BASIC ELECTRICAL AND ELECTRONICS ENGINEERING

(Computer *Science Engineering*)

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UNIT -5
SEMICONDUCTORS & DIODES

Introduction to Semiconductors

- Semiconductor : Semiconductors are the materials which have a conductivity between the conductors (generally metals) and non conductors or insulators such as ceramics.
- Semiconductors can be compounds such as gallium Arsenide or pure elements such as germanium or silicon
- Examples of semiconductors: Gallium Arsenide ,Germanium and Silicon are some of the most commonly used semiconductors
- Silicon is used electronic circuit fabrication process
- Gallium arsenide is used in solar cells, laser diodes etc.
- Holes and Electrons in semiconductors:
- Holes and electrons are the type of charge carriers accountable for the “flow of current” in semiconductors
- Holes (valence electrons) are the positively charged electric charge carrier

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- Electrons are the negatively charged particles
- Both electrons and holes are equal in magnitude and opposite in polarity
- Mobility of electrons and holes:
- In a semiconductors the mobility of electrons is higher than that of holes
- It is mainly because of their different band structures and scattering mechanism
- Electrons travels in the conduction band , holes travels in the valence band when an electric field is applied
- Mobility :it means that how fast the charge carriers move from one place to another place

$\mu = V / E$ m^2/v-sec

where V is the velocity of charge carriers   m/sec

where E is the electric field =V / L   volt/metre

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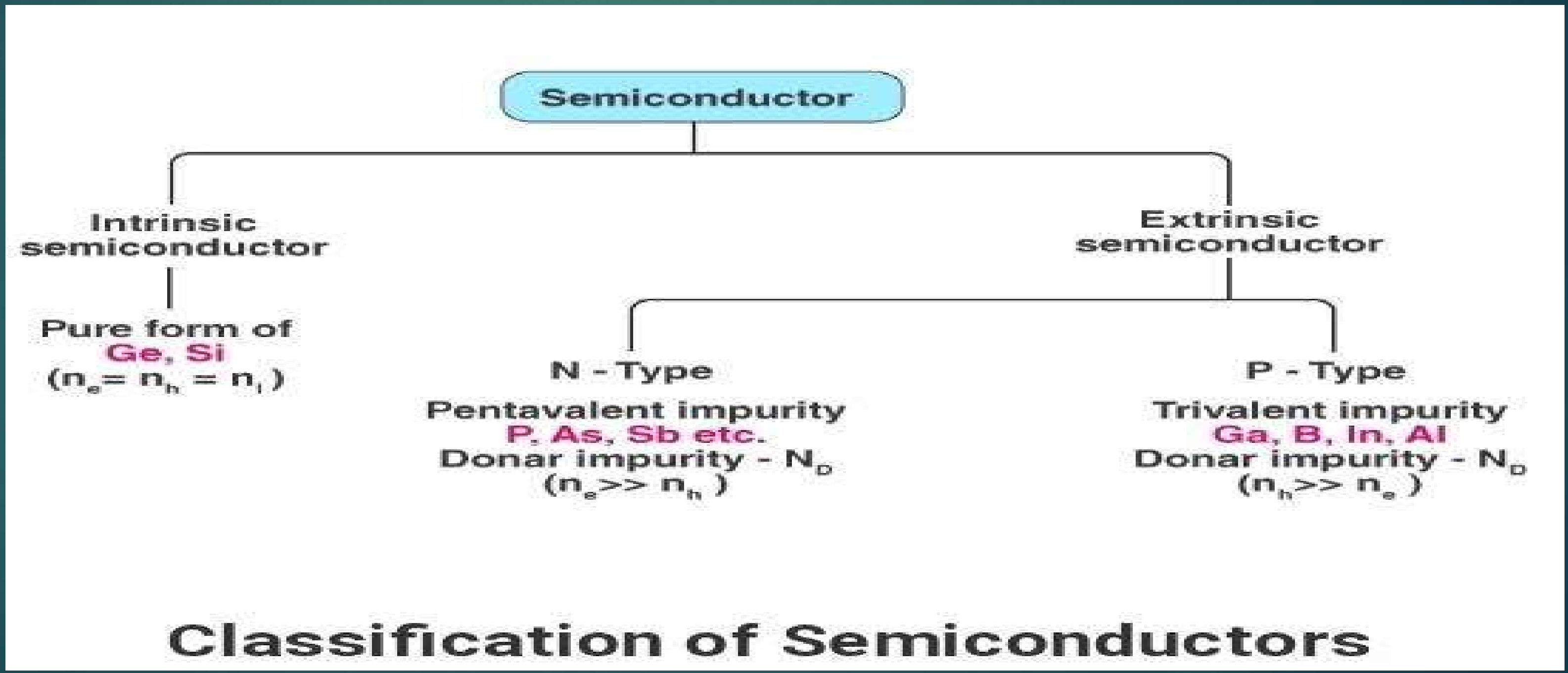
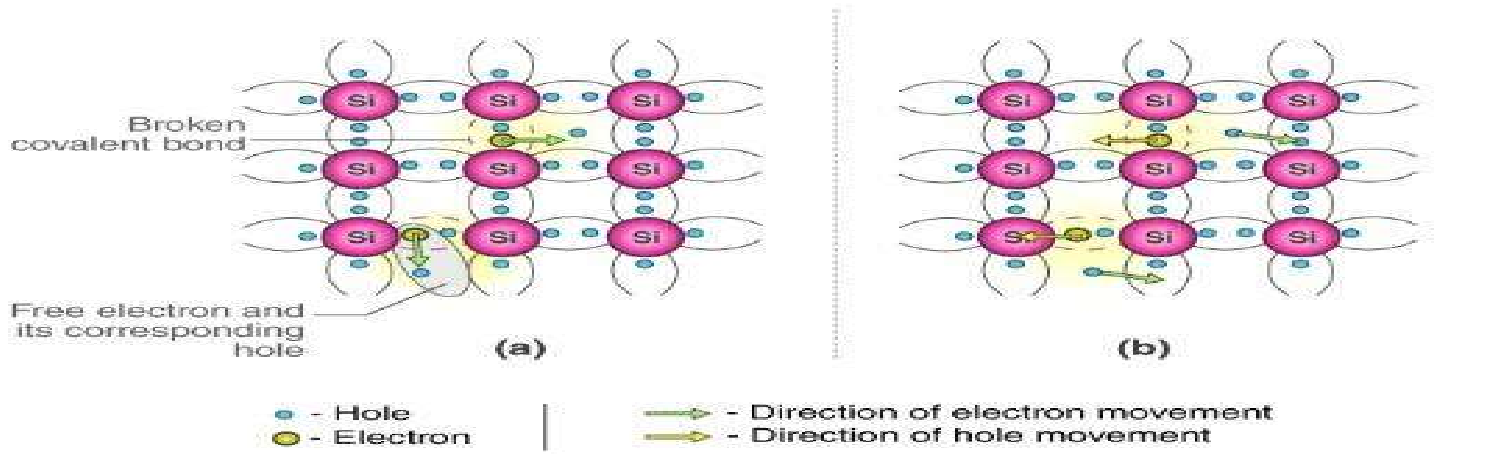
- Types of Semiconductors :There are two types of semiconductors
- (i) Intrinsic Semiconductors (pure form of semiconductor, Ge,Si) $n = p = n_i$
- (ii) Extrinsic Semiconductors



Intrinsic Semiconductor

- Intrinsic semiconductor: An intrinsic type semiconductor material is made to be very pure chemically
- It is made up of only a single type of element Si -14 -$1S^2\ 2S^2\ 2P^6\ 3S^2\ 3P^2$



Conduction Mechanism in Case of Intrinsic Semiconductors (a) In absence electric field (b) In presence of electric Field

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- Intrinsic semiconductor operation :Ge and Si are the most common type of intrinsic semiconductor elements
- They have 4 valence electronics(tetravalent)
- They are bounded to the atom by covalent bond at absolute zero temperature
- When the temperature rises , due to collisions ,few electrons are unbounded and become free to move through the lattice ,thus creating an absence in its original position(hole)
- These free electrons and holes contribute the conduction of electricity in the semiconductor
- The negative and positive charge carriers are equal in number
- Thermal energy is capable of ionizing a few atoms in the lattice ,hence their conductivity is less
- In intrinsic semiconductor total current $I = I_e + I_h$

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- In an intrinsic semiconductor, the number of electrons generated in the conduction band is equal number of holes generated in the valence band
- Hence the electron carrier concentration (n) is equal to the hole concentration (p)
- It can be written as $n_i = p = n$

  n_i = intrinsic carrier concentration K_B =Boltzman constant
- The hole concentration in the valence band given by

$$p = N_V e^{\frac{-(E_F - E_V)}{K_B T}}$$

N_V -density of atoms in Valence band

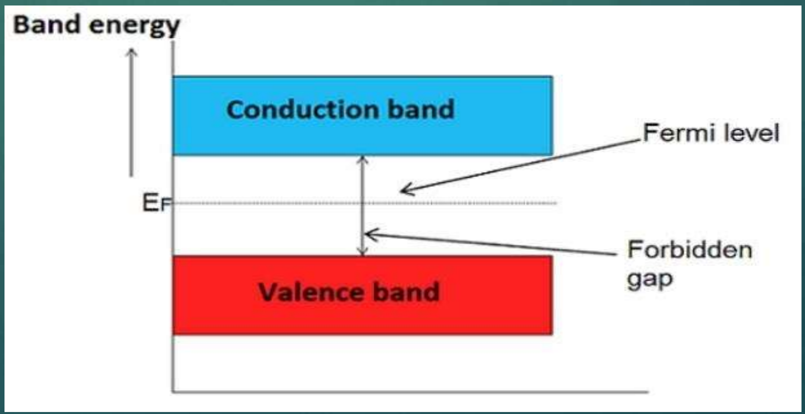
- The electron concentration in the conduction band given by

$$n = N_c e^{\frac{-(E_C - E_F)}{K_B T}}$$

N_C-density of atoms in conduction band

Continued…………

- Energy band diagram of Intrinsic Semiconductor : The gap between the conduction band and valence band is called Energy gap E_g
- Fermi level is defined as the probability of occupation of energy levels in valence band conduction band is called as fermi level
- In intrinsic semiconductor the probability of occupation of energy levels in valence band conduction band are equal
- Therefore fermi level for the intrinsic semiconductor lies in the middle of the forbidden band



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The fermi level for intrinsic semiconductor is given as,

$$E_F = \frac{E_C + E_V}{2}$$

Where E_F is the fermi level

E_C is the conduction band

E_V is the valence band

Therefore, the Fermi level in an intrinsic semiconductor lies in the middle of the forbidden gap.

Extrinsic Semiconductor

- Extrinsic Semiconductor: 1.N-Type Semiconductor 2.P-Type Semiconductor
- The semiconductor in which impurities are added is called extrinsic semiconductor
- When the impurities are added to the intrinsic semiconductor it becomes an extrinsic semiconductor
- Doping: The process of adding impurities to the pure semiconductor is called doping
- Doping increases the electrical conductivity of semiconductor
- Extrinsic semiconductor has high electrical conductivity than intrinsic semiconductor
- Hence the extrinsic semiconductor are used for the manufacturing of electronic devices such as diodes, transistors etc
- The number of free electrons and holes in extrinsic semiconductor are not equal
- Types of Impurities:1.pentavalent impurities 2.trivalent impurities

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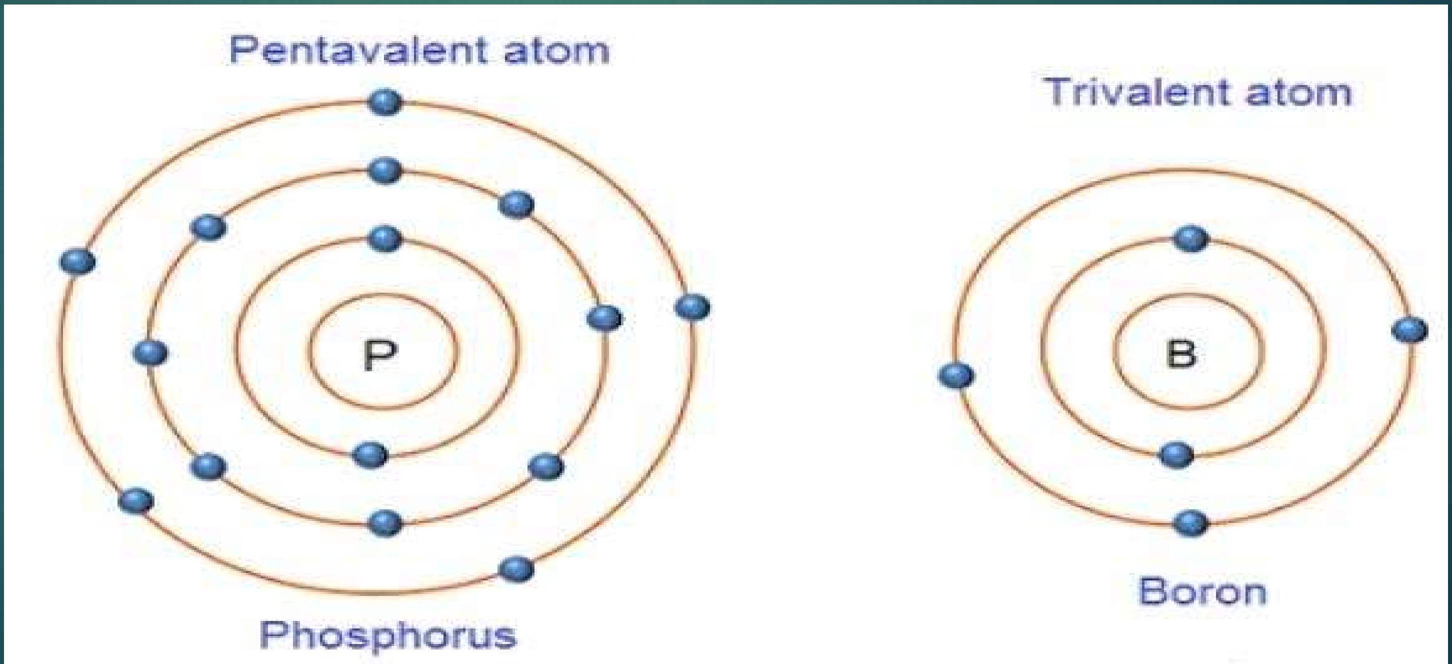
- Pentavalent & Trivalent Impurities :
- Phosphorous atomic number is -15 = $1S^2\ 2S^2\ 2P^6\ 3S^2\ 3P^3$
- Boron atomic number is -5 = $1S^2\ 2S^2\ 2P^1$



N-Type Semiconductor

- N-type Semiconductor :when pentavalent impurity is added to an intrinsic or pure semiconductor (Si, Ge),then it is said to be an N-type semiconductor
- Pentavalent impurities such as Phosphorus, Arsenic, antimony are called donor impurity
- Let us consider pentavalent impurity phosphorus is added to silicon as shown in below
- Phosphorus atom has 5 valence electrons and silicon has 4 valence electrons
- Phosphorus atom has one excess electron than silicon
- The four valence electrons of each phosphorus atom form 4 covalent bonds with the 4 neighbouring silicon atoms
- The fifth valence electron of the phosphorus atom cannot able to form the covalent bond with the silicon atom because silicon atom does not have the fifth valence electron to form the covalent bond
- The fifth valence electron in atomic structure is free electron

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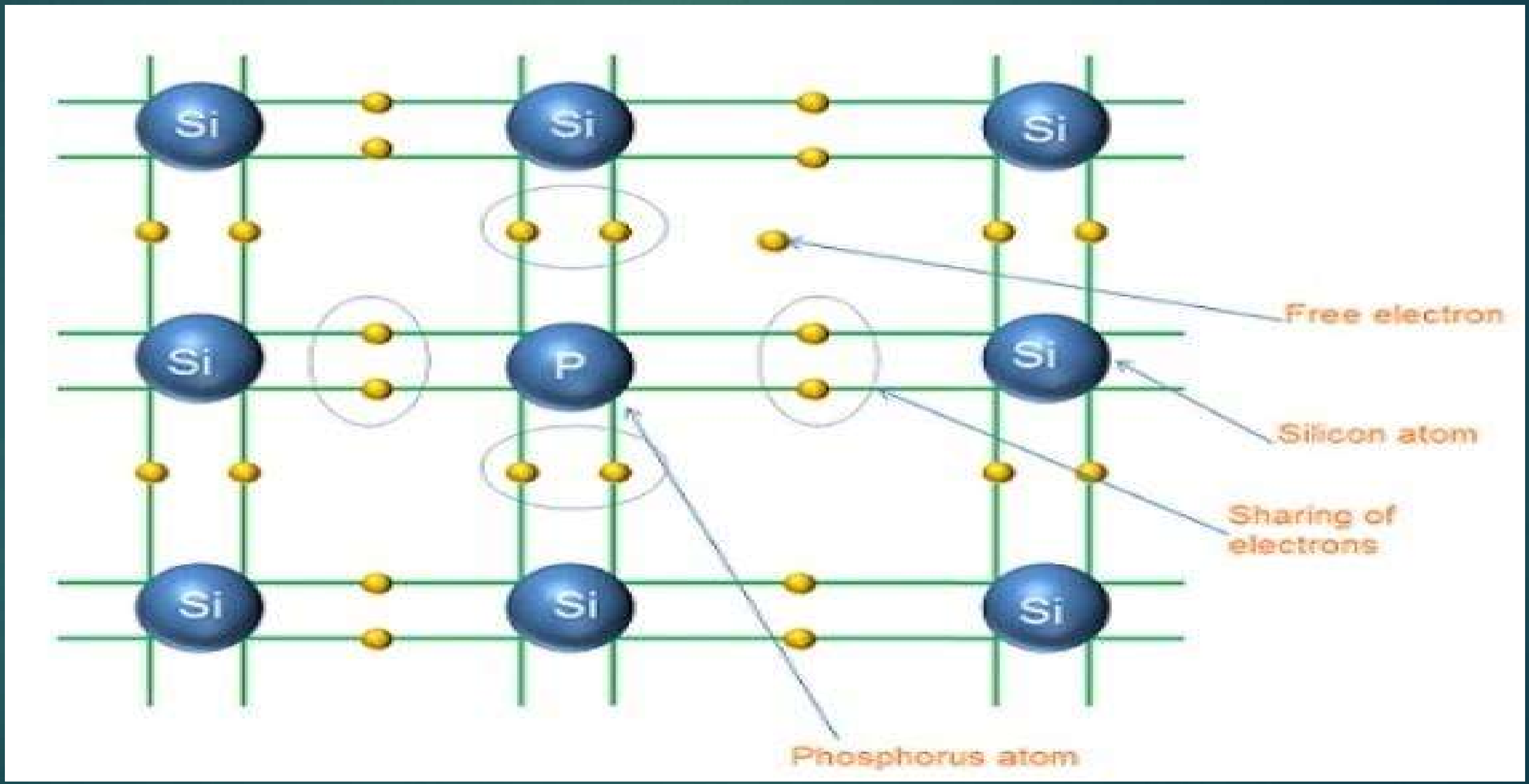
- Atomic Structure of N-type Semiconductor:



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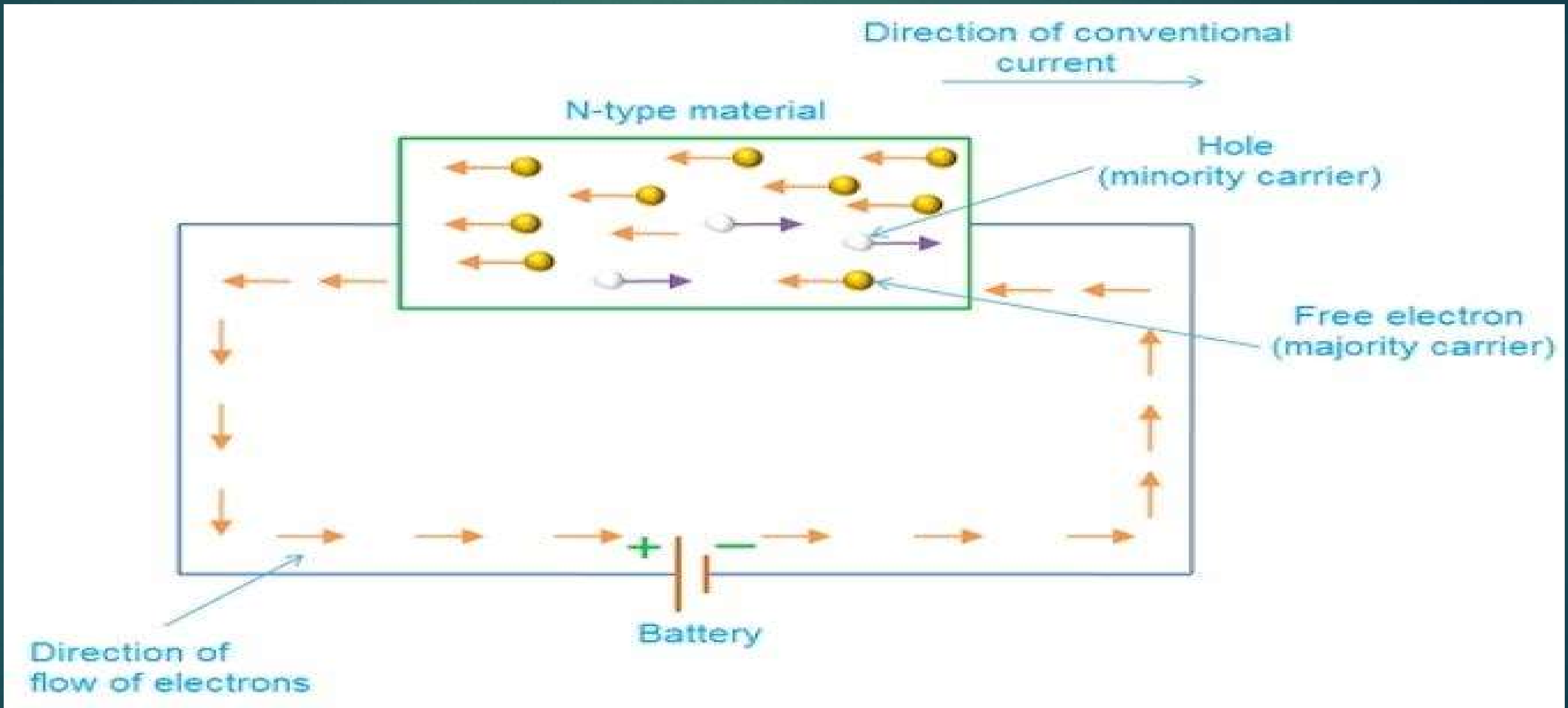
- Conduction in N-Type Semiconductor :



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- Fermi Level in Extrinsic semiconductor :In extrinsic semiconductor the number of electrons in the conduction band and number of holes in valence band are not equal
- Hence the probability of occupation of energy levels in the conduction band and valence band are not equal
- Therefore fermi level for the extrinsic semiconductor lies close to the conduction band or valence band
- Fermi Level in N-type semiconductor:In N-type semiconductor pentavalent impurity is added , Each pentavalent impurity donates a free electron
- The addition of pentavalent impurity creates a large number of free electrons in the conduction band
- At room temperature the number of electrons in the conduction band is greater than the number of holes in the valence band

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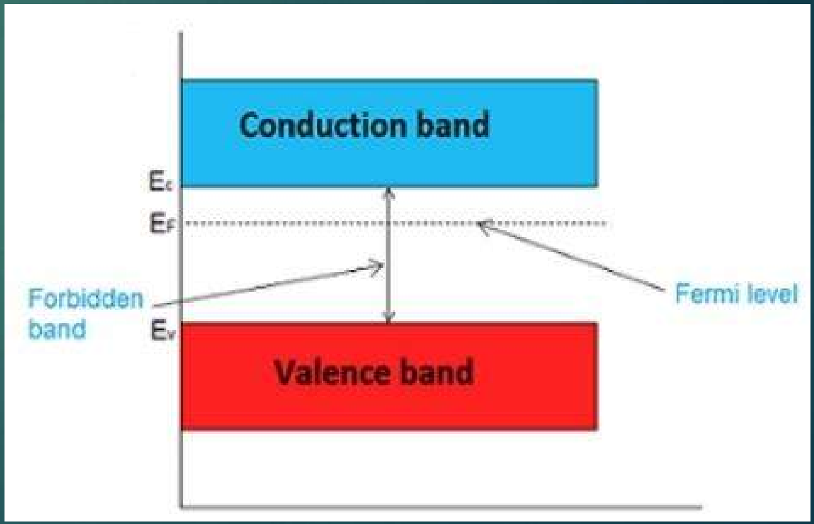
- Hence the probability of occupation of energy levels by the electrons in the conduction band is greater than the probability of occupation of energy levels by the holes in the valence band
- Therefore the fermi level in the N-type semiconductor lies close to the conduction band
- Fermi level in N-type semiconductor is given by

$$E_F = E_C - K_B T \log \frac{N_C}{N_D}$$

E_C = conduction energy

N_C = density of atoms in the conduction band

N_D = density of concentration of donor atoms



P-Type Semiconductor

- P-type semiconductor :when trivalent impurity is added to an intrinsic or pure semiconductor (Si,Ge),then it is said to be an P-type semiconductor
- Trivalent impurities such as Boron, Gallium, Indium, Aluminium are called acceptor impurity
- Let us consider trivalent impurity Boron is added to silicon as shown in below
- Boron atom has 3 valence electrons and silicon has 4 valence electrons
- The three valence electrons of each boron atom form 3 covalent bonds with the 3 neighbouring silicon atoms
- In the fourth covalent bond only silicon atom contributes one valence electron, while the boron atom has no valence electron to contribute ,hence fourth covalent band is incomplete, so electron hole pair is created

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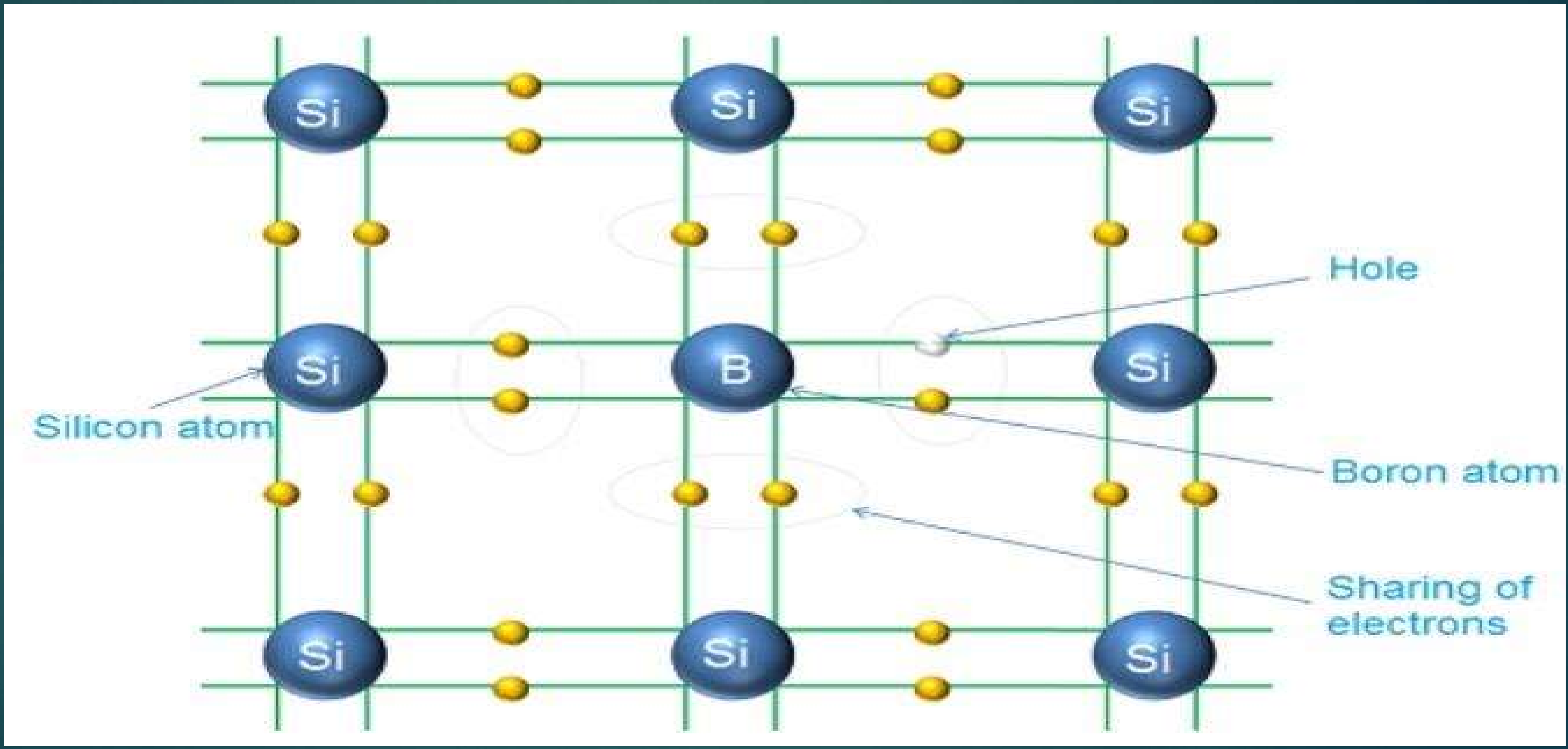
- Atomic structure of P-type semiconductor :



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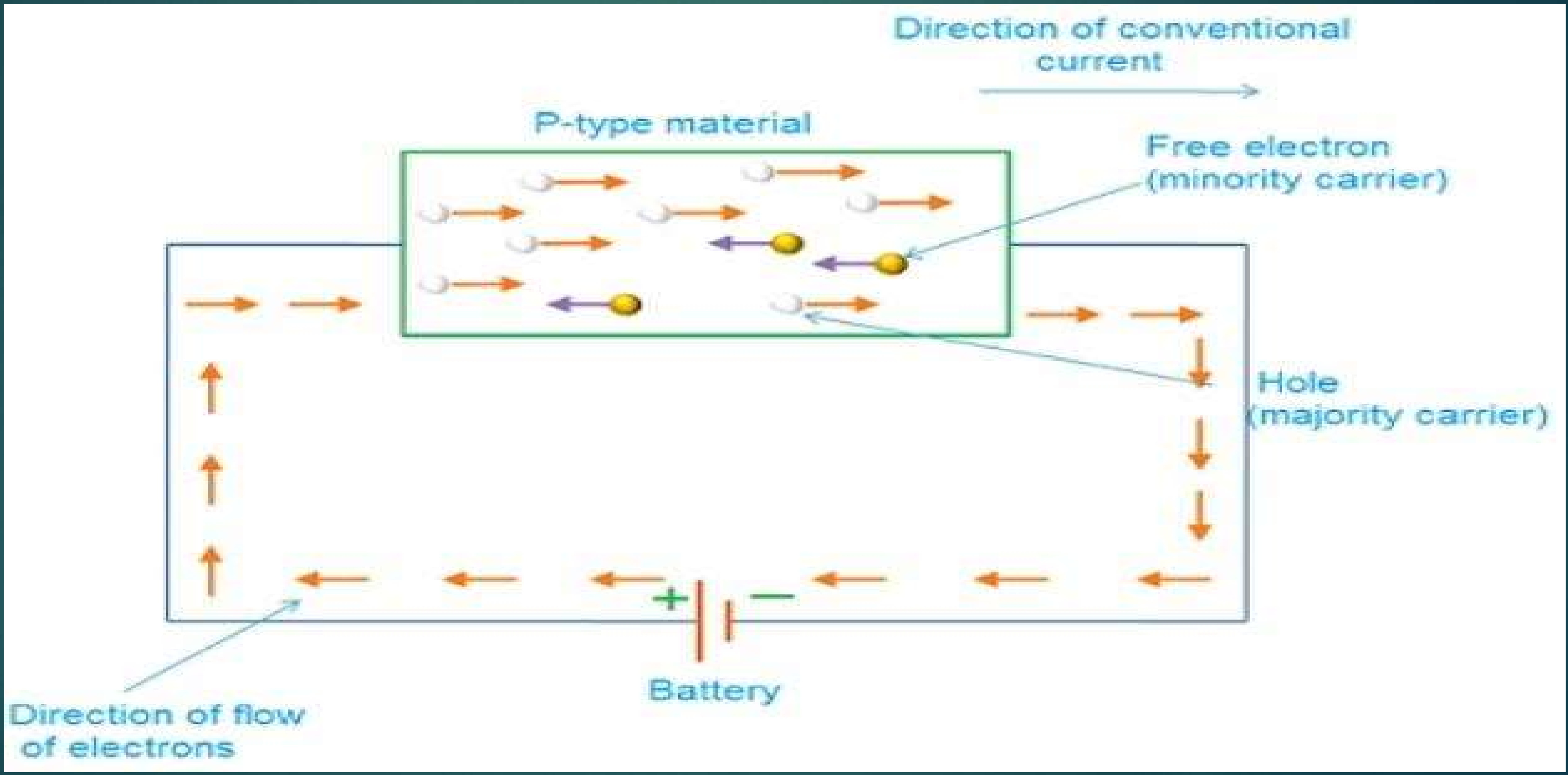
- Conduction in P-type Semiconductor :



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- Fermi level in P-type semiconductor : In P-type semiconductor trivalent impurity is added ,Each trivalent impurity creates a hole in the valence band and ready to accept an electron
- The addition trivalent impurities creates large number of holes in the valence band
- At room temperature the number of hole in the valence band is greater than the number of electrons in the conduction band
- Hence the probability of occupation of energy levels by the holes in the valence band is greater than the probability of occupation of energy levels by electrons in the conduction
- Therefore the fermi level in the P-type semiconductor lies close to the valence band
- Fermi level in P-type semiconductor is given by

$$E_F = E_V + K_B T \log \frac{N_V}{N_A}$$

E_V = valence energy

N_V = density of atoms in the valence band

N_A = density of concentration of acceptor atoms

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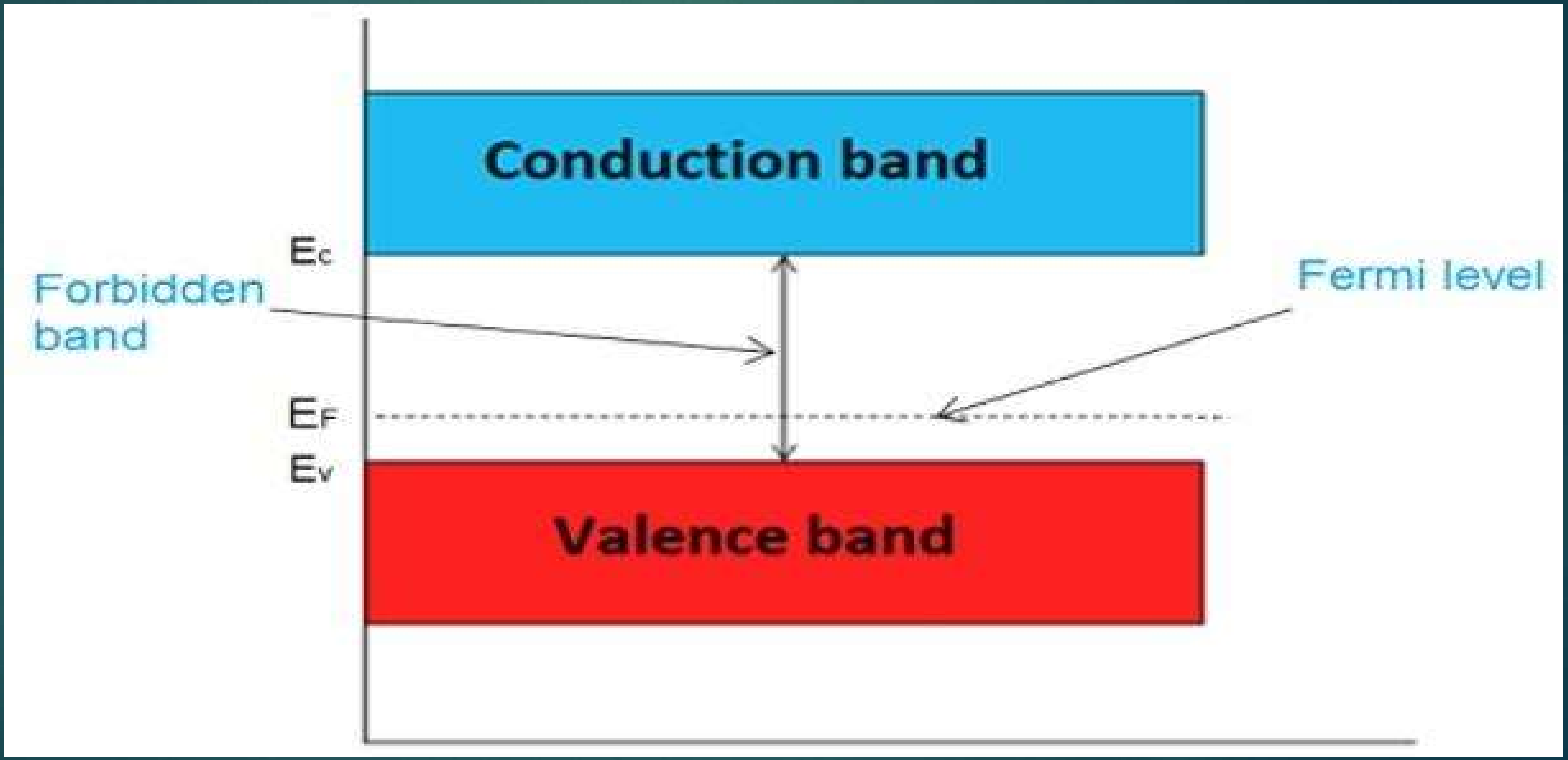
- Energy diagram of P-type Semiconductor :

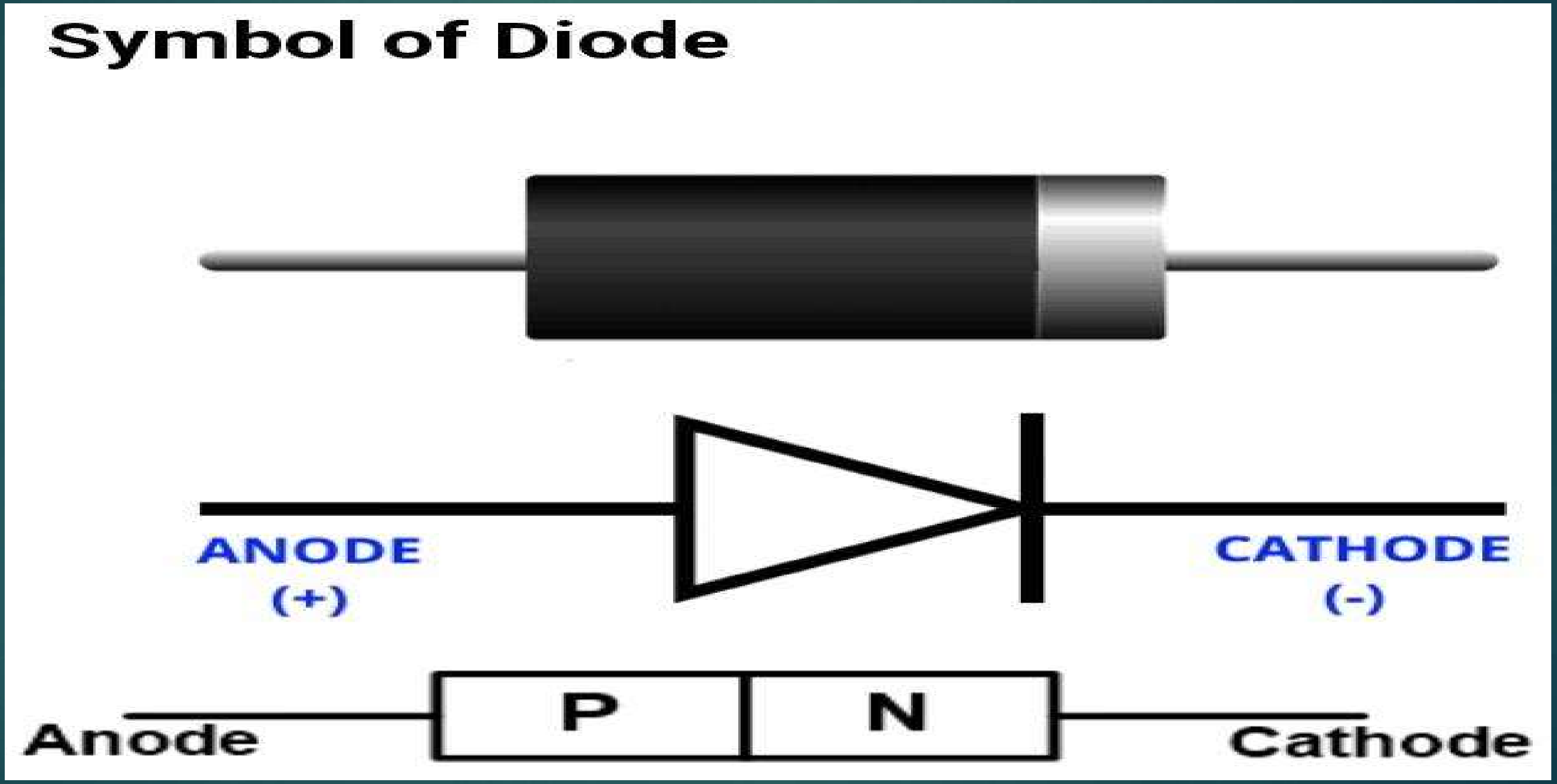


P-N Junction Diode

- What is a Diode : Di =Two and Ode = Electrodes .i.e a device or component having two electrodes viz Anode “ + ” (Positive -P) and Cathode “ – ” (Negative-N)
- A diode is a two terminal unidirectional ,single junction electronic device
- The diode is formed by joining both N-type and P-type semiconductors together
- This device is a combination of P-type and N-type semiconductor material, hence it is known as PN-junction diode
- The combination of electrons and holes depletes the holes in the P-region and electrons in the N-region near the junction
- Diode is a unidirectional i.e current flows in only one direction (anode to cathode internally)
- When a forward voltage is applied the diode conducts and the reverse voltage applied the diode does not conducts

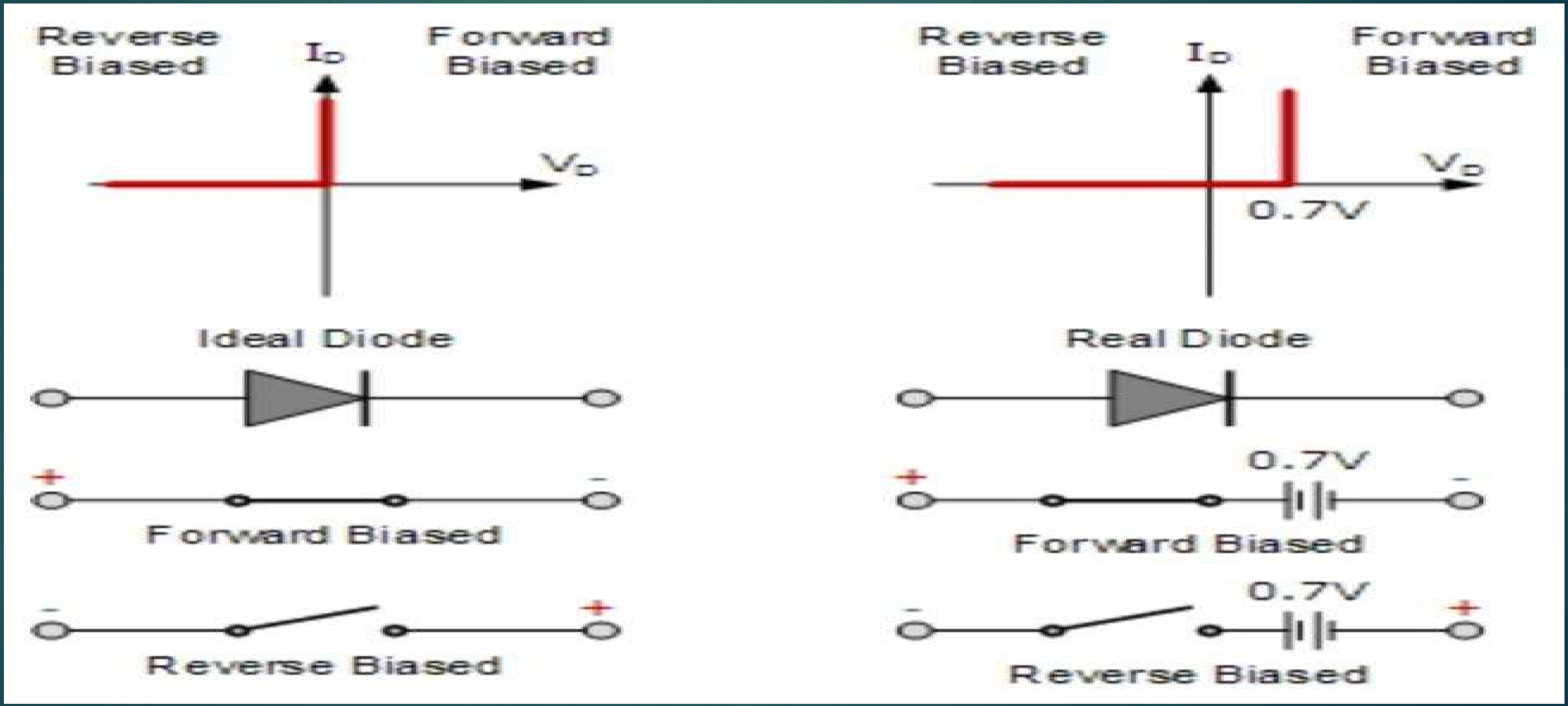
P-N Junction Diode

- Diode Symbol :



P-N Junction Diode

- Junction Diode Ideal & Practical Characteristics :



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- Diode operating Regions:
- 1. Zero Bias – No external voltage is applied to the PN junction diode
- 2. Forward Bias –P-type semiconductor is connected to the positive terminal of the battery and N-type semiconductor is connected to the negative terminal of the battery ,so the diode under forward bias, forward current is flows and width of the depletion layer decreases
- 3. Reverse Bias: P-type semiconductor is connected to the negative terminal of the battery and N-type semiconductor is connected to the positive terminal of the battery ,so the diode under forward bias, reverse current is flows and width of the depletion layer increases
- Cut-in-voltage: The voltage at which diode is starts conduction is called cut-in-voltage

For silicon diode: 0.7 Volts , Diode Current Equation $I = I_O\,(e^{V/\eta VT} - 1)$

For Germanium diode: 0.3 Volts $I_O\,(T_2) = I_O\,(T_1)\ 2^{(T2- T1/10)}$

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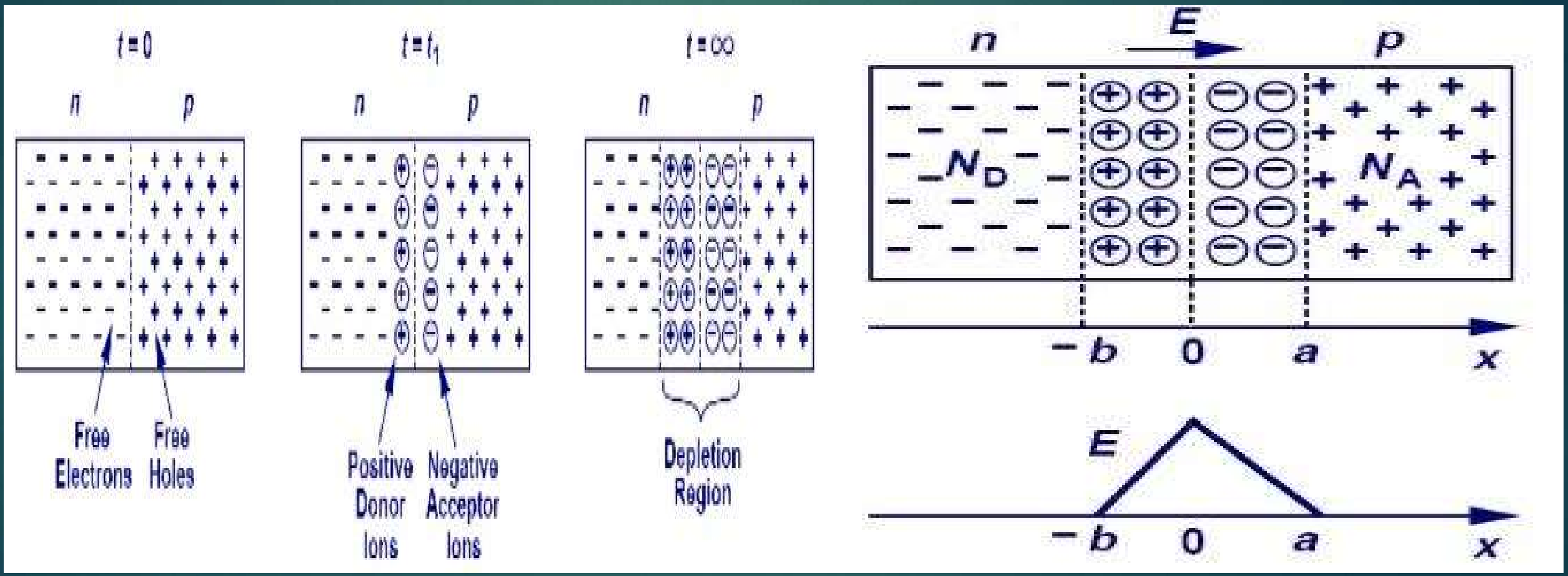
- PN junction diode Formation :



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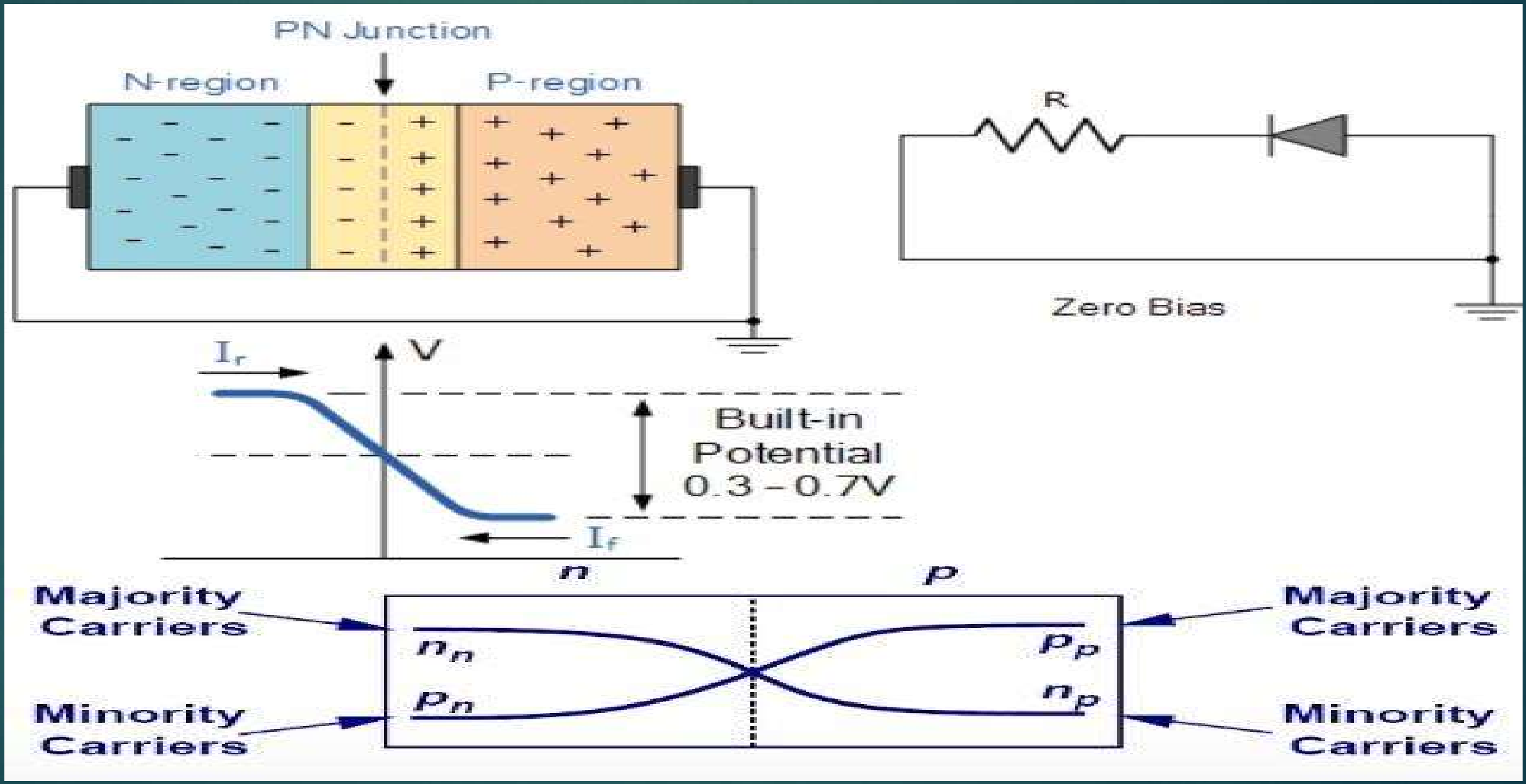
- No Bias PN junction diode :



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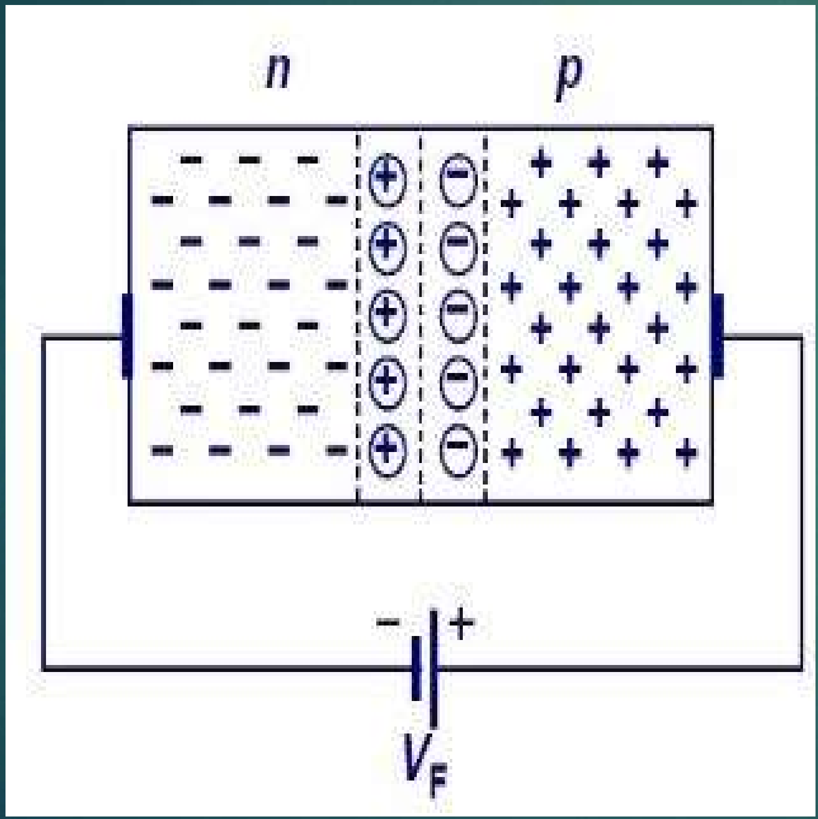
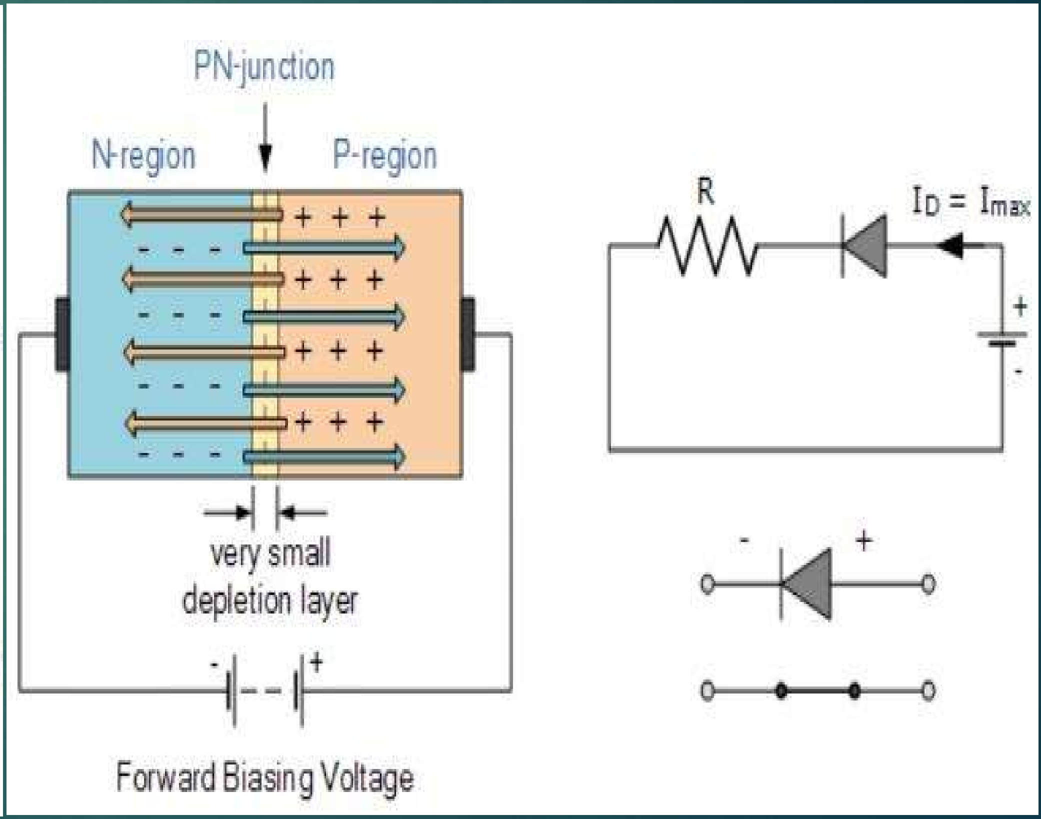
- Forward Biased PN-Junction Diode :





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- Forward Biased PN-Junction Diode :
- P-type semiconductor is connected to the positive terminal of the battery and N-type semiconductor is connected to the negative terminal of the battery ,so the diode under forward bias, forward current is flows and width of the depletion layer decreases
- Under forward biased condition P-type region holes are cross the junction and enter into N-type region
- N-type region electrons are cross the junction and enter into P-type region
- Under forward biased condition current will flows in the order of milli amperes
- Forward Resistance is offered by the diode under forward biased condition is in the order of milli ohms
- R_f = 0 ideally, milli ohms practically
- I_f = milli Amperes

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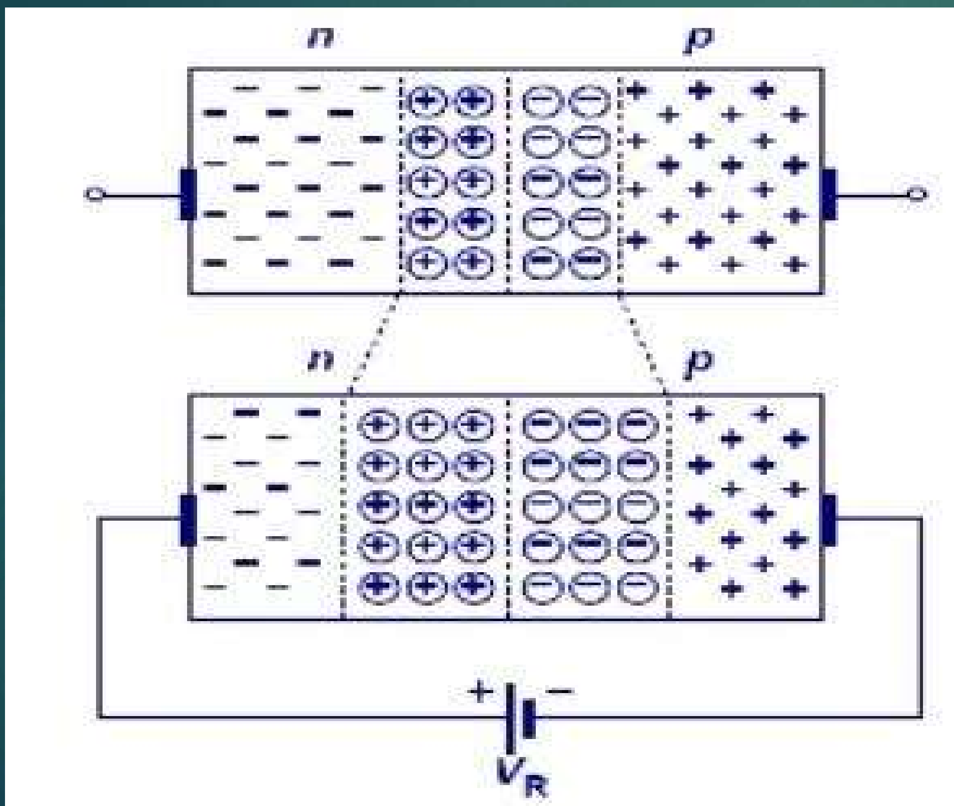
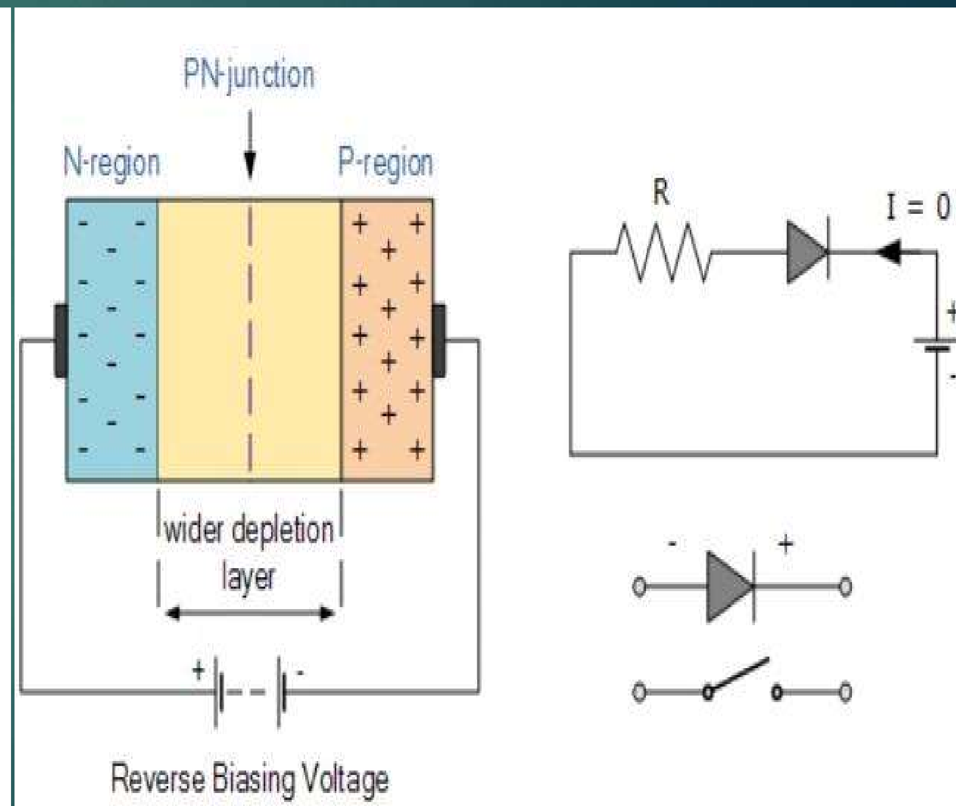
- Reverse Biased PN-Junction Diode :





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- Reverse Biased PN-Junction Diode :
- P-type semiconductor is connected to the negative terminal of the battery and N-type semiconductor is connected to the positive terminal of the battery ,so the diode under reverse bias, reverse current is flows and width of the depletion layer increases
- Under reverse biased condition P-type region holes are move away from the junction
- N-type region electrons are move away from the junction
- Under reverse biased condition no current will flows in the circuit
- Reverse Resistance is offered by the diode under reverse biased condition is in the order of Mega ohms
- R_r= infinite ideally, Mega ohms practically
- I_r = nano Amperes

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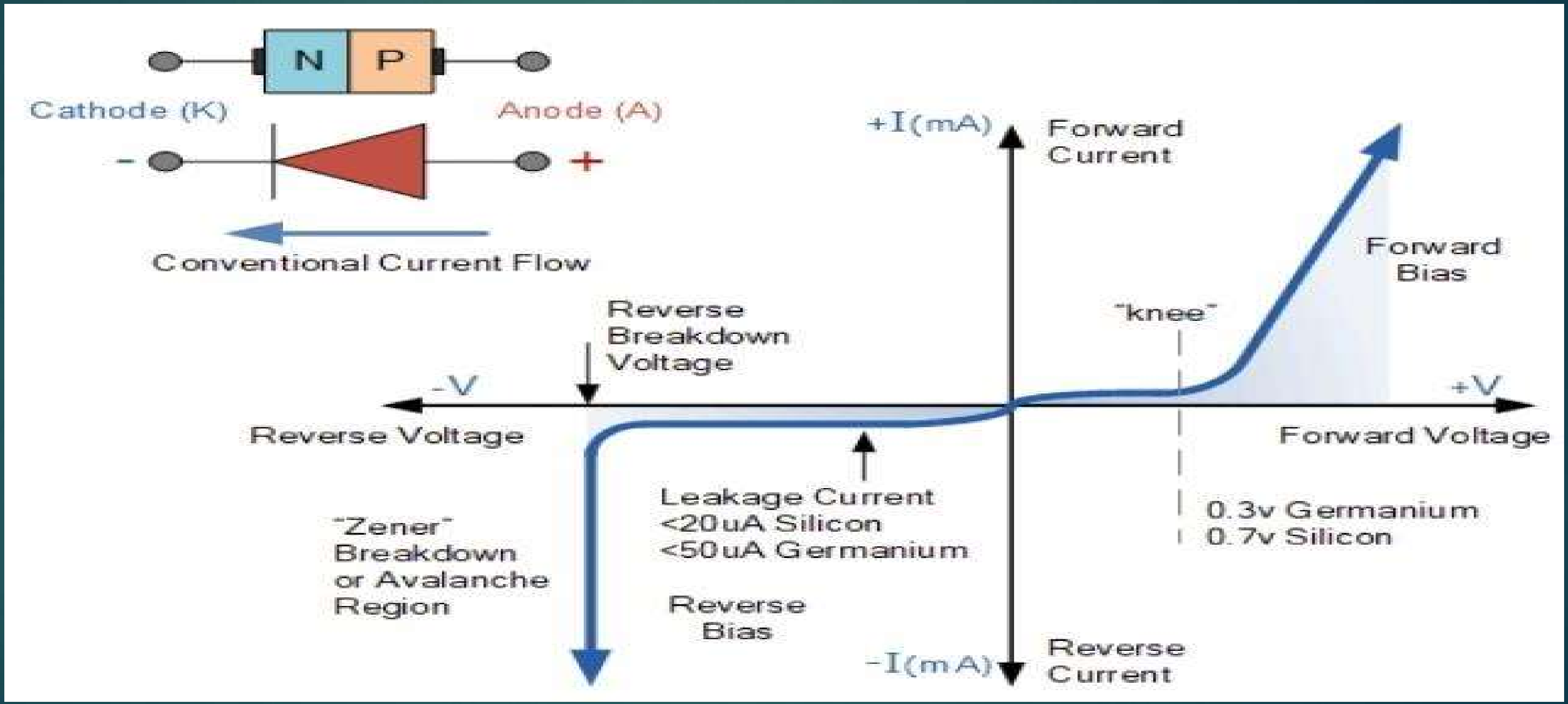
- V-I Characteristics of PN junction diode:



Diode Resistances

- Diode Resistances : There are two types of resistances

(i) Static Resistance or DC Resistance

(ii) Dynamic Resistance or AC Resistance

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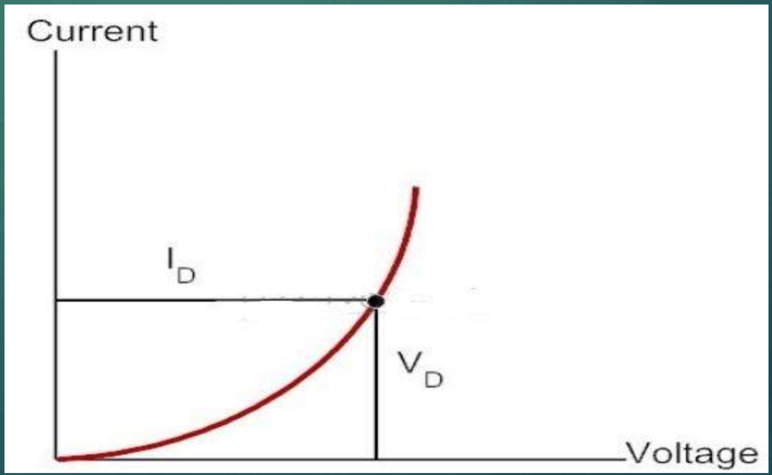
- Static Resistance : Static Resistance = Voltage / Current
- Static resistance is defined as the diodes resistive nature when a DC source is connected to it
- The static at the knee of the curve and below of it will be greater than the resistance values of vertical rise section of the characteristic curve
- Minimum is the current is passing through a diode is maximum is the level of the DC resistance $R_{DC} = V_{DC} / I_{DC}$



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- Dynamic Resistance: Dynamic Resistance = Change in voltage / Change in current

$$R_{AC} = \Delta V / \Delta I = V_2 - V_1 / I_2 - I_1$$

- It is measured by a ratio of change in voltage across the diode to the resulting change in current through it
- The opposition offered by a diode to the changing current flow I, in forward biased condition is known as its AC forward resistance
- There are two types of capacitances are occurred in a diode under FWB
- Transition Capacitance $C_T = \varepsilon A / W$ W= width of depletion region
- Diffusion Capacitance $C_D = dQ / dV$
- Drift Current: The flow of charge carriers which is due to the applied voltage or electric field is called drift current

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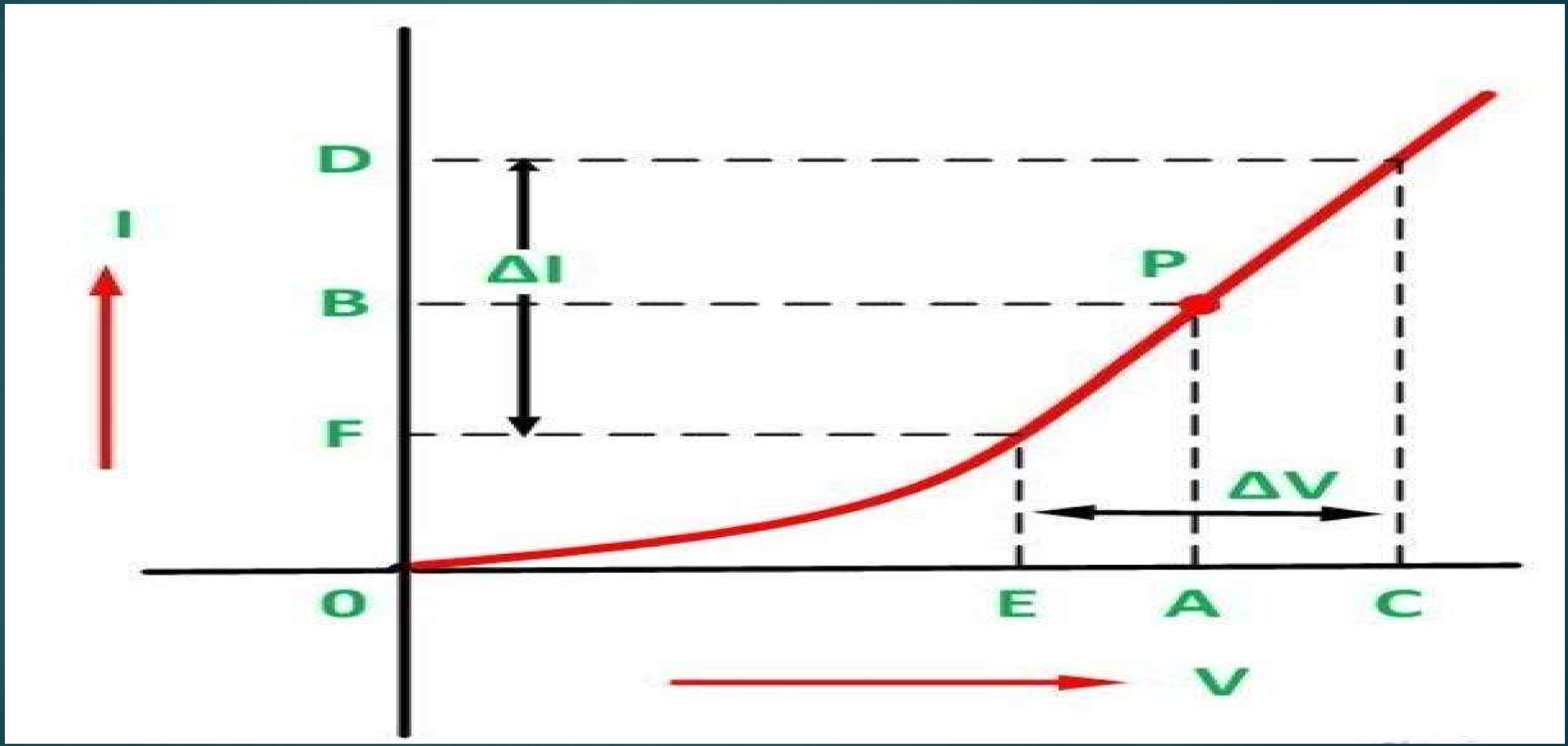
- Dynamic curve:



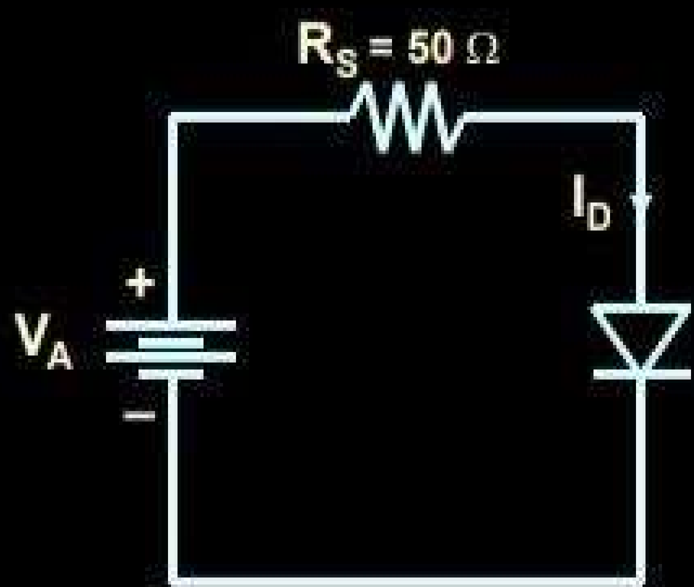
Merits & Applications of a Diode

- Merits of diode over vacuum:
- Small in size
- Less space required
- Low in weight
- Consume low power
- Low internal resistance
- Applications of diode:
- Rectifier
- Clipper and clamper
- Over voltage limiter
- Reverse current protection circuit

Problems on diodes

- Problem :

Example: Assume the diode in the circuit below is ideal. Determine the value of I_D if a) V_A = 5 volts (forward bias) and b) V_A = -5 volts (reverse bias)



a) With $V_A > 0$ the diode is in forward bias and is acting like a perfect conductor so:

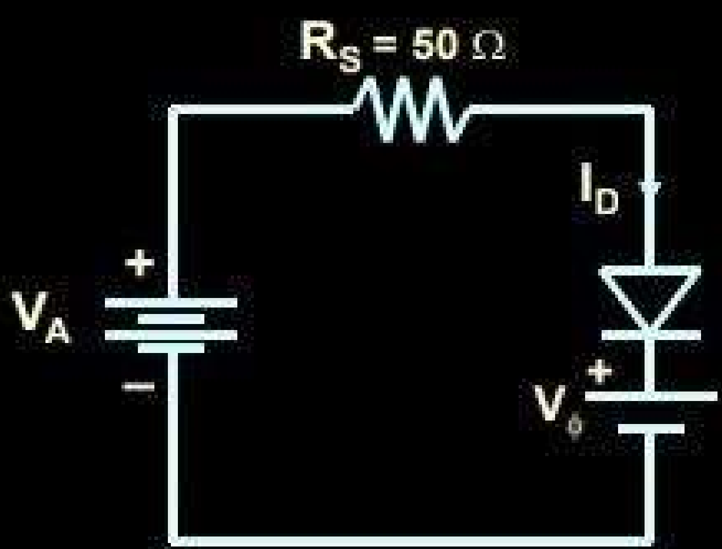
$$I_D = V_A/R_S = 5\ V\ /\ 50\ \Omega = 100\ mA$$

b) With $V_A < 0$ the diode is in reverse bias and is acting like a perfect insulator, therefore no current can flow and $I_D = 0$.

Problems on diodes

- Problem :

Example: To be more accurate than just using the ideal diode model include the barrier potential. Assume $V_\phi = 0.3$ volts (typical for a germanium diode) Determine the value of I_D if $V_A = 5$ volts (forward bias).



With $V_A > 0$ the diode is in forward bias and is acting like a perfect conductor so write a KVL equation to find I_D:

$$0 = V_A - I_D R_S - V_\phi$$

$$I_D = \frac{V_A - V_\phi}{R_S} = \frac{4.7\ \text{V}}{50\ \Omega} = 94\ \text{mA}$$

Zener Diode

- What is Zener diode: A Zener diode is a special type of device designed to operate in the Zener breakdown region
- Zener diode acts like normal P-N junction diode under forward biased condition
- When forward biased voltage is applied to the Zener diode it allows large amount of electric current and blocks only small amount of electric current
- Zener diode is heavily doped than the normal P-N junction diode
- Hence it has very thin depletion region ,Doping directly proportional to 1/W
- It also allows electric current in reverse direction if the applied voltage is greater than the Zener voltage
- Zener diode always connected in reverse direction because it specially designed to work in reverse direction

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- Zener diode definition : A Zener diode is a heavily doped semiconductor device that is designed to operate in reverse direction
- The breakdown voltage of a Zener diode is carefully set by controlling the doping level during manufacture
- Zener diodes are mainly used to protect electronic circuit from over voltages
- Breakdown in Zener diode:
- There are two types of reverse break down regions in a Zener diode
- (i) Avalanche breakdown > 6 V (ii) Zener breakdown < 6 V
- Avalanche breakdown:
- Avalanche breakdown occurs in both normal diodes and Zener diodes at high reverse voltage
- When high reverse voltage is applied to the P-N junction diode the free electrons

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- Minority carriers gains large amount of energy and accelerated to greater velocities
- The free electrons moving at high speed collides with the atoms and knock of more electrons
- These electrons are again accelerated and collide with the other atoms
- Because of this continuous collisions with the atoms a large number of free electrons are generated
- As a result electric current in the diode increases rapidly
- This sudden increase in electric current may permanently destroys the normal diode
- However avalanche may not be destroyed because they are carefully designed to operate in avalanche breakdown region
- Avalanche breakdown occurs in Zener diode with Zener voltage V_z greater than 6V

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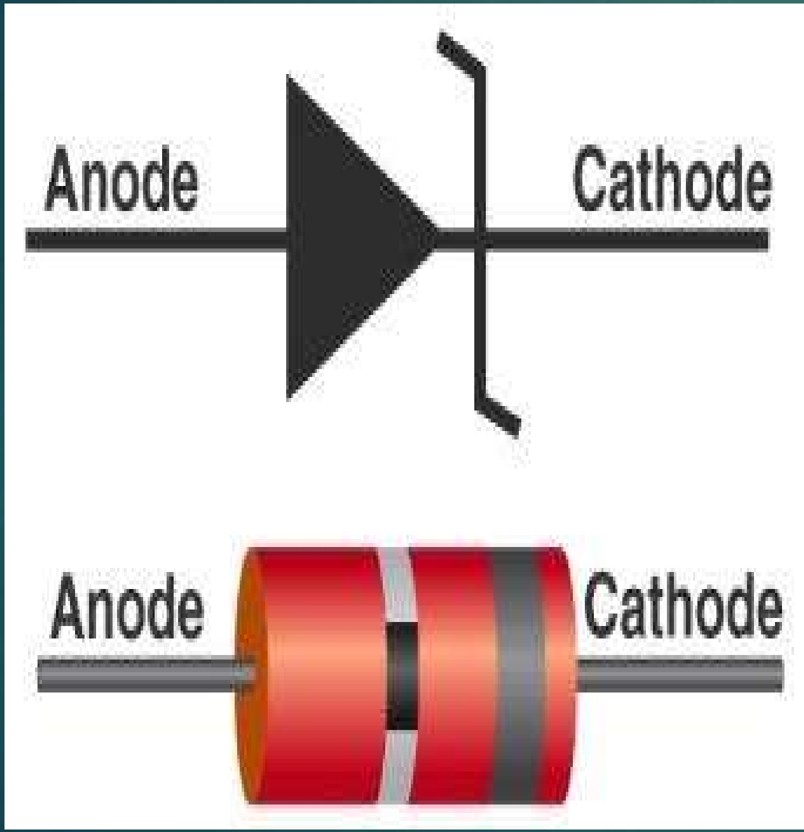
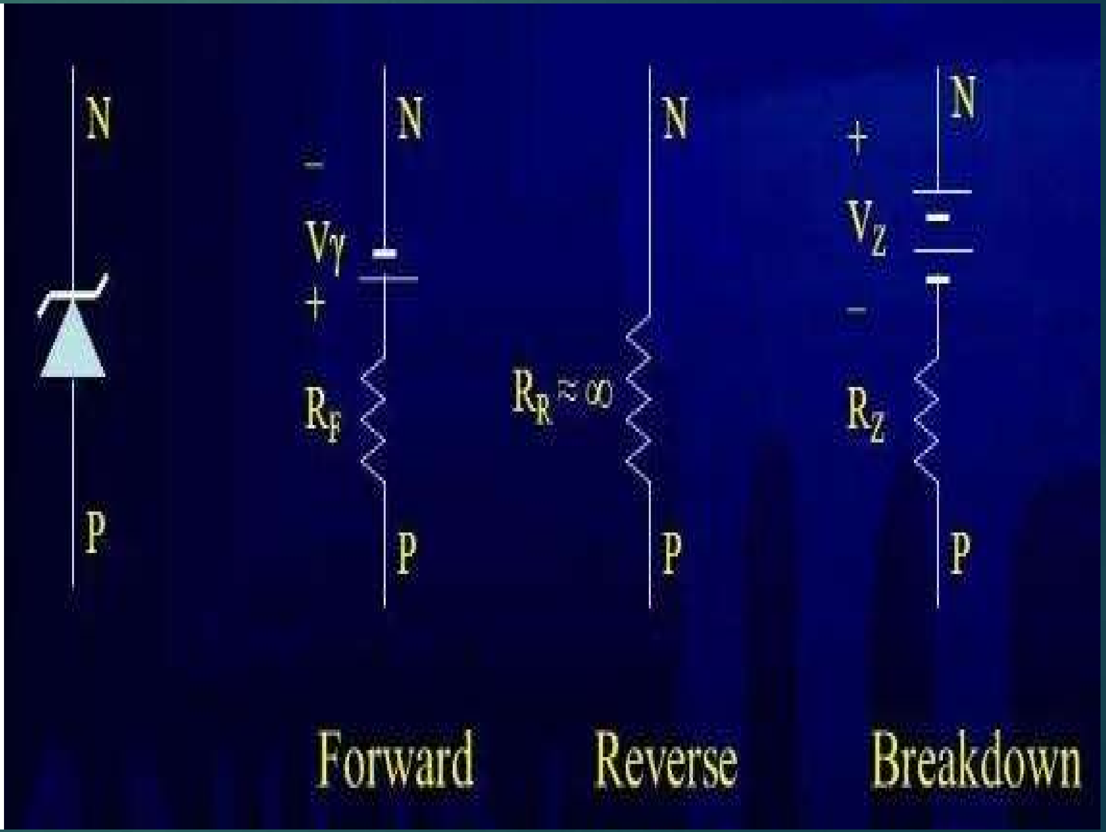
- Symbol & Equivalent circuit of Zener diode:





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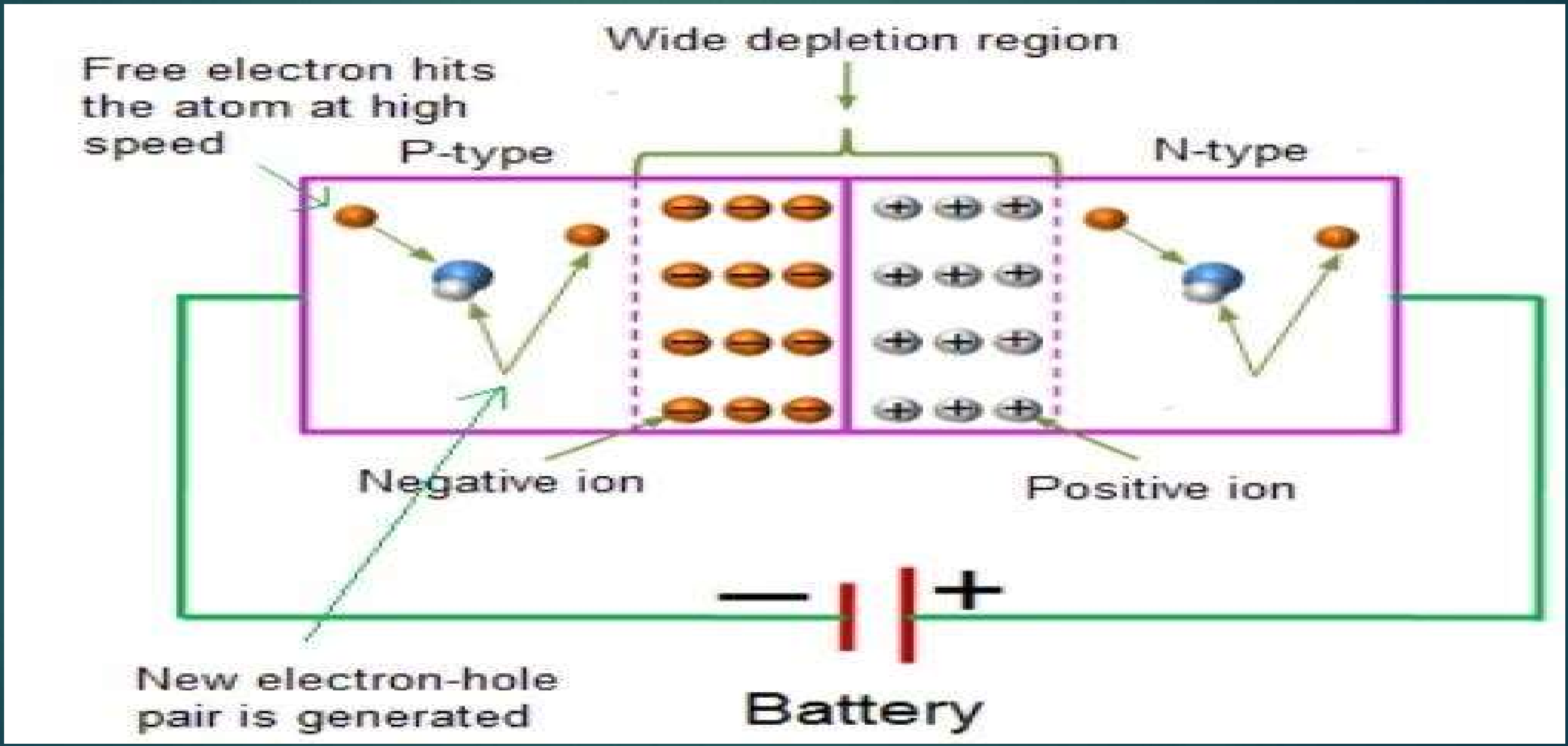
- Avalanche breakdown circuit>6 V :



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- Zener breakdown (Vz < 6V) : The Zener breakdown occurs in heavily doped P-N junction diodes because of their narrow depletion region
- When reverse biased voltage applied to the diode is increased ,the narrow depletion region generates strong electric field
- At Zener breakdown region a small increase in voltage will rapidly increases the electric current
- Zener breakdown occurs at low reverse voltage where as avalanche breakdown occurs at high reverse voltage
- Zener breakdown occurs in Zener diode because they have very thin depletion layer
- Zener breakdown occurs in Zener diodes with Zener voltage V_z less than 6 V

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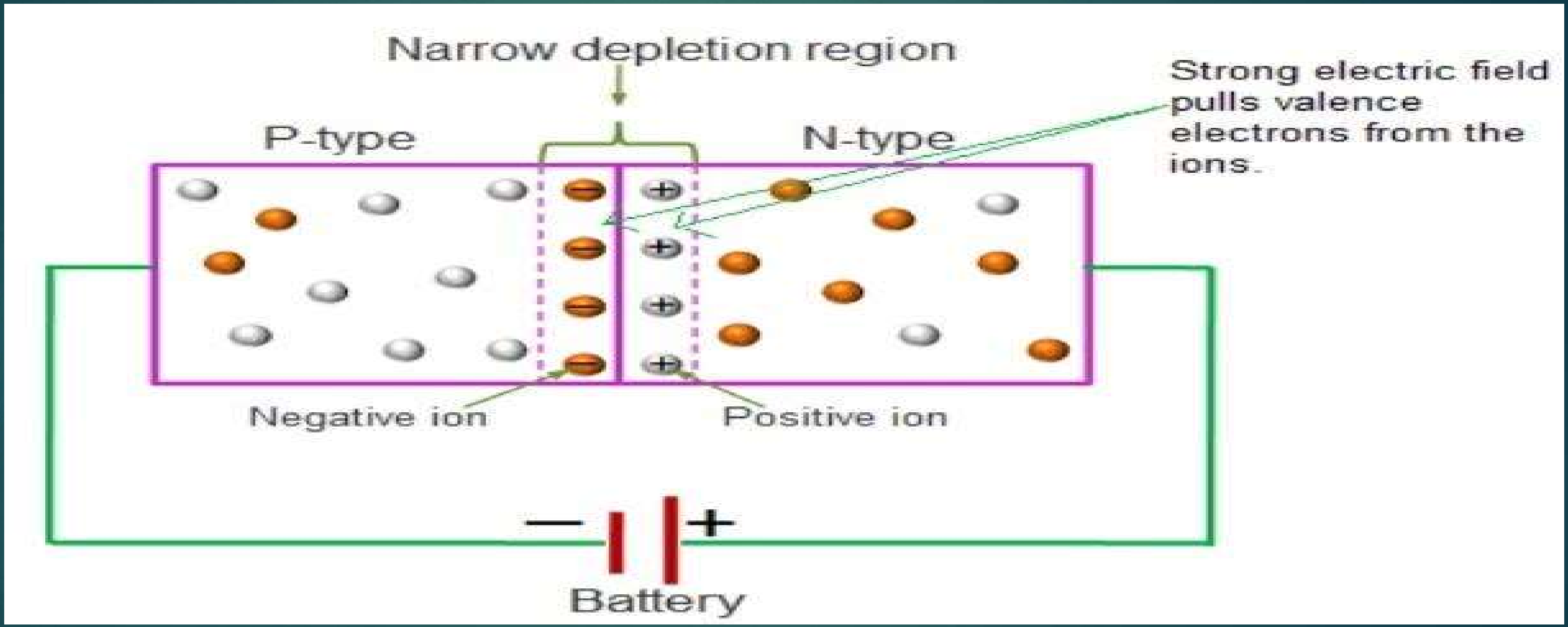
- Zener breakdown region <6V :



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- V-I characteristics of Zener diode : When forward biased voltage is applied to the Zener diode , it works like a normal diode
- When reverse biased voltage is applied to the Zener diode , it works like different manner
- When reverse biased voltage is applied to a Zener diode ,it allows only a small amount of leakage current until the voltage is less than Zener voltage
- When reverse biased voltage is applied to a Zener diode reaches the Zener voltage ,it starts allowing large amount of electric current
- At this point a small increase in reverse voltage will rapidly increase the electric current

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- Zener diode forward & reverse biased curves :

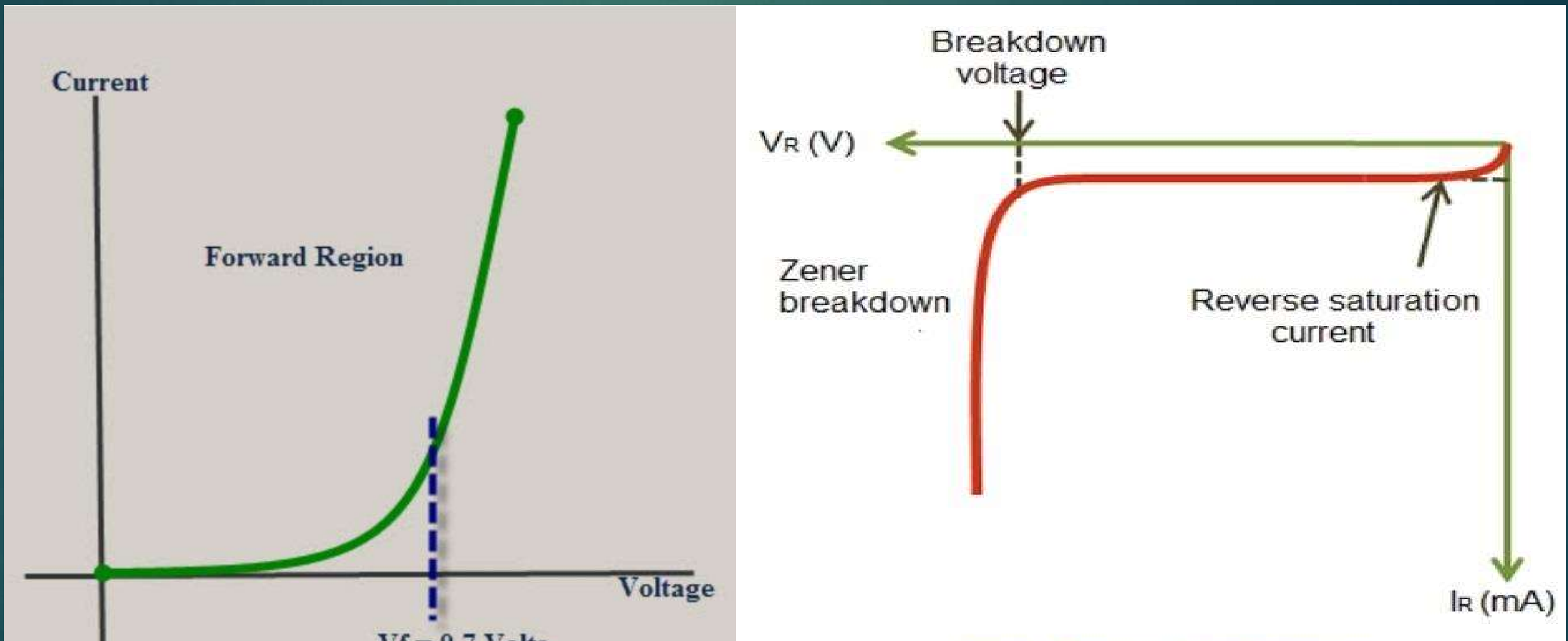

Fig: Zener breakdown

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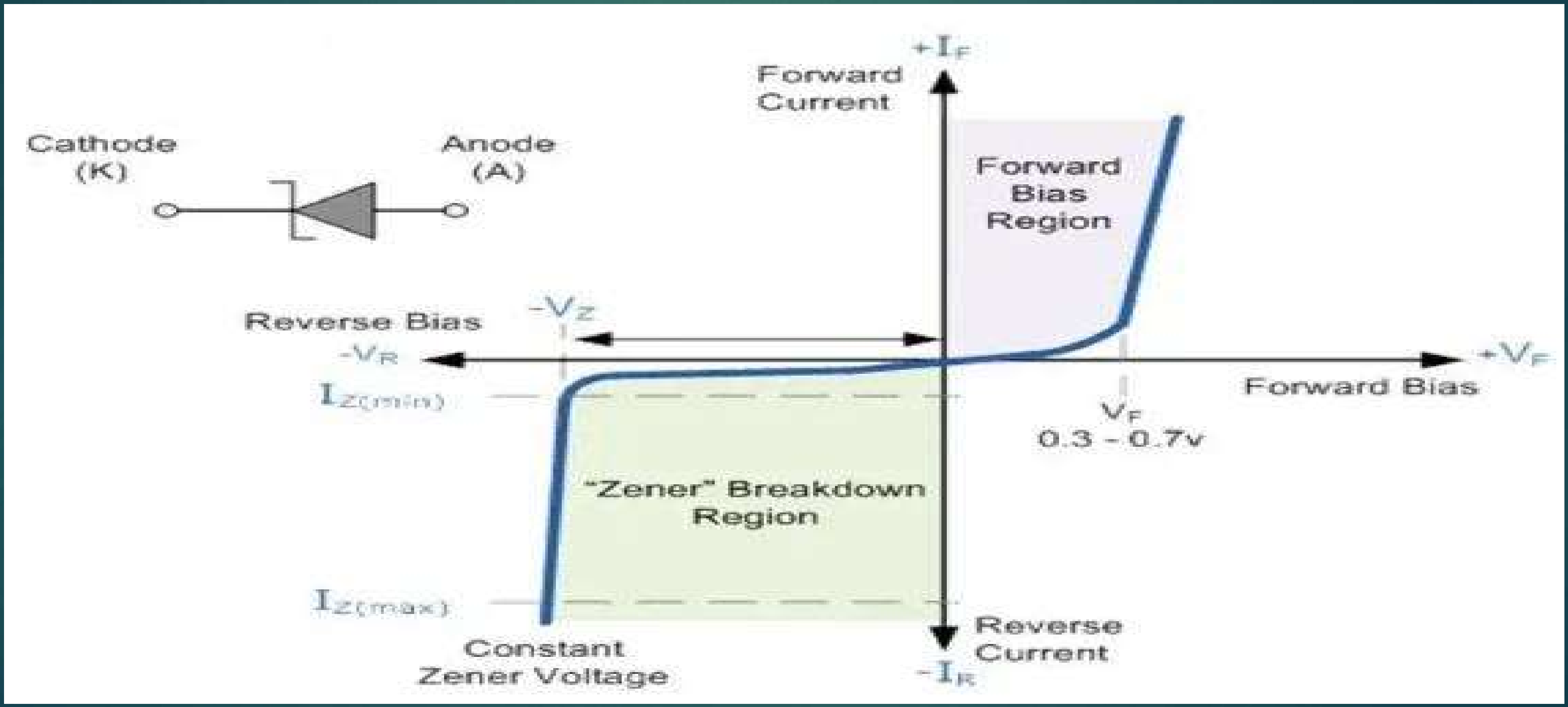
- V-I Characteristics of Zener diode :

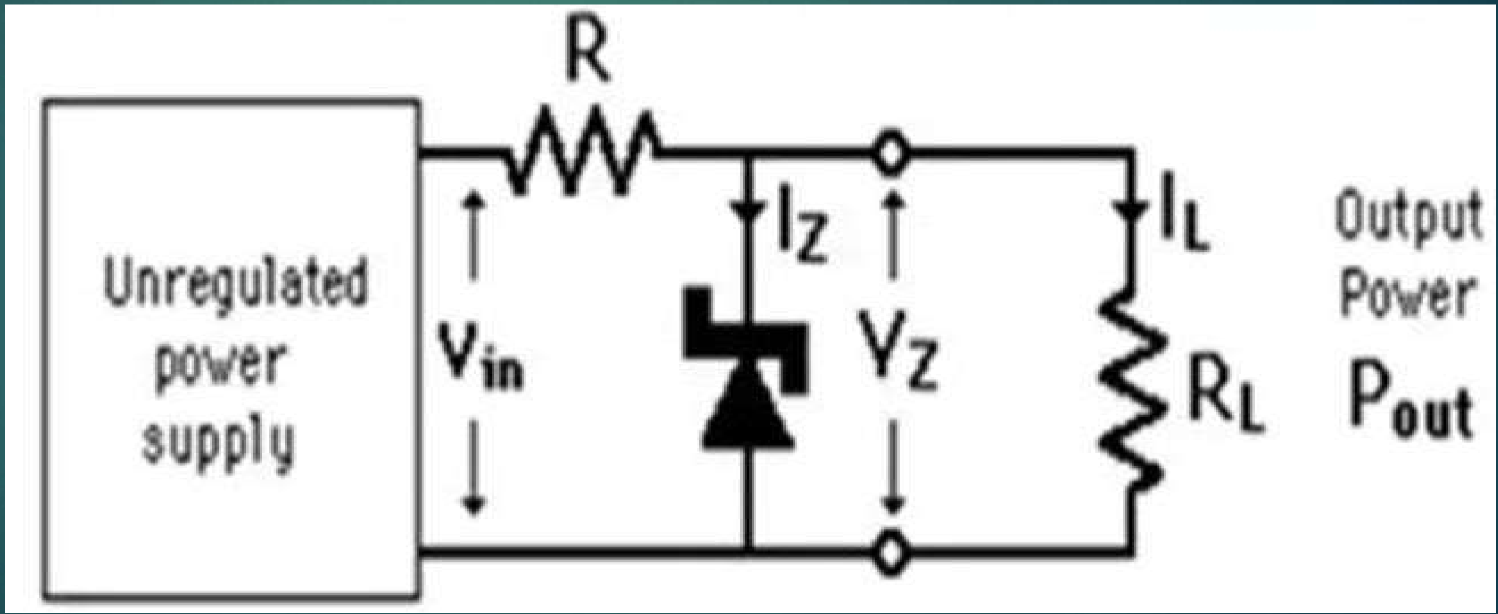


Merits & Applications of Zener diode

- Merits : High accuracy
- Small size
- Low cost
- Power dissipation capacity is very high
- Zener diode available with Vz ranging from 1.8 V to 200 V
- Power ranging from 50 mW to 50 W
- Applications:
- It is normally used as a voltage reference
- Zener diodes are used in voltage stabilizers or regulators
- Zener diodes are used in various protection circuits

Zener diode as a Voltage Regulator

- Regulator : It is defined as the "unregulated voltage is converting in to regulated voltage irrespective changes of time, temperature and applied input parameters
- It provides "constant output voltage" irrespective changes of time, temparature and applied input parameters



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- The circuit holds the voltage across the load R_L almost is equal to the voltage across Zener diode V_Z even after the input V_{in} and load resistor R_L undergo changes
- If unregulated dc voltage Vin is raises ,the current through the R increases
- If the load requires more current when R_L is decreased ,the Zener diode can supply the extra current with out affecting the load voltage
- Let I be the current through the resistor R we can write
- $I = I_Z + I_L$

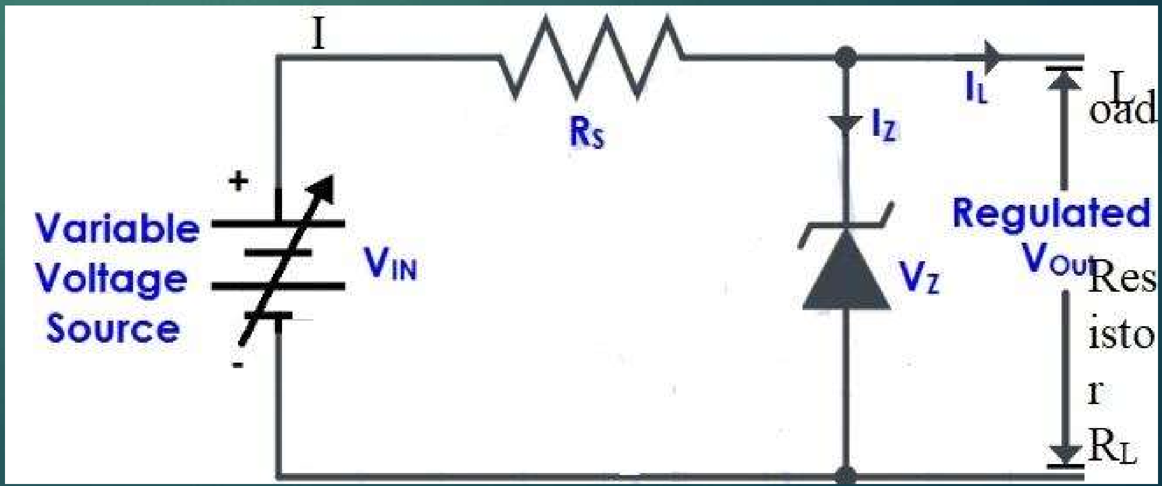
Case (i) $I = I_{zmax} + I_{Lmin}$

Case (ii) $I = I_{zmin} + I_{Lmax}$

$I = V_{in}-V_Z / R_S$

$V_{out} = V_L = I_L R_L$

$V_Z = I_Z R_Z$



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- From the circuit $V_Z = V_L$

$$I_Z R_Z = I_L R_L$$

$$I_Z / I_L = R_L / R_Z$$

$$I \geq I_{zmax} + I_{Lmin}$$

$$\boxed{V_{in} - V_Z / R_S \geq I_{zmax} + I_{Lmin}}$$

- Problem: The Zener diode in a regulator circuit has a break down voltage of 15 V and power rating of 0.5 W, if the input voltage of 40 V, what is the minimum value of R that prevents Zener diode from being destroyed R_L = 1K ohms
- Solution: Given data Vz = 15 V, Pz = 0.5 W, Vin= 40 V, Vz /Iz =Rz = 450 ohm

  Pz = Vz Iz = Iz = Pz / Vz =0.5/15 =0.033 A= 33.33 mA

Zener Diode Specifications

- Zener diode specifications:

(i) Zener / Breakdown voltage: The Zener / Reverse breakdown voltage ranges from 2.4 V to 200 V, some times it can go up to 1KV while the maximum for the surface mounted device is 47 V

(ii) Current $I_{Z\,max}$: It is the maximum current at the rated Zener voltage 200 µ A to 200 A

(iii) Current $I_{Z\,min}$: it is the minimum value current required for the diode to break down

(iv) Power rating: Maximum power the Zener diode can dissipate ,it is given by the product of the voltage of the diode and current flowing through the diode

(v) Temperature stability: Diodes around 5 V have best stability

(vi) Zener Resistance R_Z : it is the resistance to the Zener diode exhibits

Continued…………

- Problem:

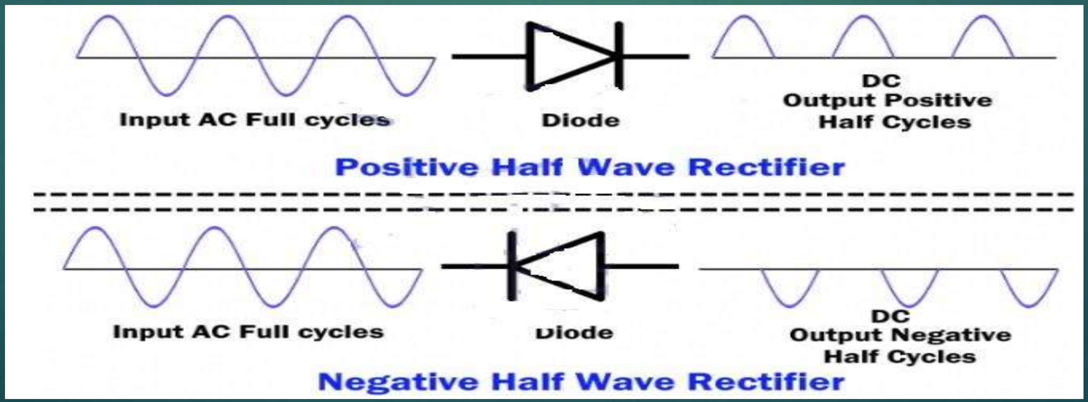
1) In a Zener diode regulator circuit, V_L =15V,maximum load current is 100 mA, input voltage range is 18V to 20V, R =10 ohm.

Determine,

a) Maximum power dissipated by R
b) Minimum diode current.
c) The power that must be dissipated by R if the output is accidentally short circuited.

Diode Application : Rectifiers

- Rectifier : Rectifier is a device which converts pure AC to pulsating DC
- Rectifier is an electrical device that is made of one or more than one diodes that converts alternating current (AC) into direct current (DC)
- It is used for the rectification
- What is Rectification:
- Rectification is the process of conversion of the alternating current (which periodically changes direction) into direct current (flow in a single direction)



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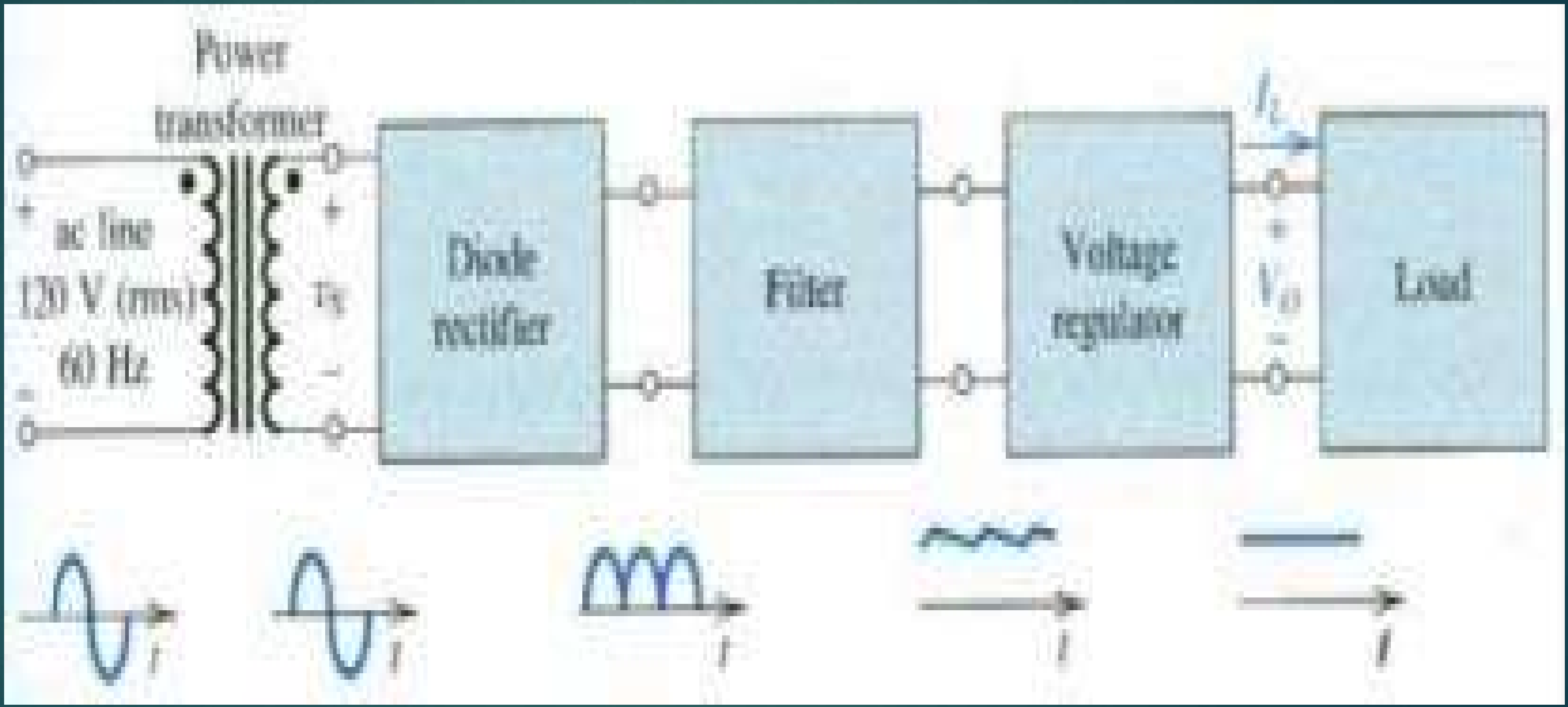
- Block diagram of DC Supply :



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- Types of Rectifiers :There are three types of rectifiers
- (i) Half wave rectifier (1 - diode)
- (ii) Full wave rectifier (2 - diodes)
- (iii) Full wave Bridge rectifier (4 - diodes)
- The main function of p-n junction diode is in rectification circuits
- These circuits are used to describe the conversion of AC signal to DC in power supplies
- Diode rectifier gives an alternating voltage which pulsates in accordance with time
- Filter smoothens the pulsation in the voltage
- What is half wave rectifier:
- In a half wave rectifier one half of each ac input cycle is rectified
- When the PN junction diode is forward biased ,it gives little resistance and when it is

Continued…………

- Reverse biased it provides high resistance
- During the positive half cycle diode is forward biased when the input voltage is applied
- During the negative half cycle diode is reverse biased when the input voltage is applied
- During alternate half cycles the optimum results can be obtained
- Working of Half wave Rectifier:
- The half wave rectifier has both positive and negative cycles
- During the positive half of the input the current will flow from positive to negative which will generates only a positive half cycle of the AC supply
- When AC supply is applied to the transformer the voltage will be decreasing at the secondary winding of the diode
- All the variations in the AC supply will reduce and we will get the pulsating DC voltage to the load resistor

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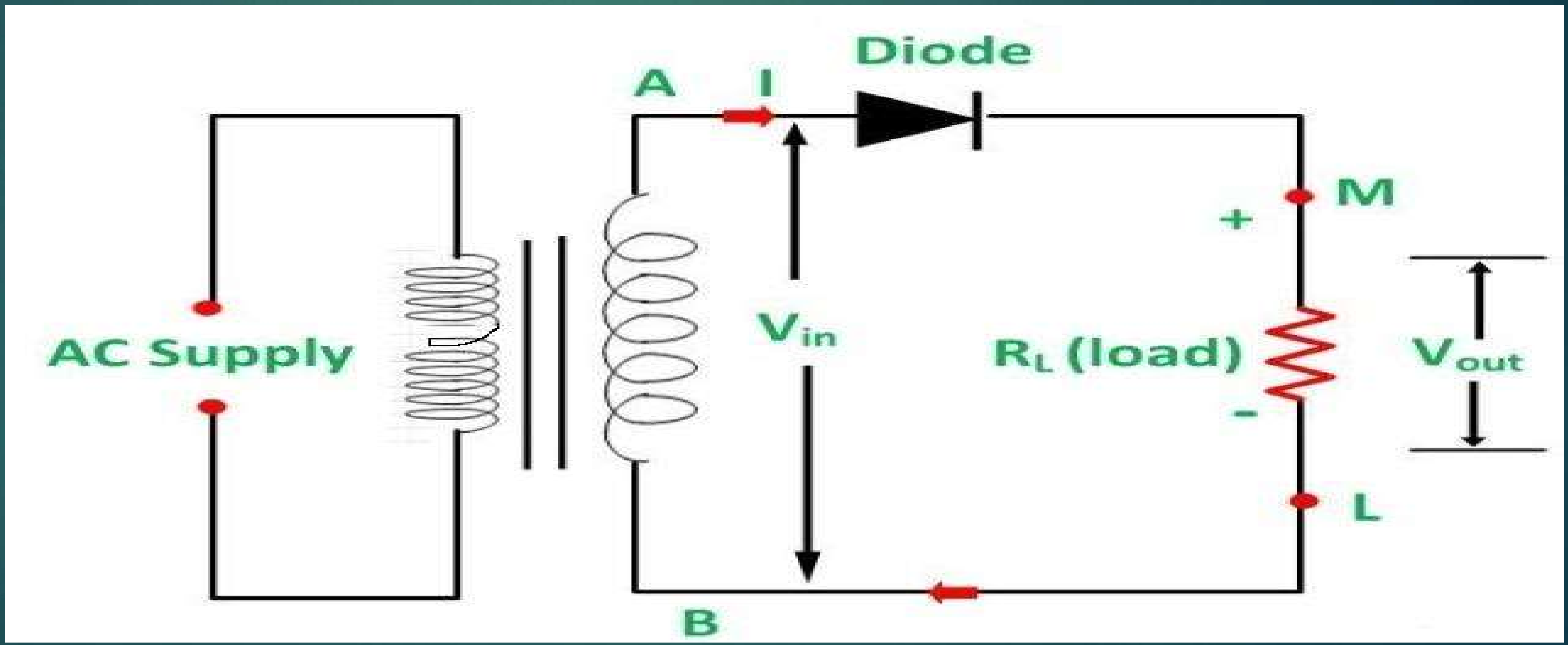
- During the negative half cycle the will flow from negative to positive and the diode will be reverse biased
- Thus at the output side there will be no current generated



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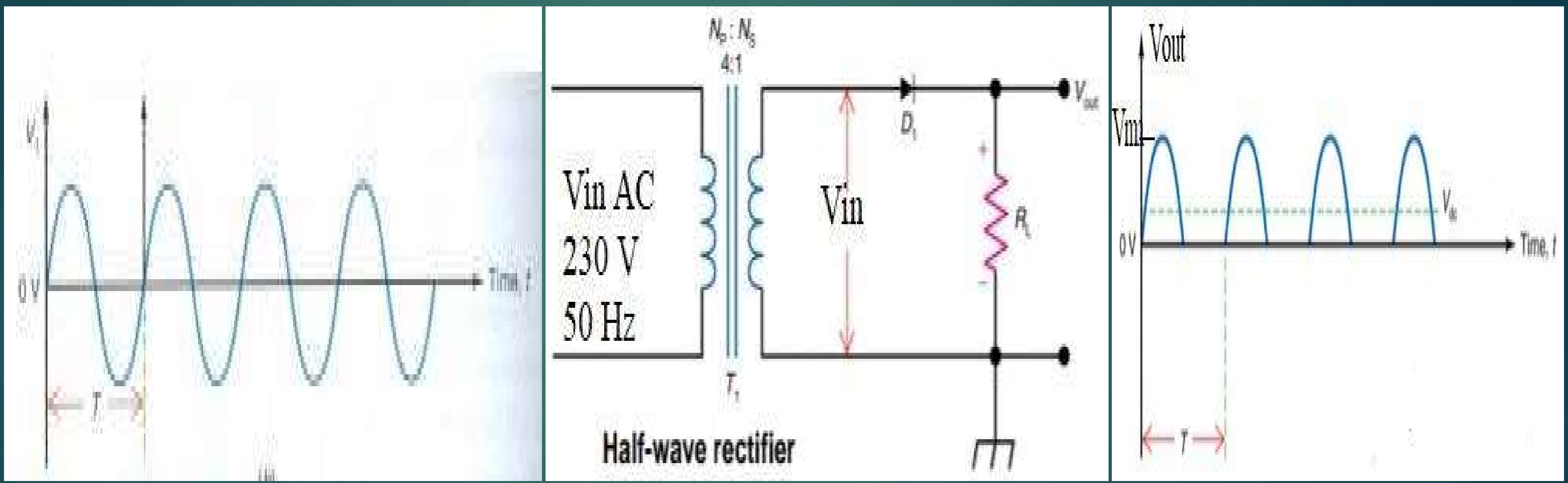
- Half wave rectifier circuit & wave forms :



Characteristics of Half wave rectifier

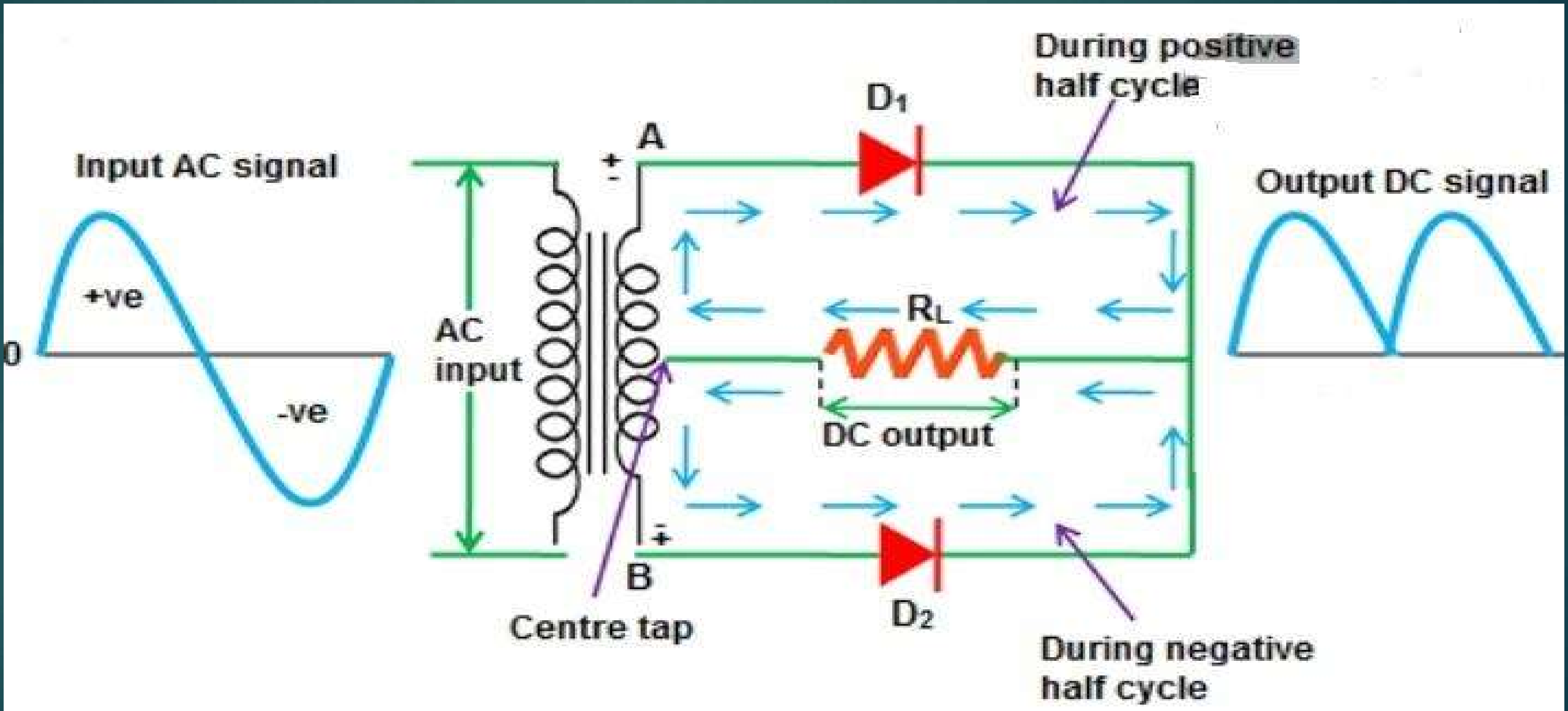
- Ripple factor : It is the ratio of RMS value of the AC component of the output voltage to the DC component of the output voltage

$$\gamma = \sqrt{\left(\frac{V_{rms}}{V_{DC}}\right)^2 - 1}$$

- DC Current (I_{DC}): DC current is given by $I_{DC} = I_{max} / \Pi$, Imax is the maximum DC load current
- DC Voltage (V_{DC}): The output DC voltage appears at the load resistor R_L which is obtained by multiplying output DC voltage with the load resistor R_L $V_{DC} = V_{smax} / \Pi$, V_{smax} is the maximum secondary voltage
- Form factor : The form factor is defined as the ratio of RMS value to the DC value

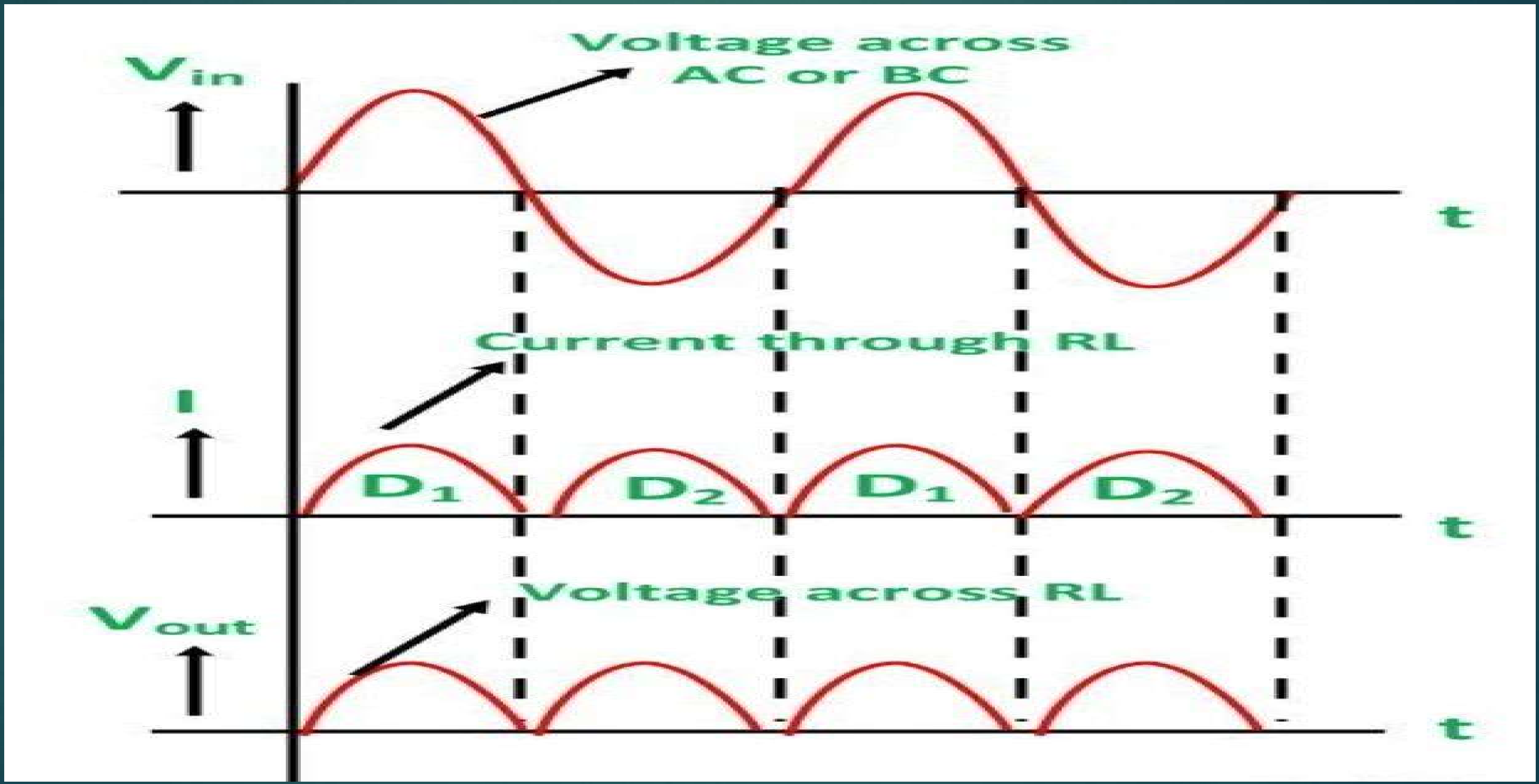
Full Wave Rectifier

- Full wave Rectifier Circuit & Wave forms :



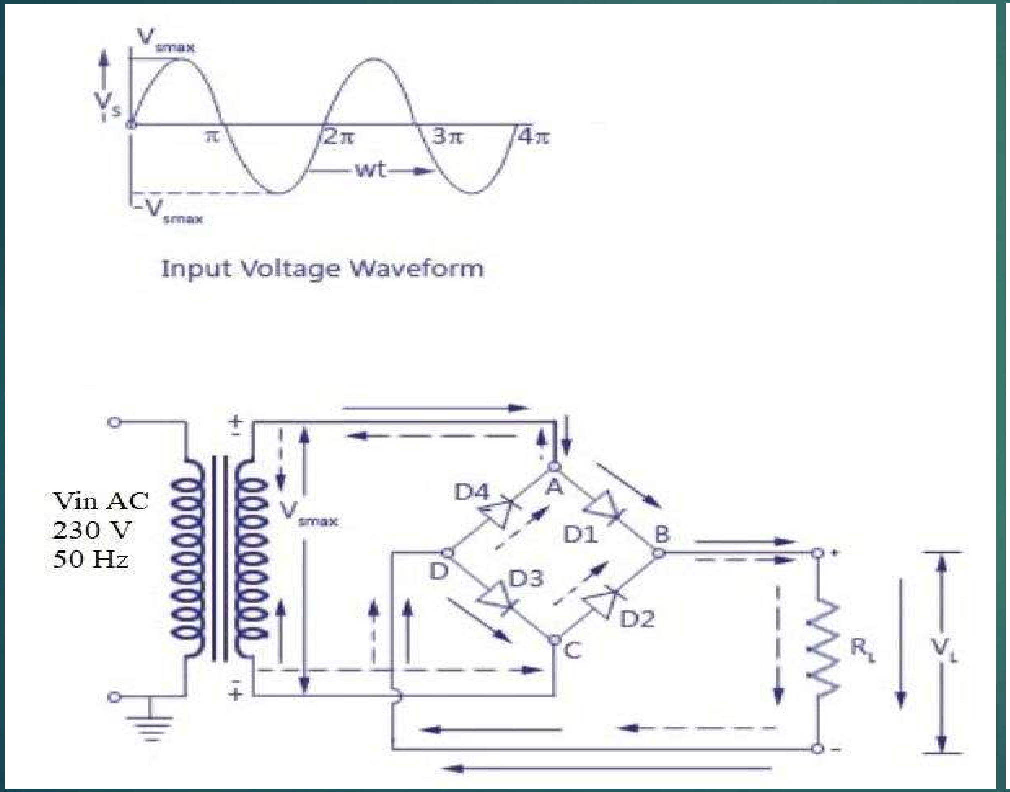
Full Wave Rectifier

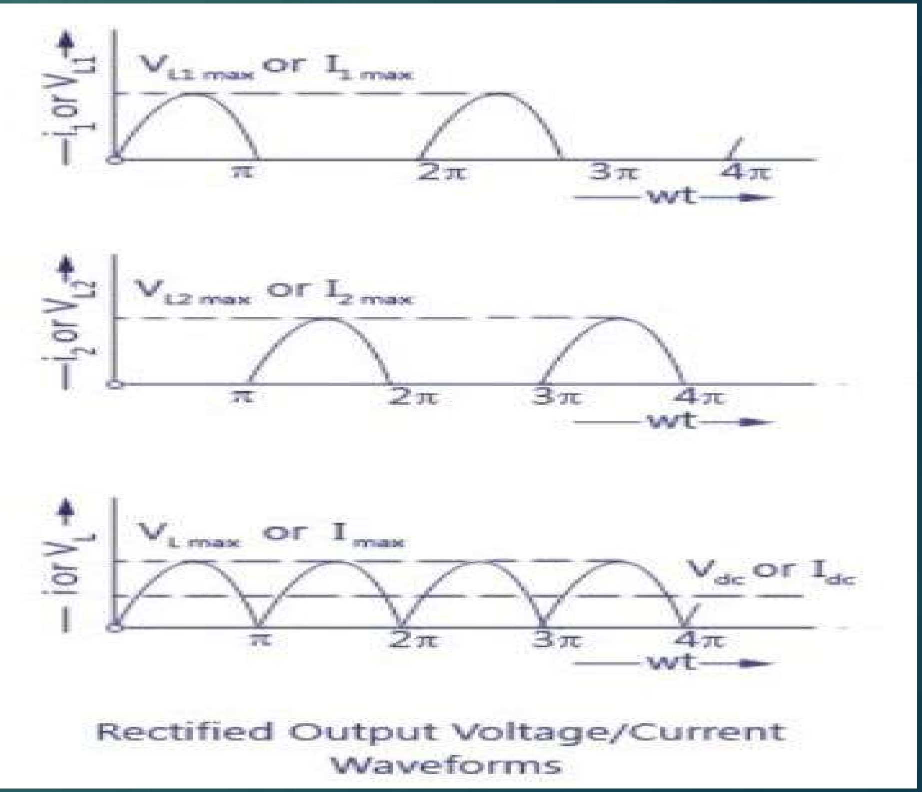
- Full wave Rectifier Circuit & Wave forms :



Bridge Rectifier

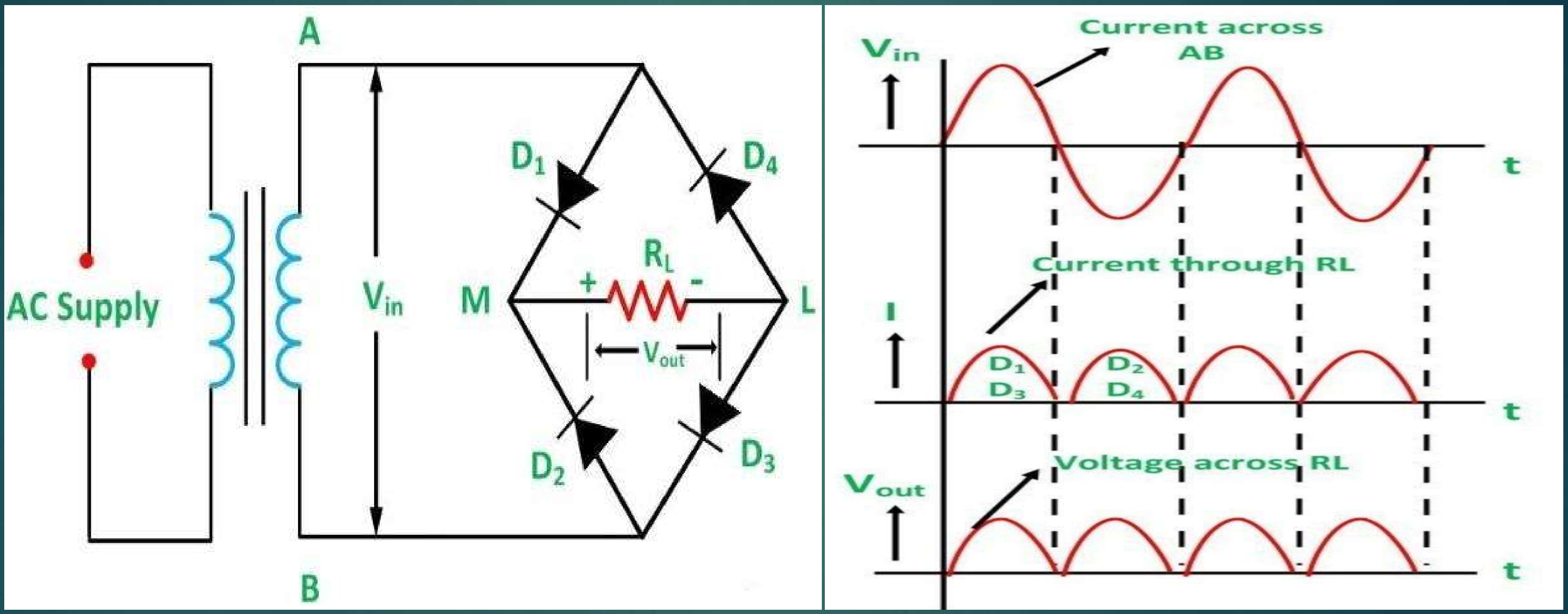
- Bridge rectifier circuit & wave forms :





Bridge Rectifier

- Bridge rectifier circuit & wave forms :



Bridge Rectifier

- Bridge rectifier Equivalent circuit :

During the Positive Half Cycle

During the Negative Half Cycle