Introduction

This is a learning as well as an exam preparation video.

At the end of the video are practice assignments for you to attempt.

Please go to www.eastpoint.intemass.com/ or click on the link at the bottom of this video to do the assignments for this topic.

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Chapter 14: Semiconductor Electronics

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Classification of Metals:

On the basis of the relative values of electrical conductivity (σ) or resistivity $\left(\rho = \frac{1}{\sigma}\right)$,

the solids are broadly classified as:

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Classification of Metals:

Metals:

They possess very low resistivity (or high conductivity).

$$\rho \sim 10^{-2} - 10^{-8}\,\Omega\,\text{m}$$

$$\sigma \sim 10^{2} - 10^{8}\,\text{S m}^{-1}$$

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Classification of Metals:

Semiconductors:

They have resistivity or conductivity intermediate to metals and insulators.

$$\rho \sim 10^{-5} - 10^{6}\,\Omega\text{ m}$$

$$\sigma \sim 10^{5} - 10^{6}\,\text{S m}_{-1}$$

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Classification of Metals:

Insulators:

They have high resistivity (or low conductivity).

$$\rho \sim 10^{11} - 10^{19} \Omega \text{ m}$$

$$\sigma \sim 10^{-11} - 10^{-19} \text{S m}_{-1}$$

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Classification of Metals on the Basis of Energy Bands:

When the atoms come together to form a solid they are so close to each other that the fields of electrons of outer orbits from neighboring atoms overlap. This makes the nature of electron motion in a solid very different from that in an isolated atom. Inside the solid, each electron has a unique position, and no two electrons have same pattern of surrounding charges.

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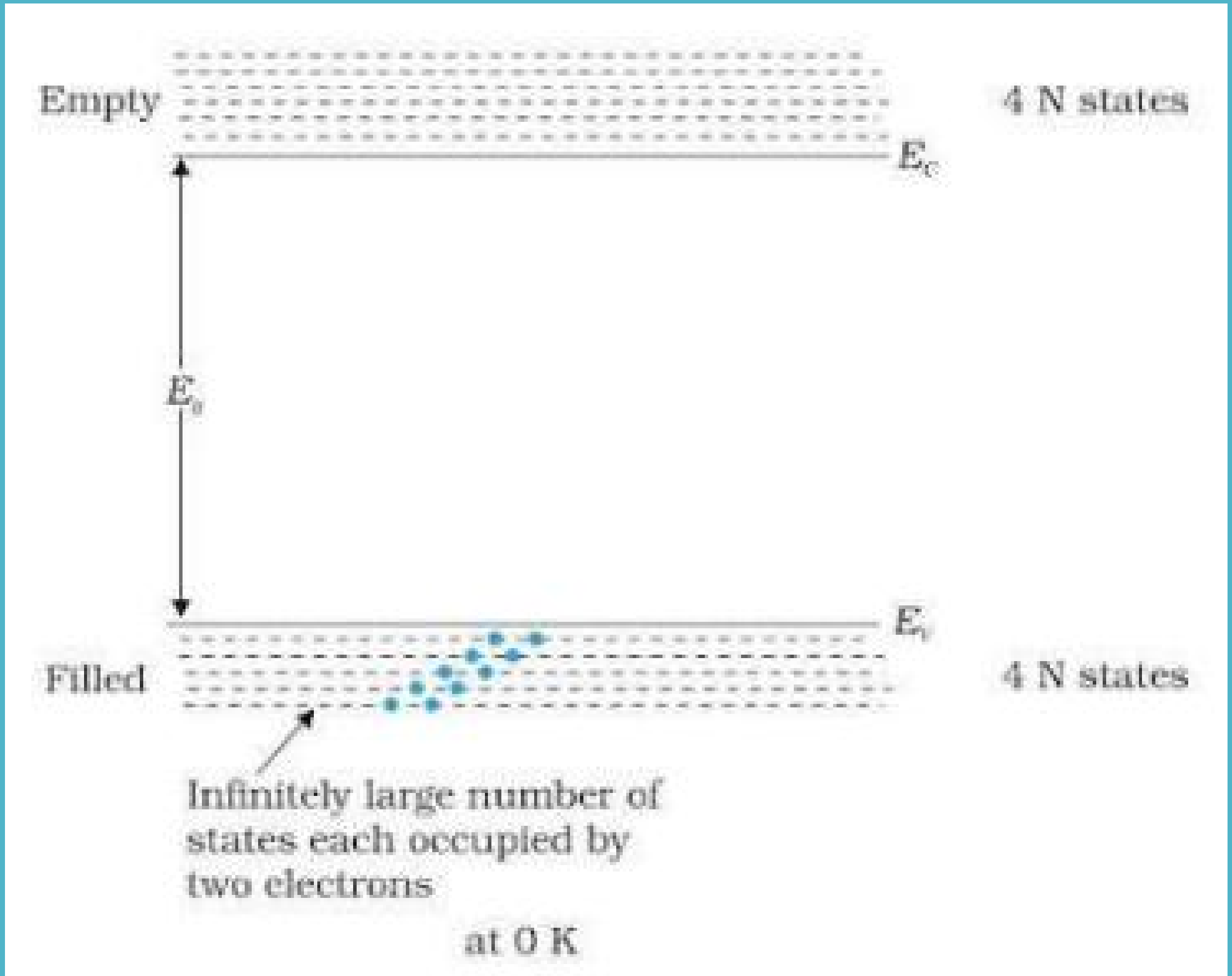
Classification of Metals on the Basis of Energy Bands:



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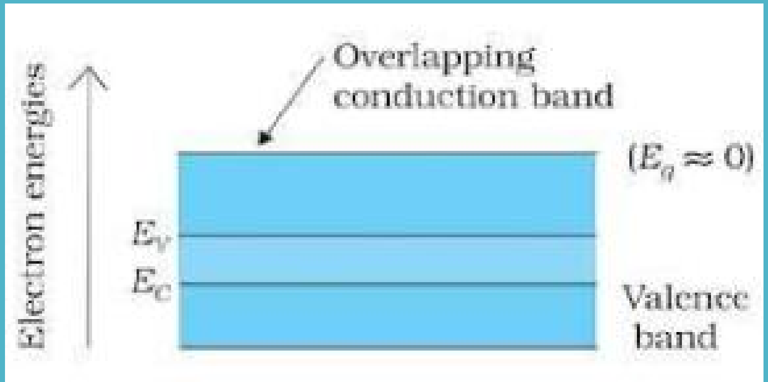
Metals:

In metals, conduction band and valence band are overlapped to each other. The electrons from the valence band can easily move into the conduction band. Normally, the conduction band is empty but when it overlaps on the valence band, electrons can move freely into it, and it conducts electric current through it.



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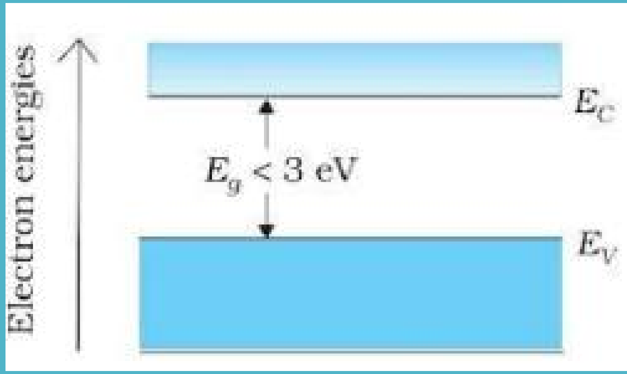
Semiconductors:

Semiconductors are the core fundamental materials which are used in solid-state electronic devices such as transistors, diodes etc. The material's atomic structure decides whether the material will turn out to be a metal, semiconductor, or insulator. Semiconductors could also be elements such as Ge, Si or compounds such as CdS or GaAs.



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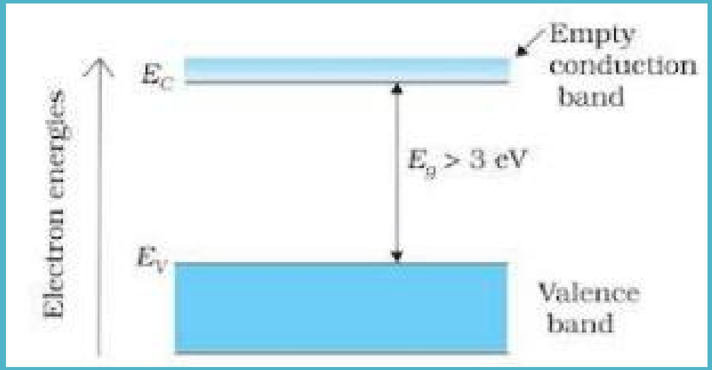
Insulators:

In semiconductors, a small and finite energy band gap exists. Because of the small energy band gap some electrons from valence band, at room temperature, acquire enough energy to cross the energy gap and enter the conduction band. These electrons are very few and can move in the conduction band. Hence, the resistance of semiconductors is not as high as that of the insulators.



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Intrinsic Semiconductor:

The pure semiconductors in which the electrical conductivity is totally governed by the electrons excited from the valence band to the conduction band and in which no impurity atoms are added to increase their conductivity are called intrinsic semiconductors and their conductivity is called intrinsic conductivity. Electrical conduction in pure semiconductors occurs by means of electron-hole pairs. In an intrinsic semiconductor,

$$n_e = n_h = n_i$$

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Intrinsic Semiconductor:

where ne = the free electron density in conduction band, nh = the hole density in valence band, and ni = the intrinsic carrier concentration.

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Extrinsic Semiconductors:

A Semiconductor doped with suitable impurity atoms so as to increase its conductivity is called

an extrinsic semiconductor.

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Types of Semiconductor:

Extrinsic semiconductors are basically of two types:

1. n-type semiconductors
2. p-type semiconductors:

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Types of Semiconductor:

n-type semiconductors:

The pentavalent impurity atoms are called donors because they donate electrons to the host crystal and the semiconductor doped with donors is called n-type semiconductor. In n-type semiconductors, electrons are the majority charge carriers and holes are the minority charge carriers. Thus, $n_e \gg n_h$

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Types of Semiconductor:

p-type semiconductors:

The trivalent impurity atoms are called acceptors because they create holes which can accept electrons from the nearby bonds. A semiconductor doped with acceptor type impurities is called a p-type semiconductor. In p-type semiconductor, holes are the majority carriers and electrons are the minority charge carriers Thus,

$$n_h \gg n_e$$

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Diode:

Diodes are being for the purpose of AC voltage rectification which means restricting the voltage to follow one direction only using a capacitor or a filter, a dc voltage can be achieved.

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The types of diodes are:

Zener Diode:

This is used in places where voltage regulation is needed.

P-N junction diode:

It is used in photonic or optoelectronic devices and the entity is the photon.

Examples are solar cells, light-emitting diodes etc.

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The types of diodes are:

Holes:

The vacancy or absence of electron in the bond of a covalently bonded crystal is called a hole. A hole serves as a positive charge carrier.

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The types of diodes are:

p-n Junction Formation:

In the n-region of a p-n junction, the concentration of free electrons is higher than that of holes, whereas in the p-region, the concentration of holes is much higher than that of free electrons. Therefore, when a p-n junction is formed, some electrons from the n-region will diffuse into the p-region. Since the hole is nothing but the vacancy of an electron, an electron diffusing from the n- to the p-region simply fills this vacancy, i.e., it completes the covalent bond. This process is called electron-hole recombination.

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The types of diodes are:

Semiconductor Diode:

A semiconductor diode is basically a p-n junction with metallic contacts provided at the ends for the application of an external voltage. The symbol for the simplest electronic device, namely the p-n junction is shown as. The direction of the thick arrow is from the p to the n-region. The pside is called the anode and the n-side is known as the cathode.

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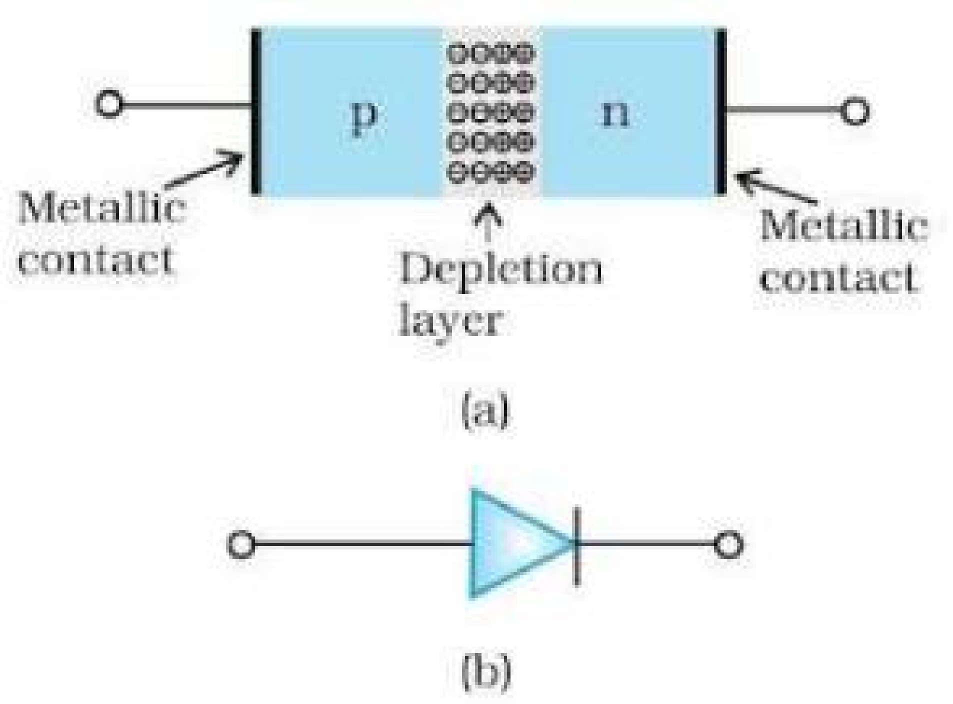
The types of diodes are:

Semiconductor Diode:



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The types of diodes are:

Forward Biasing of a pn-junction:

If the positive terminal of a battery is connected to the p-side and the negative terminal to the nside, then the pn-junction is said to be forward biased. Both electrons and holes move towards the junction. A current, called forward current, flows across the junction. Thus, a pn-junction offers a low resistance when it is forward biased.

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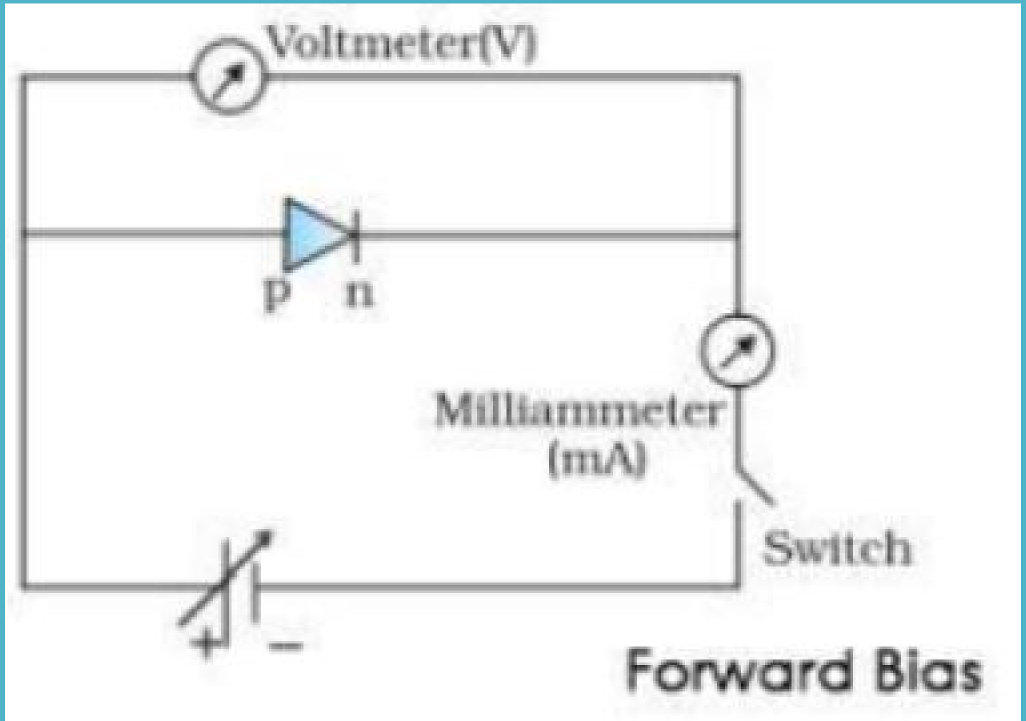
The types of diodes are:

Forward Biasing of a pn-junction:



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The types of diodes are:

Reverse Biasing of a pn-junction:

If the positive terminal of a battery is connected to the n-side and negative terminal to the pside, then pn-junction is said to be reverse biased. The majority charge carriers move away from the junction. The potential barrier offers high resistance during the reverse bias. However, due to the minority charge carriers a small current, called reverse or leakage current flows in the opposite direction. Thus, junction diode has almost a unidirectional flow of current.

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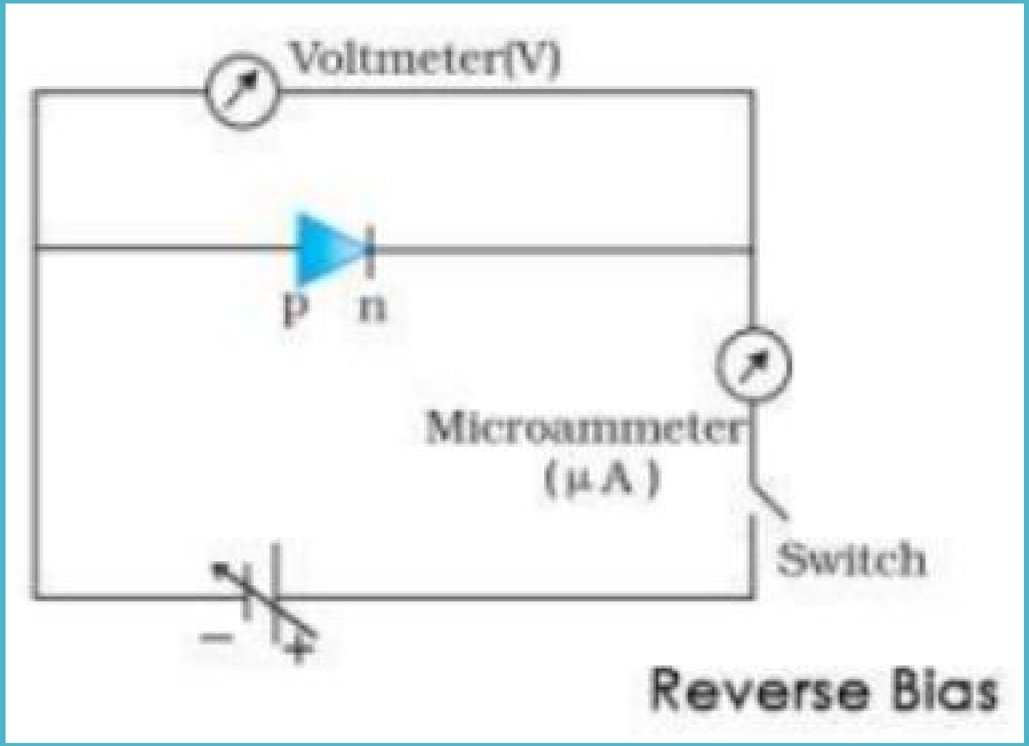
The types of diodes are:

Reverse Biasing of a pn-junction:



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The types of diodes are:

Characteristics of Junction Diode:

With increasing forward bias, the current first increases non-linearly up to a certain forwardbiased voltage called knee voltage or cut-in voltage and beyond which the current varies nonlinearly.

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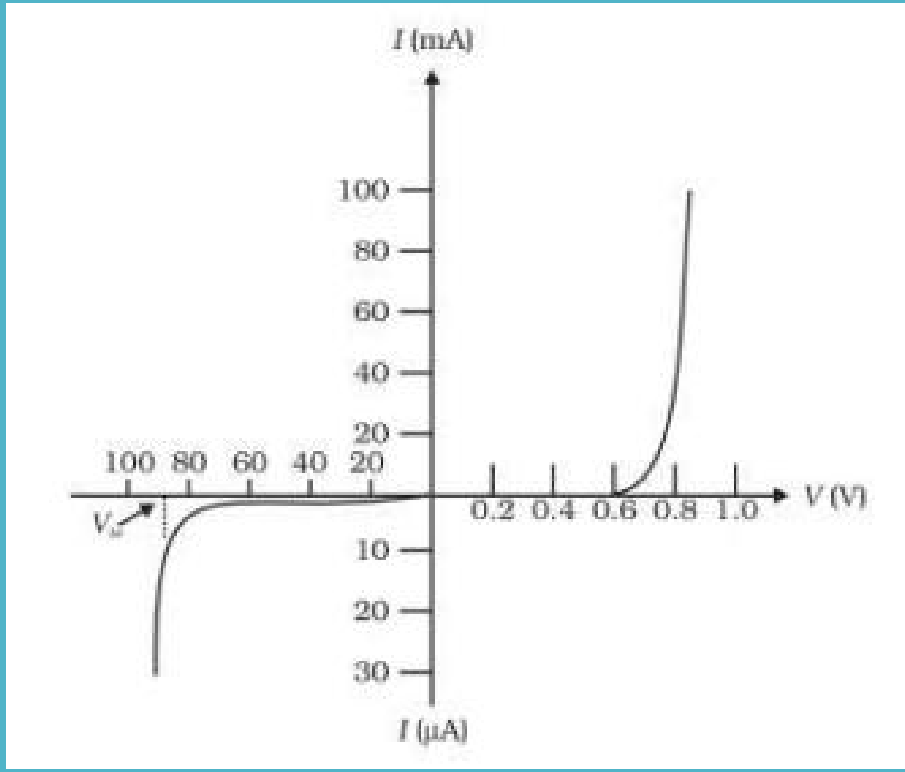
The types of diodes are:

Characteristics of Junction Diode:



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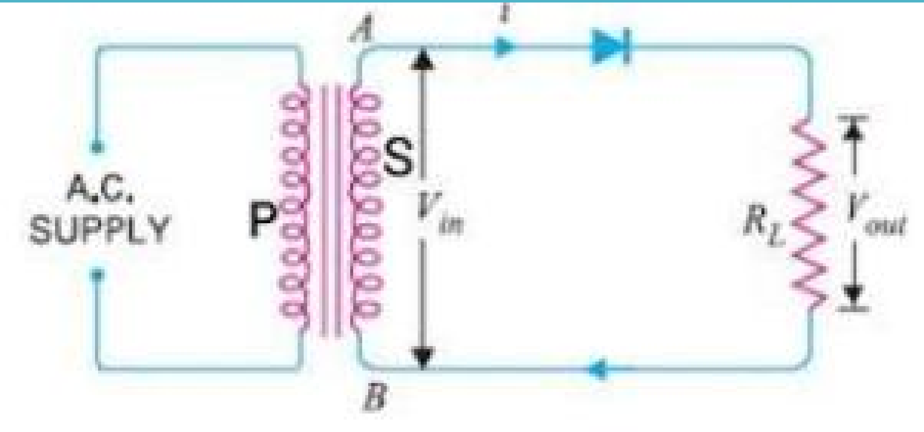
Diode as Rectifier:

The process of converting alternating voltage/ current into direct voltage/ current is called rectification. Diode is used as a rectifier for converting alternating current/ voltage into direct current/ voltage.

There are two ways of using a diode as a rectifier i.e.



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Half-wave Rectifier:

Let during the first half of AC input cycle, the end A of secondary S of transformer be at positive potential and end B at the negative potential. In this situation, the diode is forward biased and a current flow in the circuit. Consequently, an output voltage across load RL is obtained.

During the second half of AC input, the end A of secondary S of transformer is at negative potential and diode D is in reverse bias. So, no current flows through load RL and there is no output voltage across RL.

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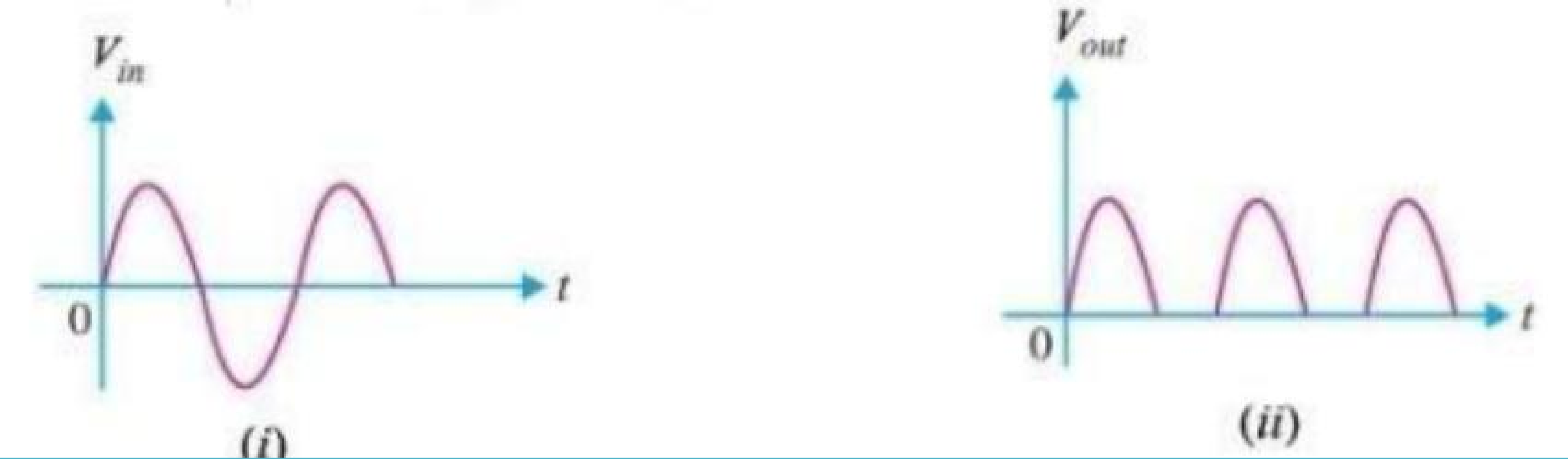
Half-wave Rectifier:



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Half-wave Rectifier:

In the next positive half-cycle of AC input, we again get the output and so on. Thus, we get output voltage as shown in Fig. Here, the output voltage, though still varying in magnitude, is restricted to only one direction, and is said to be rectified. Since, the rectified output of the circuit is obtained only for half of the input AC wave, the device is called half-wave rectifier.

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Full-wave rectifier:

During the first half cycle of the input voltage, the terminal A is positive with respect to O while B is negative with respect to O. Diode first is forward bias and conducts while diode second is reverse bias and does not conduct, the current flow through RL from D To O. During the second half cycle, A is negative, and B is positive with respect to O, thus diode first is reverse bias and diode second is forward biased. The current through RL is in the same direction as during the first half cycle. The resulting output current is a continuous series.

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Full-wave rectifier:

As we are getting output in positive half as well as negative half of AC input cycle, the rectifier is called a full wave rectifier. Obviously, this is a more efficient circuit for getting rectified voltage or current than a half wave rectifier.

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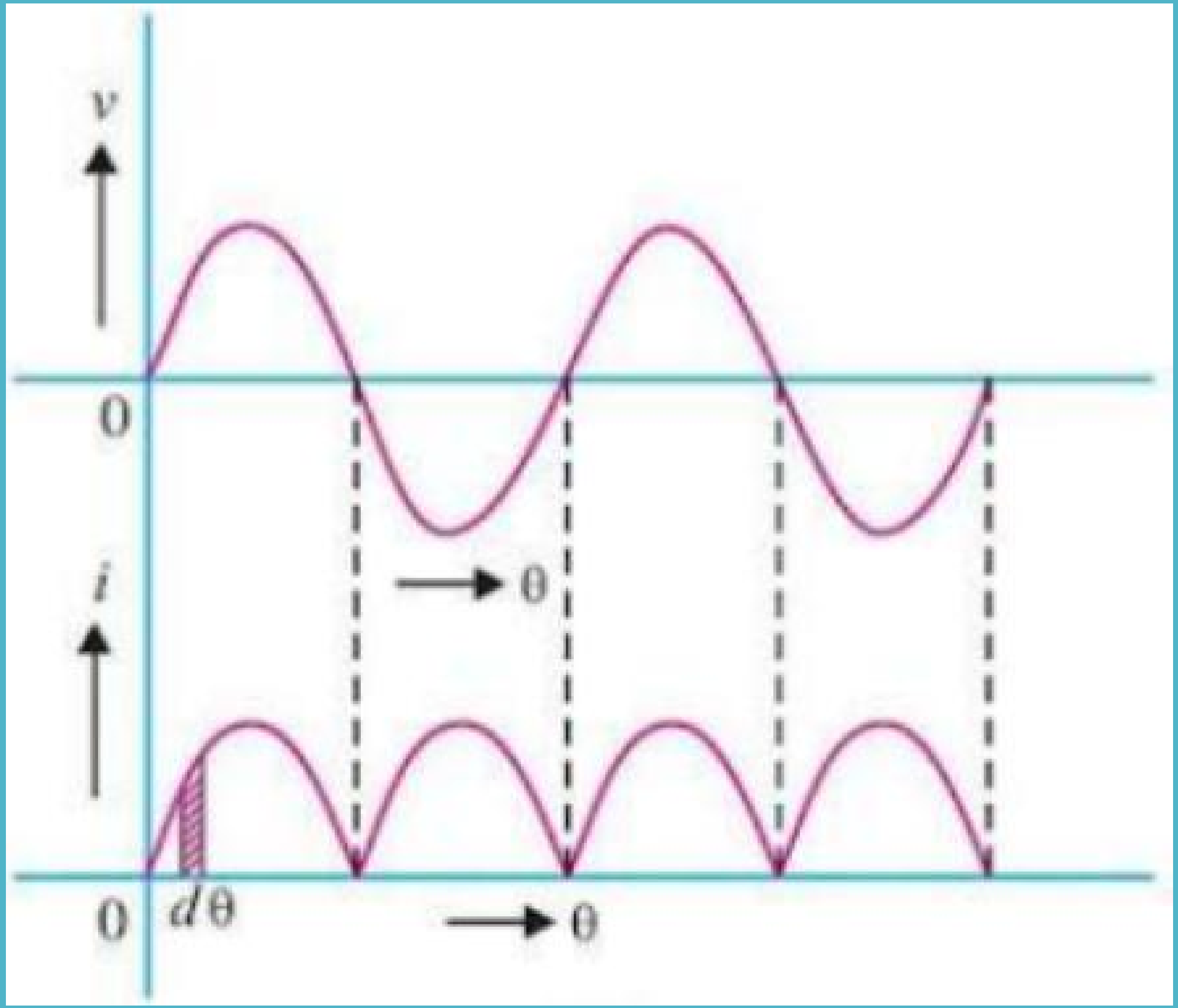
Full-wave rectifier:



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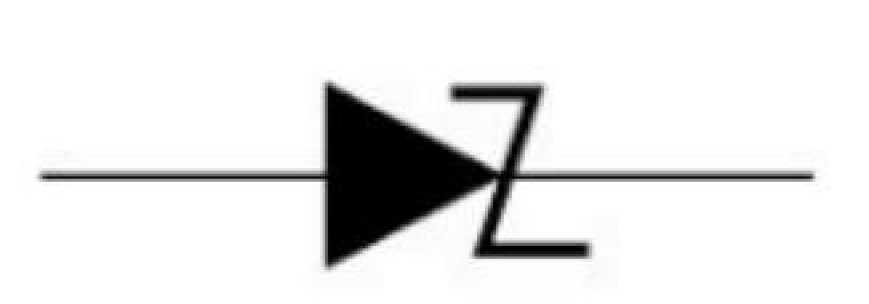
Zener diode:

The specially designed junction diodes which can operate in the reverse breakdown voltage region continuously without being damaged, are called Zener diodes.



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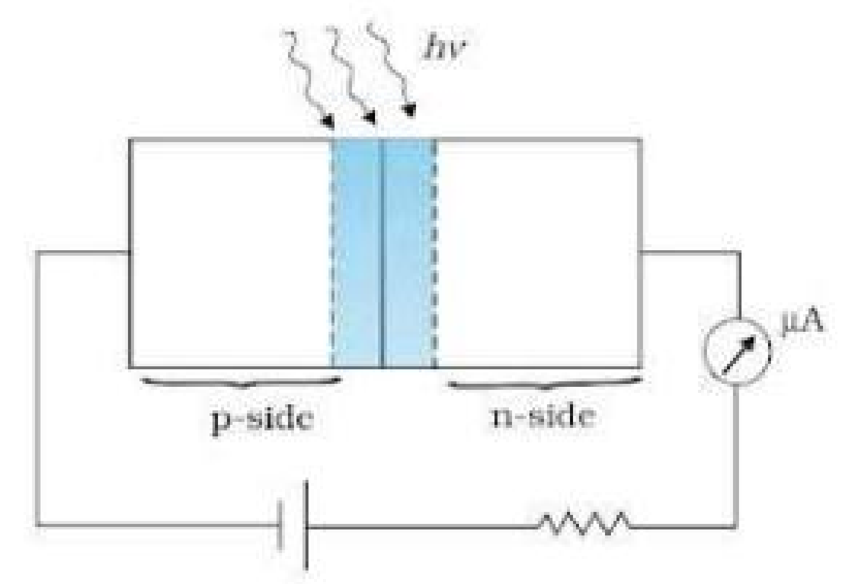
Photodiode:

A junction diode made from photosensitive semiconductor is called a photodiode. In photodiode one region is made so thin that incident light may reach the depletion region.



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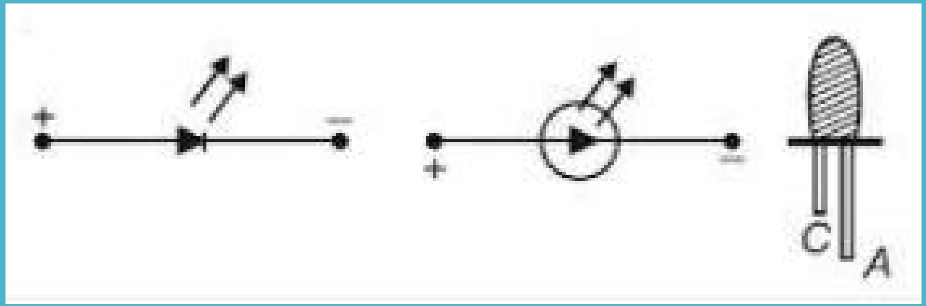
Light-Emitting Diode (LED):

Light-emitting diode is a heavily doped p-n junction encapsulated with a transparent cover so that emitted light can come out. When the forward current of the diode is small the intensity of light emitted is small. As the forward current increases, intensity of light increases and reaches a maximum.



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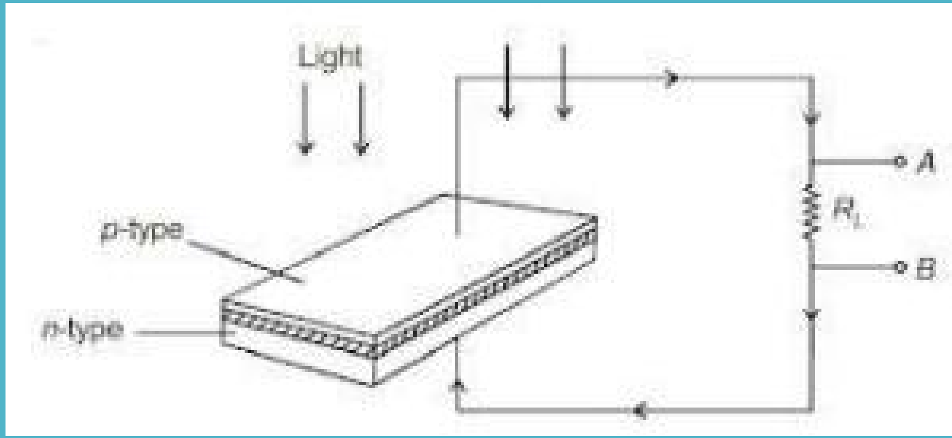
Solar cell:

In a solar cell, one region is made very thin so that most of the light incident on it reaches the depletion region. In this diode when photons of visible light incident to depletion region, electrons jump from valence band to conduction band producing electron-hole pairs.



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Action of a transistor:

When the emitter-base junction of an n-p-n-transistor is forward biased, the electrons are pushed towards the base. As the base region is very thin and lightly doped, most of the electrons cross over to the reverse biased collector. Since few electrons and holes always recombine in the base region, so the collector current Ic is always slightly less then emitter current IE.

$$I_E = I_C + I_B$$

Where IB is the base current.

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Digital Electronics and Logic Gates:

There are three basic logic gates:

(i) OR gate
(ii) AND gate, and
(iii) NOT gate.

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Digital Electronics and Logic Gates:

NOT Gate:

This is the most basic gate, with one input and one output. It produces an inverted version of the input at its output i.e., it produces a ‘1’ output if the input is ‘0’ and vice versa. This is why it is also known as an inverter.

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Digital Electronics and Logic Gates:

AND gate:

An AND gate can have any number of inputs but only one output. It gives a high output (1) if inputs A and B are both high (1), or else the output is low (0). It is described by the Boolean expression.

$A.B = Y$

Which is read as ‘A and B equals Y.

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Digital Electronics and Logic Gates:

Combination of Gates:

The NAND gate:

If the output Y' of AND gate is connected to the input of NOT gate, the gate so obtained is called NAND gate. Boolean expression for the NAND gate is $Y = \overline{A.B}$

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Digital Electronics and Logic Gates:

The NOR gate:

If the output (Y') of OR gate is connected to the input of a NOT gate, the gate so obtained is called the NOR gate. Boolean expression for the NOR gate is $Y = \overline{A + B}$.

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Digital Electronics and Logic Gates:

Integrated Circuits:

The concept of fabricating an entire circuit (consisting of many passive components like R and C and active devices like diode and transistor) on a small single block (or chip) of a semiconductor has revolutionized the electronics technology. Such a circuit is known as Integrated Circuit (IC).

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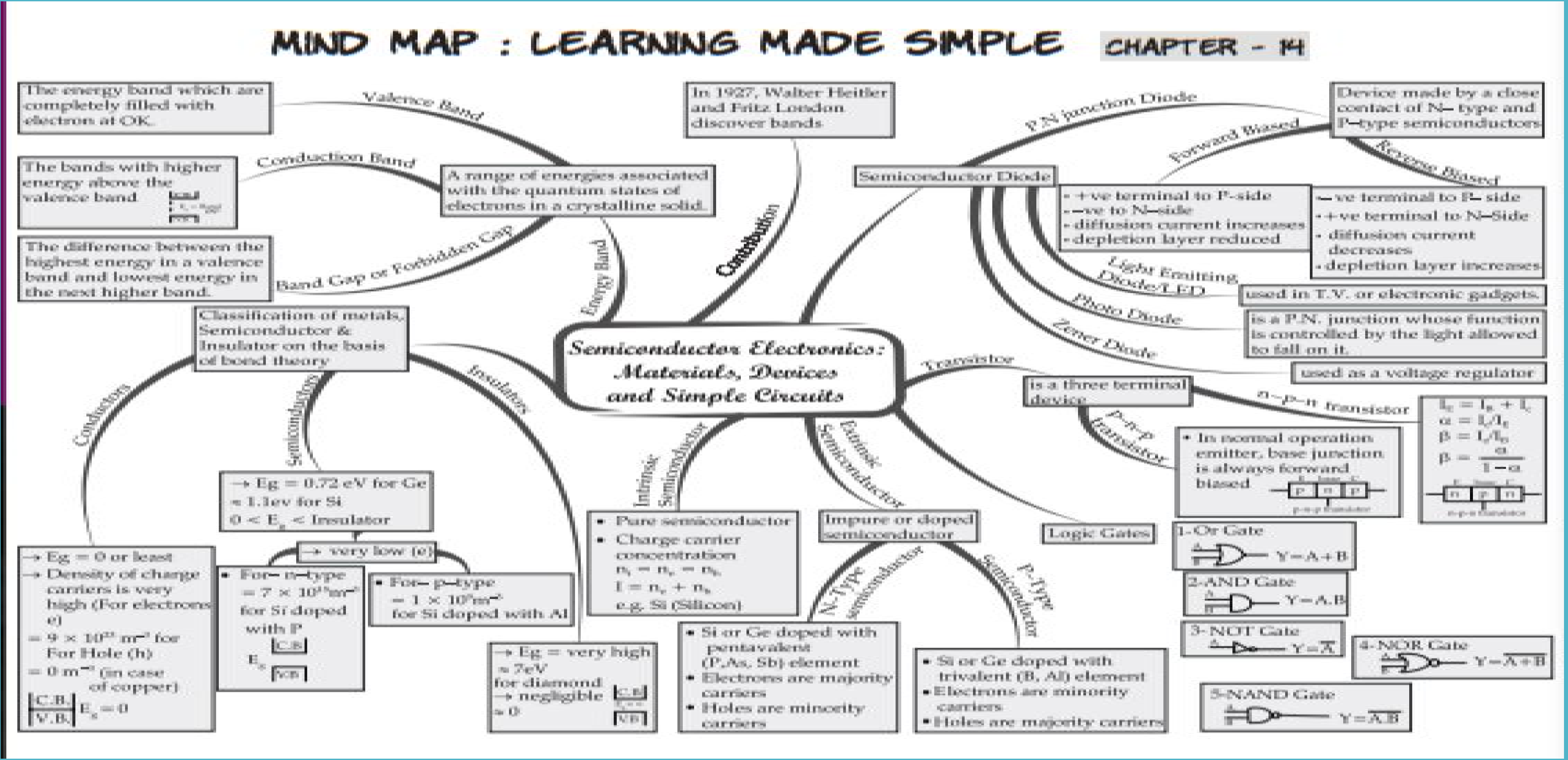

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