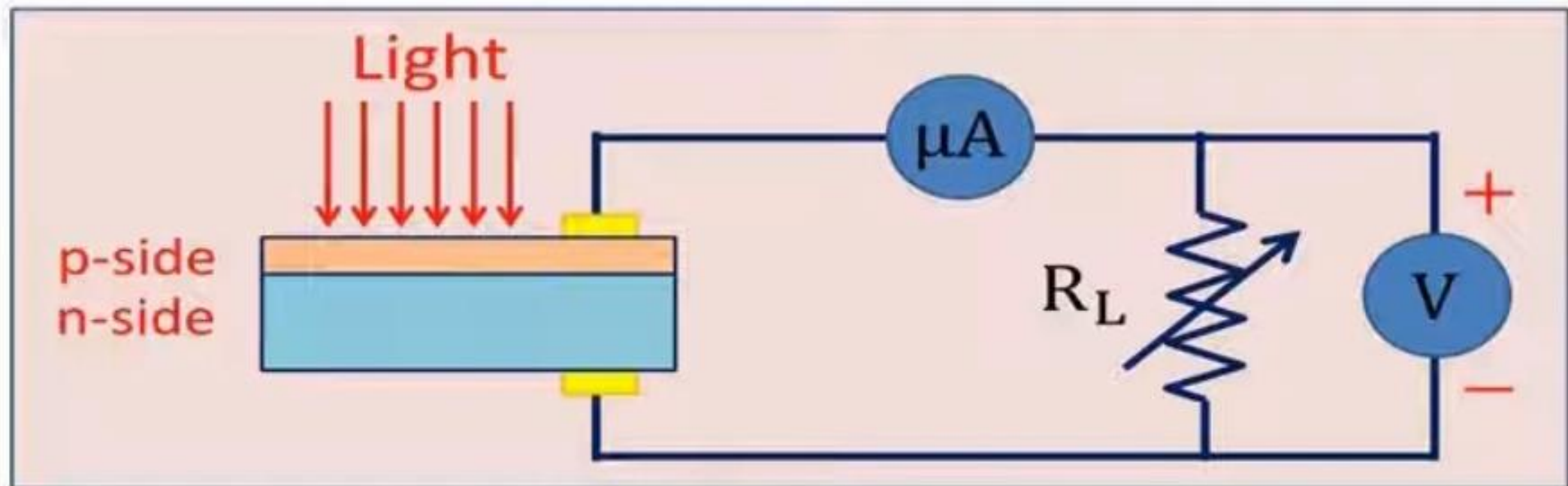
## Applications of LED



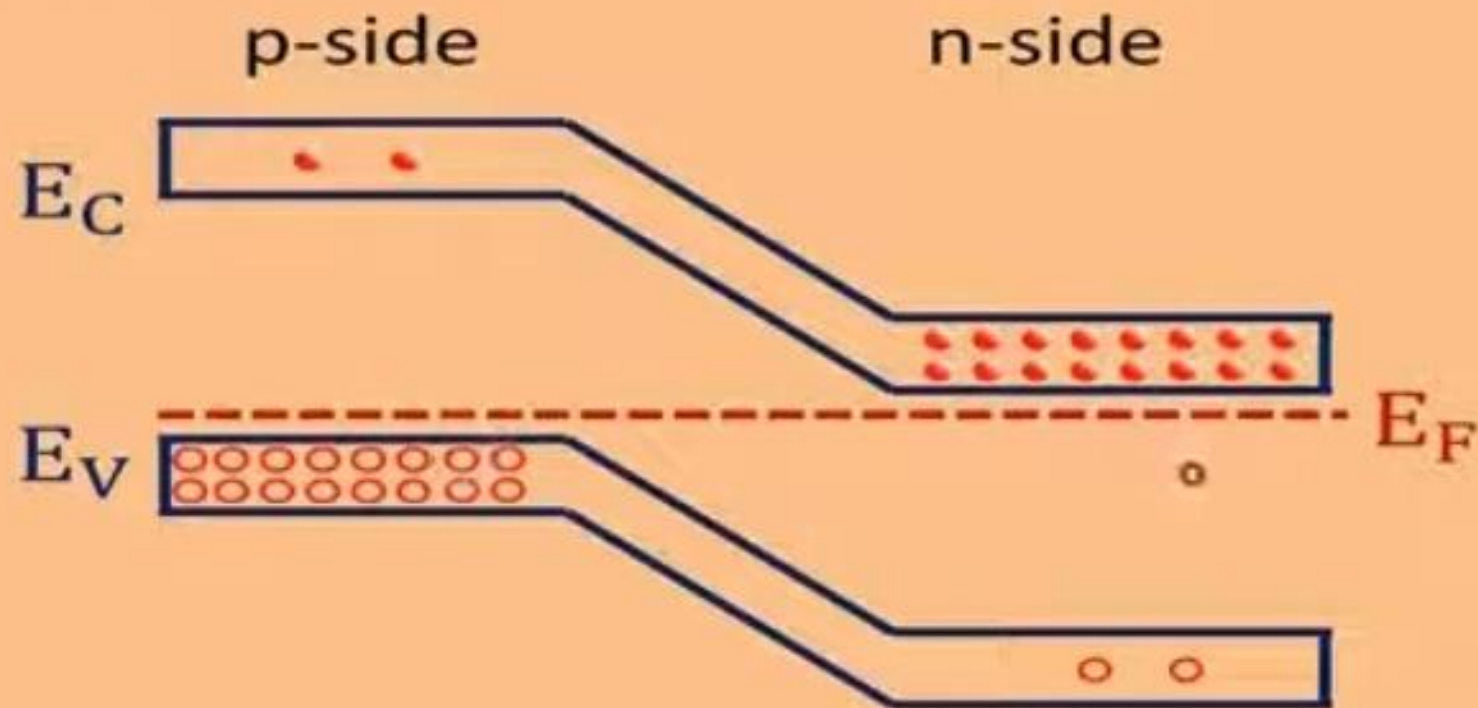
- Digital displays.
- Optical source in fibre optic communication.
- Infrared LEDs used in remote control devices.
- Widely used in automobile industry.

## Solar Cell (Photovoltaic Cell)

- It is alternative source of energy which converts solar energy into electrical energy.
- It is a p-n junction with a large surface area as compared to normal p-n junction diodes and very thin p-layer so that most of the light energy reaches the junction area.

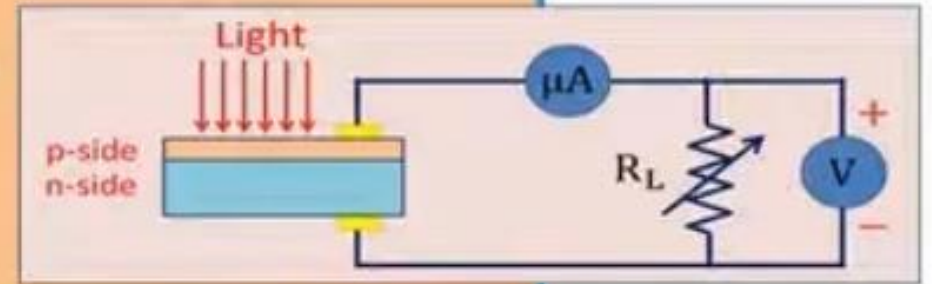
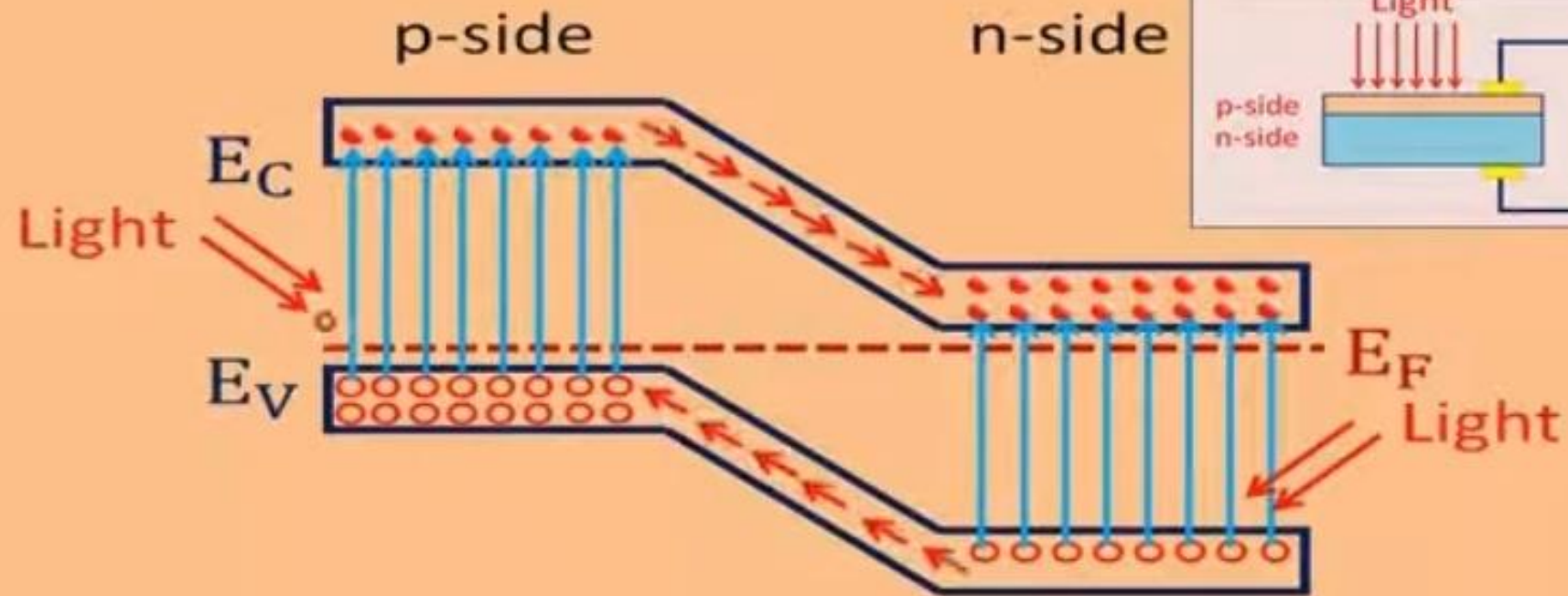


## Solar Cell (Photovoltaic Cell)





## Solar Cell (Photovoltaic Cell)



Electron Hole pair generation in solar Cell

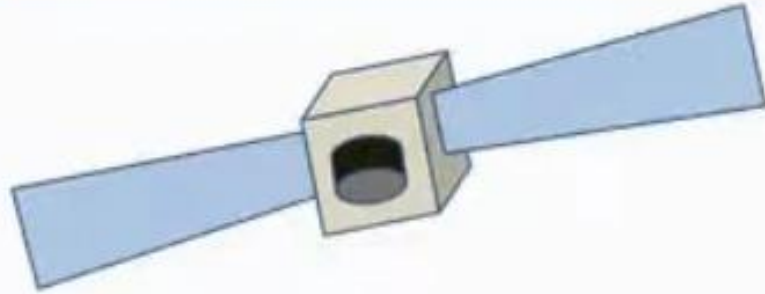
## Materials Used in Solar Cell

- ❑ The materials which are used for this purpose must have band gap close to 1.5ev.  
Commonly used materials are-
- ❑ Silicon.
- ❑ GaAs.
- ❑ CdTe.
- ❑ CuInSe<sub>2</sub>

## Criteria for Materials to be Used in Solar Cell

- ❑ Must have band gap from 1ev to 1.8ev.
- ❑ It must have high optical absorption.
- ❑ It must have high electrical conductivity.
- ❑ The raw material must be available in abundance and the cost of the material must be low.

# Applications of Solar Cell (Photovoltaic Cell)



- Used in satellites, space vehicles and at remote places as a source of energy.
- Used in battery charging system, outdoor lighting systems.
- Used in low power consumption electronic equipments like calculator.
- Pollution free source of energy.
- Maintenance free and cost effective in long run.

# What is Photodiode ?

**A photodiode is a semiconductor device that converts lights into current.**



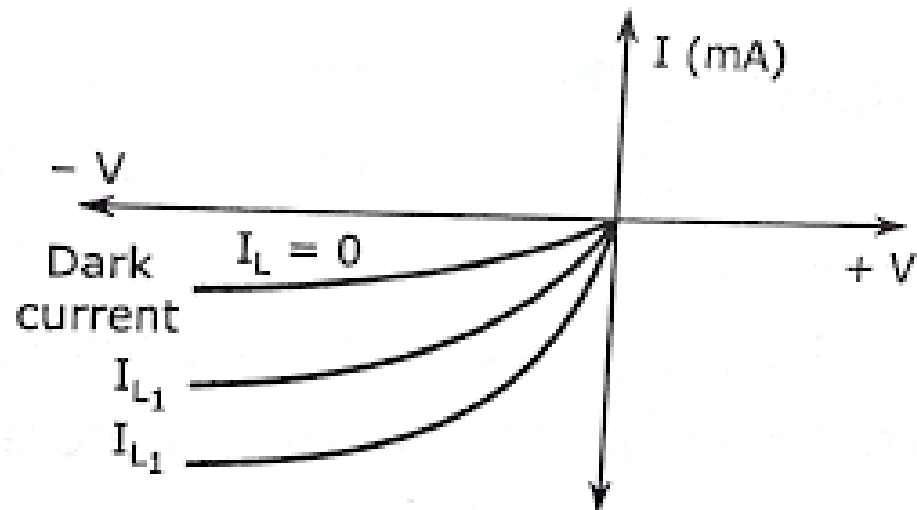
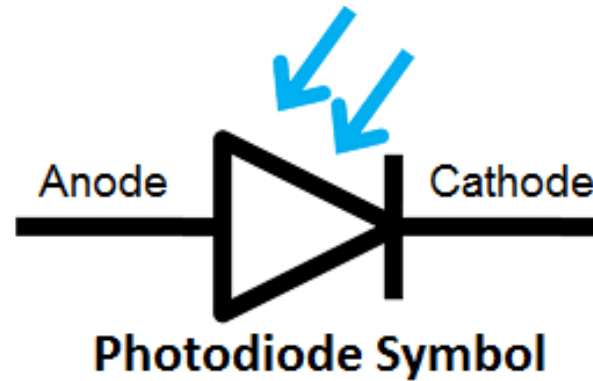
Photodiode

Infrared LED

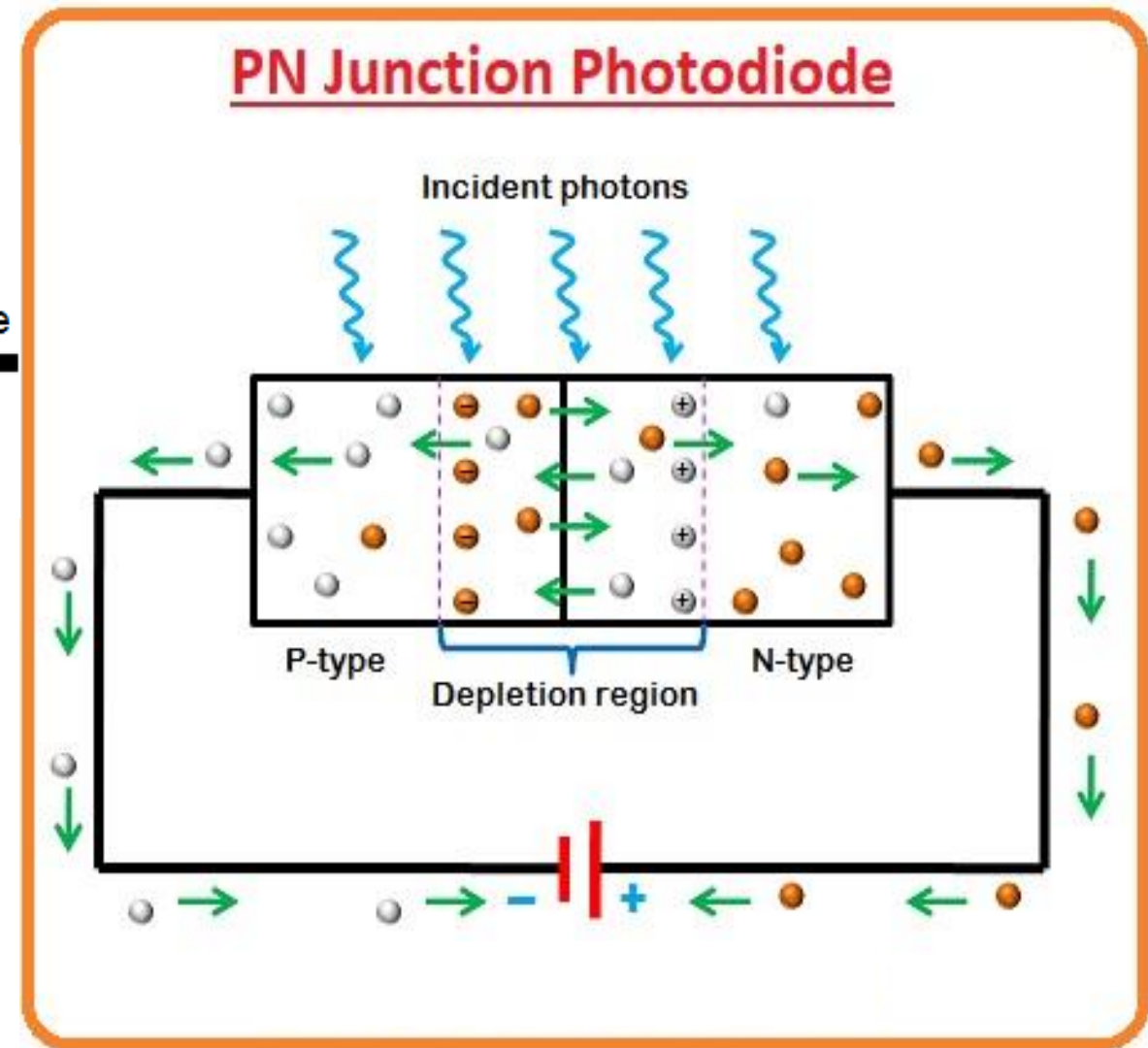


# Photodiode

- ✓ A photodiode is a semiconductor device with a P-N junction that converts photons (or light) into electrical current.
- ✓ Operated in reverse bias
- ✓ Acts as a detector of light



(b) I - V characteristic



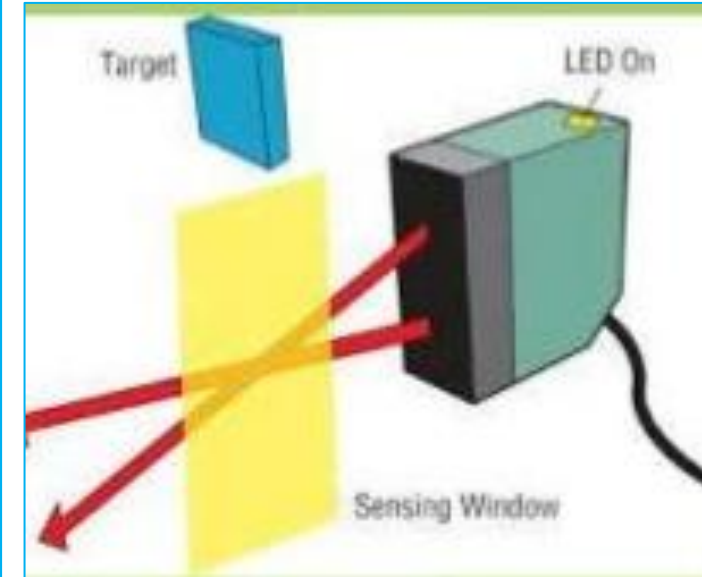
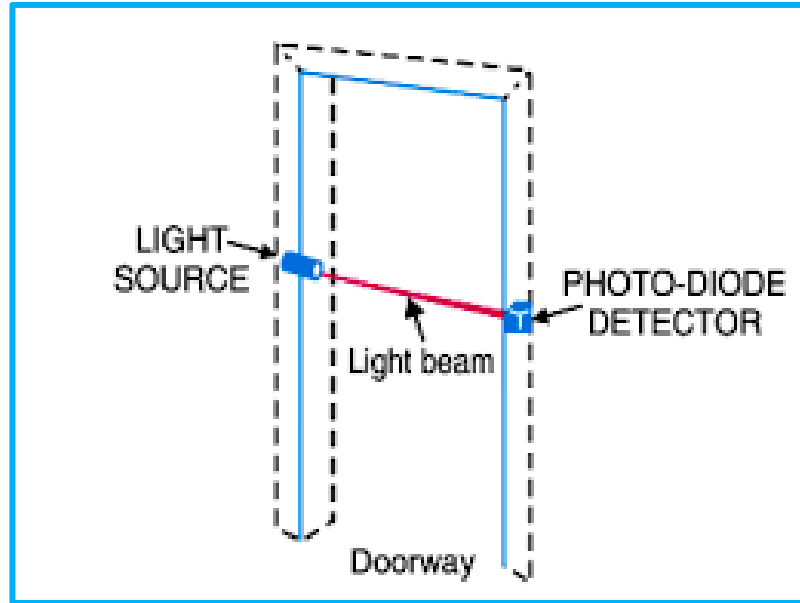
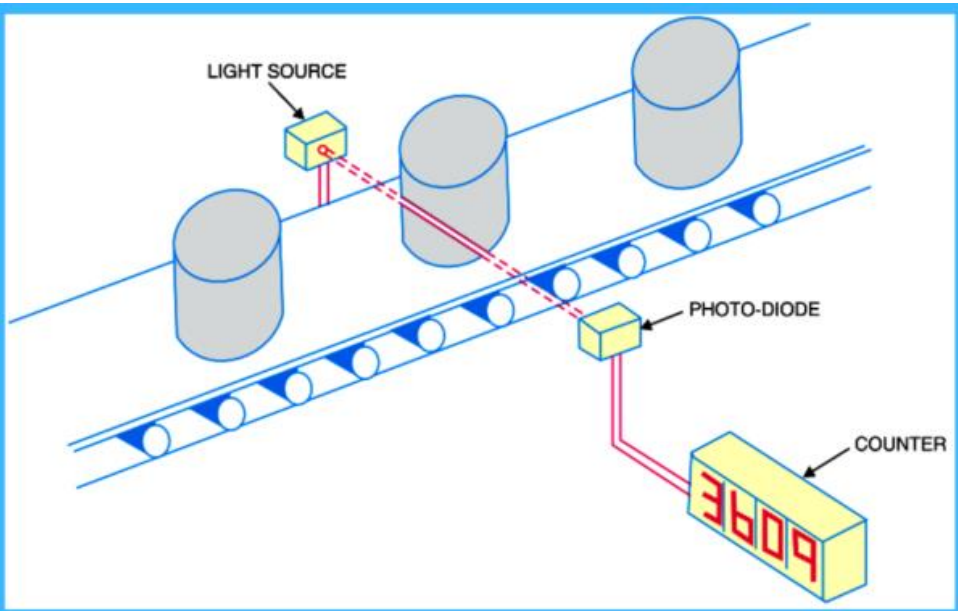
# Photodiode Working

A photodiode is subjected to photons in the form of light which affects the generation of electron-hole pairs. If the energy of the falling photons ( $h\nu$ ) is greater than the energy gap ( $E_g$ ) of the semiconductor material, electron-hole pairs are created near the depletion region of the diode. The electron-hole pairs created are separated from each other before recombining due to the electric field of the junction. The direction of the electric field in the diode forces the electrons to move towards the n – side and consequently the holes move towards the p-side. As a result of the increase in the number of electrons on the n – side and holes on the p-side, a rise in the electromotive force is observed. Now when an external load is connected to the system, a current flow is observed through it.

The more the electromotive force created, the greater is the current flow. The magnitude of the electromotive force created depends directly upon the intensity of the incident light. This effect of the proportional change in photocurrent with the change in light intensity can be easily observed by applying a reverse bias.

Since photodiodes generate current flow directly depending upon the light intensity received, they can be used as photodetectors to detect optical signals. Built-in lenses and optical filters may be used to enhance the power and productivity of a photodiode.

# Photodiode applications

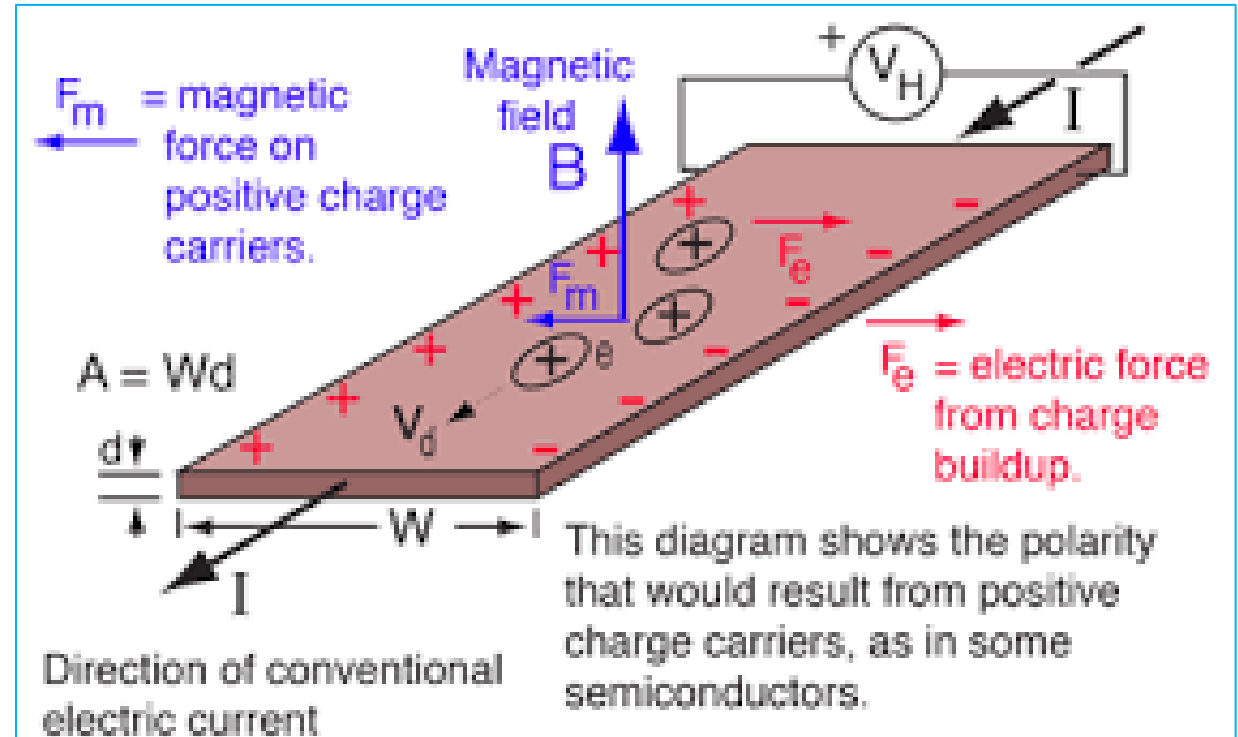
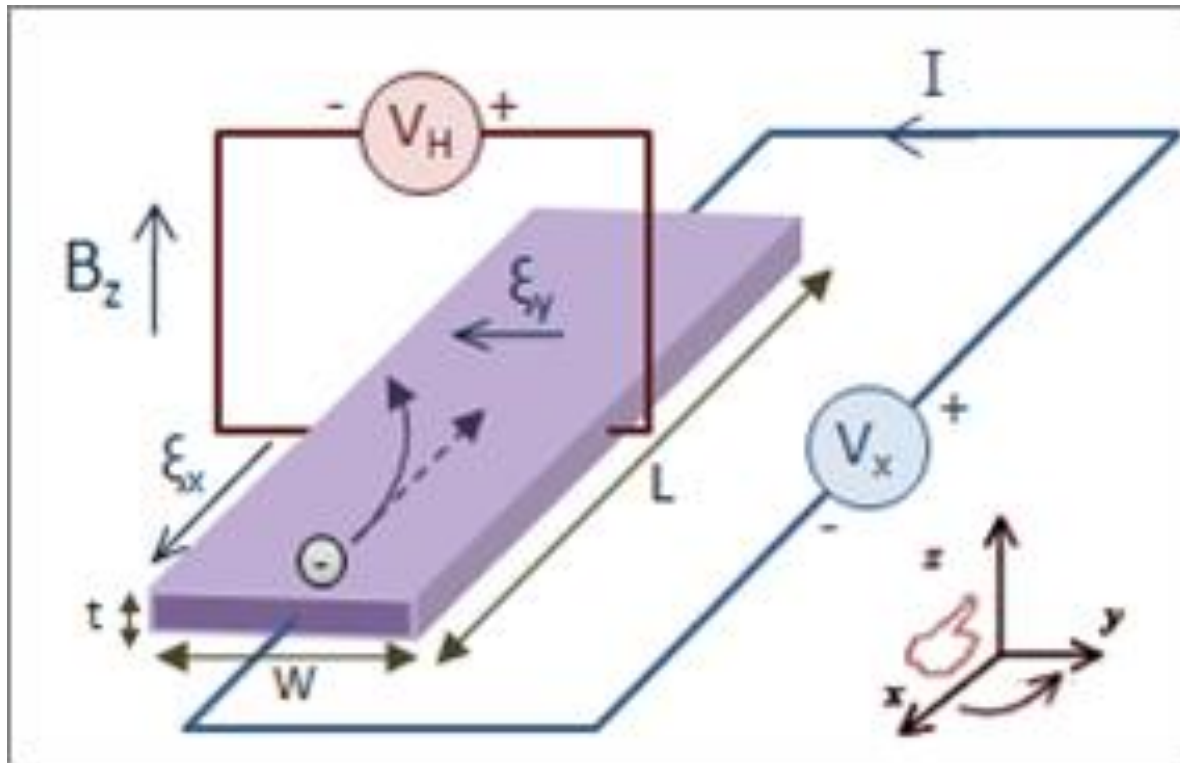


- Photo diodes are used as photo detectors.
- Photo diodes are used in cameras as photo sensors, Slotted optical switch, in scintillators e.t.c.
- Photo diodes are used in consumer electronics.

# Hall Effect (Edwin H. Hall, 1879)

## Principle of Hall Effect

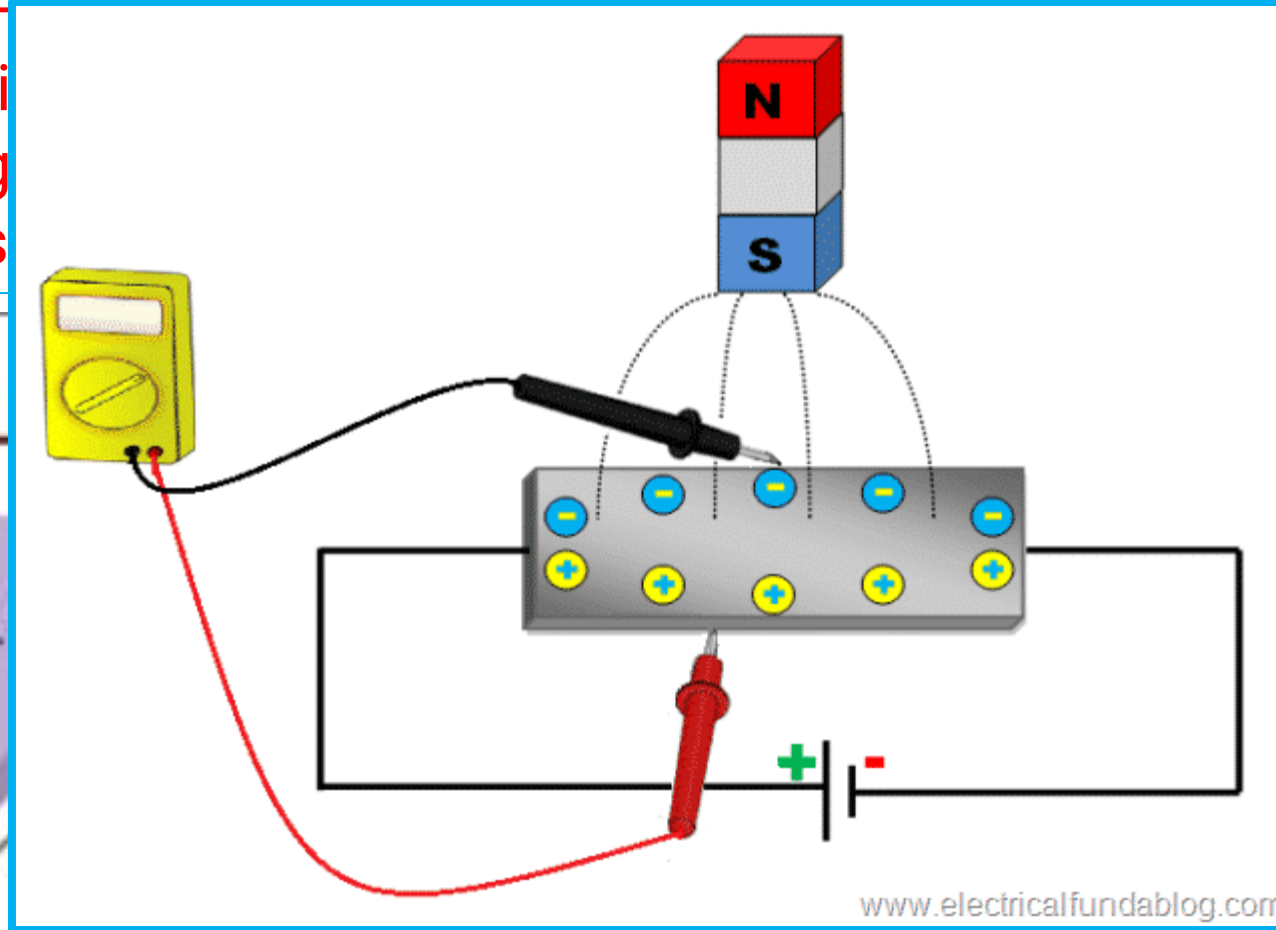
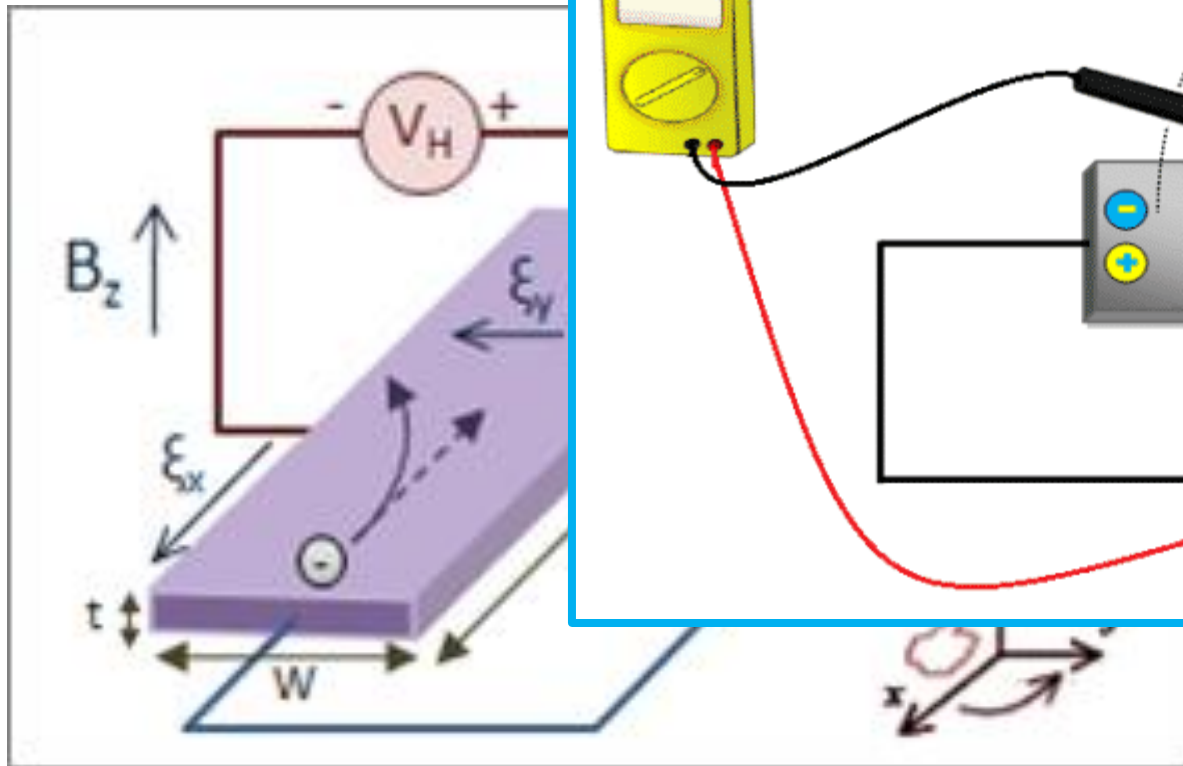
The principle of Hall Effect states that when a current-carrying conductor or a semiconductor is introduced to a perpendicular magnetic field, a voltage can be measured at the right angle to the current path. This effect of obtaining a measurable voltage is known as the Hall Effect.



# Hall Effect (Edwin H. Hall, 1879)

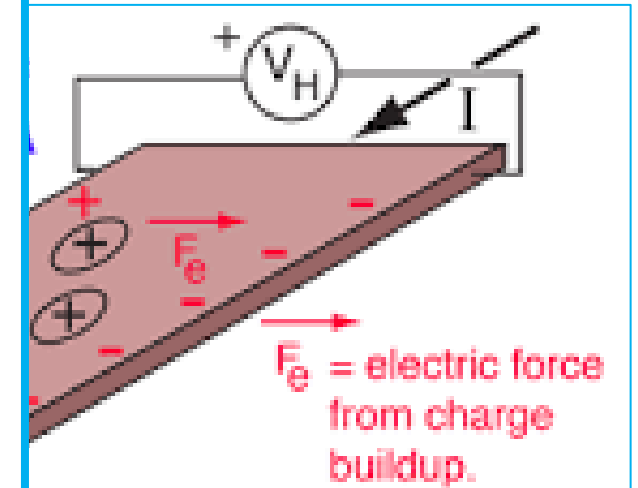
## Principle of Hall Effect

The principle of Hall Effect is that when a current carrying conductor or a semiconductor is placed in a magnetic field, a voltage can be obtained across it. This voltage is known as Hall voltage.



[www.electricalfundablog.com](http://www.electricalfundablog.com)

Direction of conventional electric current



This diagram shows the polarity of the Hall voltage. The positive terminal of the Hall voltage would result from positive charge carriers, as in some semiconductors.

The Hall voltage represented as  $V_H$  is given by the formula:

$$V_H = \frac{IB}{qnd}$$

$I$  is the current flowing through the sensor

$B$  is the magnetic Field Strength

$q$  is the charge

$n$  is the number of charge carriers per unit volume

$d$  is the thickness of the sensor.

The Hall Coefficient  $R_H$  is mathematically expressed as

$$R_H = \frac{E}{jB} \text{ (m}^3\text{/C)}$$

$j$  is the current density of the carrier electron,

The hall coefficient is positive if the number of positive charges is more than the negative charges. Similarly, it is negative when electrons are more than holes.

**Carrier concentration**  $n = \frac{1}{eR_H} \text{ (m}^{-3}\text{)}$



# Hall Effect applications

Hall Effect Principle is used in:

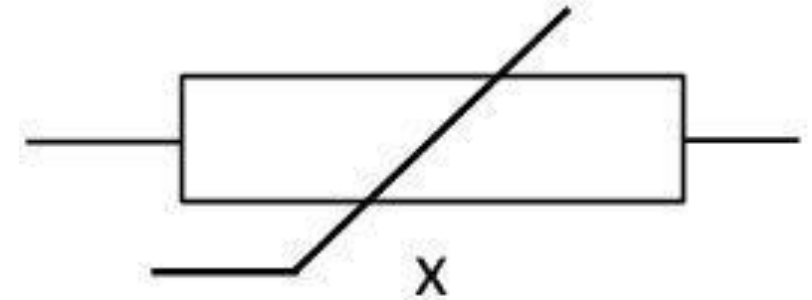
- ✓ Magnetic field sensing equipment.
- ✓ Multiplier applications to provide actual multiplications.
- ✓ Phase angle measurement. For Example – in measuring angular position of the crank shaft to accurately align with the firing angle of the spark plugs
- ✓ Linear or Angular displacement transducers. For example – to identify the position of the car seats and seat belts and act as an interlock for air-bag control.
- ✓ Proximity detectors.
- ✓ Hall Effect Sensors and Probes
- ✓ For detecting wheel speed and accordingly assist anti-lock braking system (ABS).

**Hall effect can be used to identify type of Semiconductor used?**

# Magnetoresistance

The **resistance** of some of the **metal and the semiconductor material** **varies** in the **presence** of the **magnetic field**, this effect is called the magnetoresistance. The **element** which has **these effects** is known as the **magnetoresistor**.

The magnetoresistor is used for determining the presence of a magnetic field their strength and the direction of the force. **It is made of the indium antimonide or indium arsenide semiconductor material.**

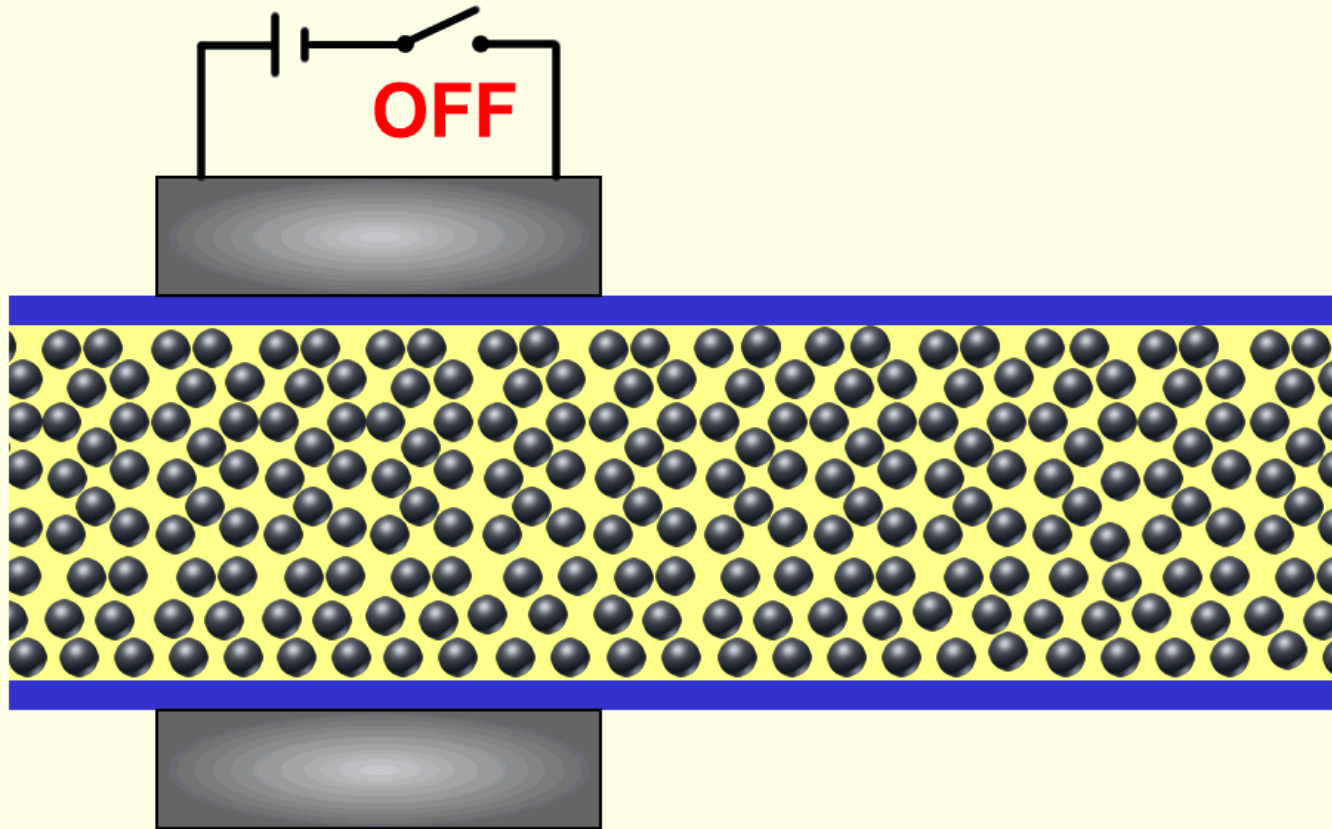


Magnetoresistors

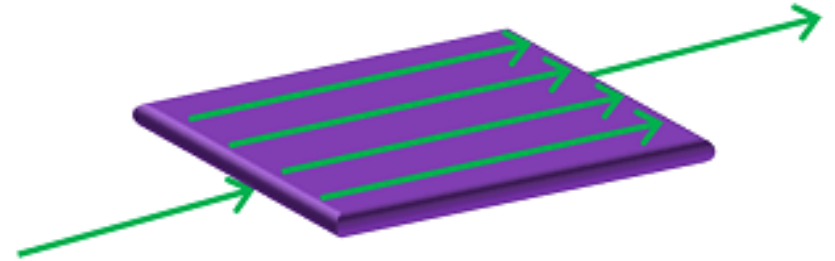
The magnetoresistor operates without physical contacts which is their major advantage. The magnetoresistor has various applications like it is used in the hard disk of the computer, an electronic compass, for measuring the current



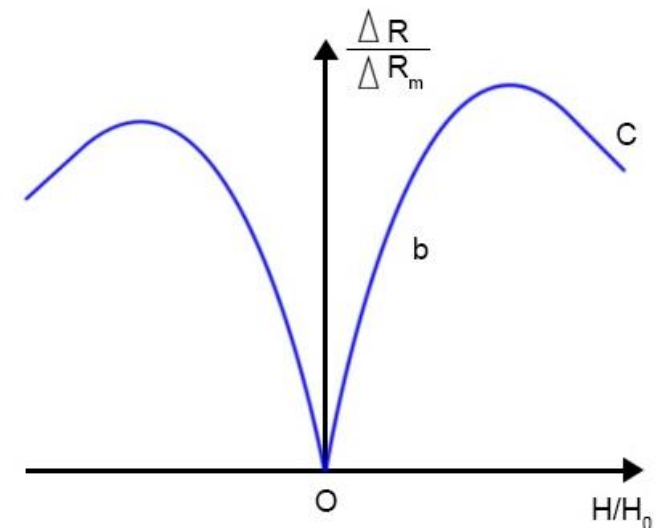
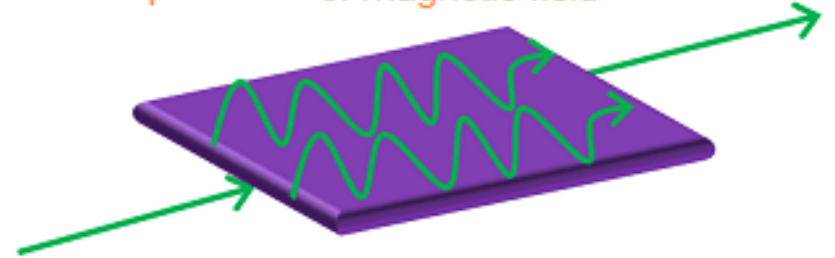
# Magnetoresistance – How does it work?



Electric current path in the absence of magnetic field



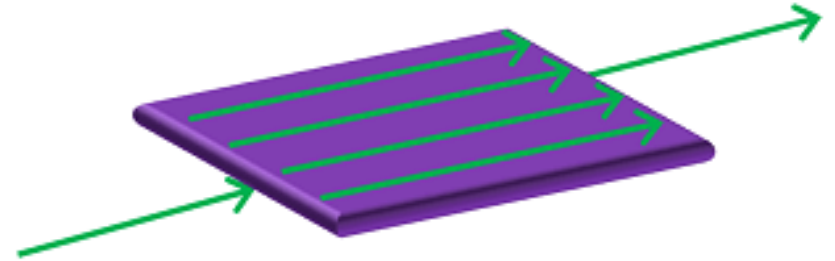
Electric current path in the presence of magnetic field



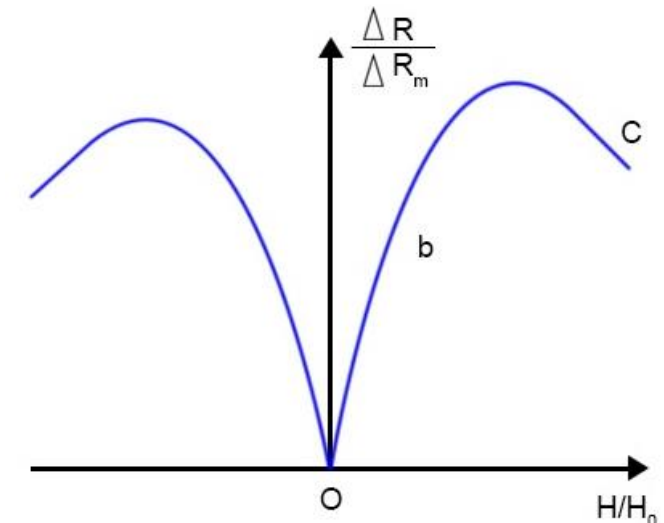
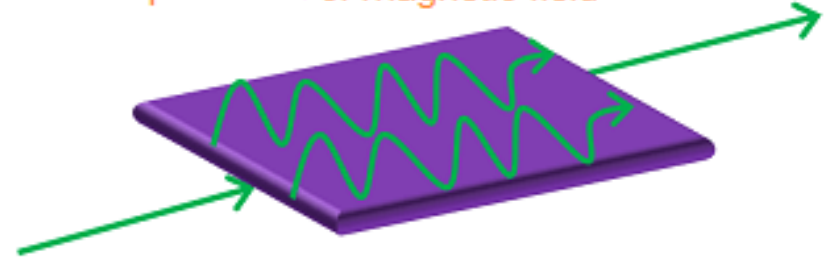
# Magnetoresistance – How does it work?

- ❑ In the absence of magnetic field, the charges carriers in the material move in a straight path. Therefore, electric current flows in a straight path.
- ❑ When the magnetic field is applied to the material, the magnetic forces cause the mobile charge carriers (free electrons) to change their direction from direct path to indirect path. This increases the length of electric current path.
- ❑ Hence, large number of free electrons collides with the atoms and loses their energy in the form of heat and only a small number of free electrons flow through the conductive path. The small number of free electrons moving from one place to another place carries the electric current. **Therefore, the resistance of the material increases with increasing magnetic field.**

Electric current path in the absence of magnetic field



Electric current path in the presence of magnetic field



## Magneto Resistor – Uses and Applications

- ❑ Magneto resistors find a good use in **magnetic field sensing devices**. Some of them include, electromagnetic compass, magnetometers which measure magnetic field intensity and direction, position sensors and ferrous metal detection.
- ❑ Position sensors can be angle, rotary or linear position sensors.
- ❑ They also have very much use in bio sensors and hard disk drives.



## Quiz 10, 11

15<sup>th</sup> Feb 2022 (Tuesday)

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- Unit 5

## Mid 3, Quiz 12

17-18<sup>th</sup> Feb 2022 (Thursday, Friday)

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- Unit 5 (Quiz 12)
- Mid 3 (Unit 4 and 5)

## Assignment 2

Before 20<sup>th</sup> Feb 2022

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- Shorts answers and numerical problems