SRI MANAKULA VINAYAGAR ENGINEERING COLLEGE
(An Autonomous Institution)
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Madagadipet, Puducherry - 605 107

BASIC ELECTRICAL AND ELECTRONICS ENGINEERING

PART-B
ELECTRONICS

1. SEMICONDUCTORS DIODE AND ITS APPLICATION

UNIT I SEMICONDUCTOR DIODE AND APPLICATION

- Introduction
- Semiconductor material
- Doping
- Intrinsic and Extrinsic semiconductor
- PN junction diode
- Structure & Characteristics

Diode applications:

- Rectifiers- half wave rectifier and full wave rectifier

- Zener diode
  - VI Characteristics
  - Zener as regulator
  - LED
  - PV cell/Solar panel

Course Outcome

- *After completion of the course, the students will be able to*

Use the PN junction diode for applications like rectifiers, and Zener as regulator circuits

SEMICONDUCTOR

- The material whose electrical conductivity lie between those of conductors and insulators are known as Semiconductors

- Examples
  - Germanium (Ge)
  - Silicon (Si)
  - Gallium Arsenide (GaAs)
  - Cadmium Sulfide (CdS)
  - Lead Telluride etc…

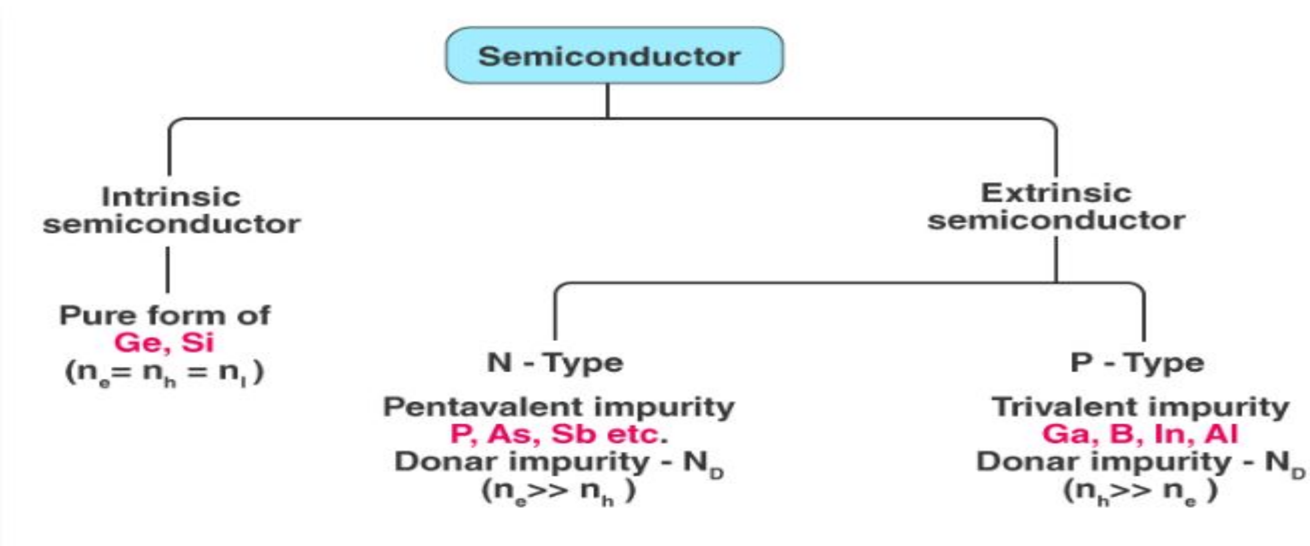
Semiconductors can conduct electricity under preferable conditions or circumstances

Properties of Semiconductors

- Semiconductor acts like an insulator at Zero Kelvin. On increasing the temperature, it works as a conductor.
- Due to their exceptional electrical properties, semiconductors can be modified by doping to make semiconductor devices suitable for energy conversion, switches and amplifiers.
- Lesser power losses.
- Smaller in size and possess less weight.
- The resistance of semiconductor materials decreases with the increase in temperature and vice-versa.

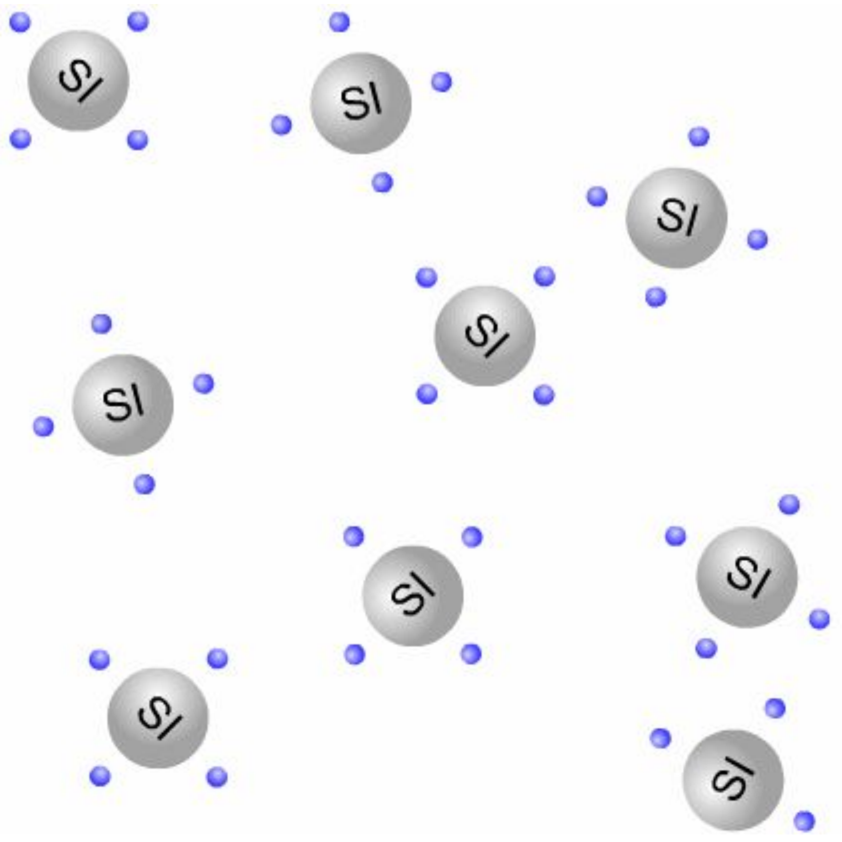
SEMICONDUCTOR TYPES

- Intrinsic semiconductor
- Extrinsic semiconductor
    - N – Type semiconductor
    - P – Type semiconductor



INTRINSIC SEMICONDUCTOR

- No impurities
- Pure semiconductor
- No semiconductors are truly pure but less amount of impurity level
- For germanium – Impurity level less than 1 part in 10^8 parts
- For Silicon – Impurity level less than 1 part in 10^{12} parts



EXTRINSIC SEMICONDUCTOR

- Making intrinsic semiconductor into useful
- Also called as impurity semiconductor
- The process of adding impurities to a semiconductor is called DOPING
- Doping 1 atom of impurity per 10^6 to 10^8 semiconductor atom
- Purpose to add impurity to increase either No. of free electrons (or) holes in a semiconductor

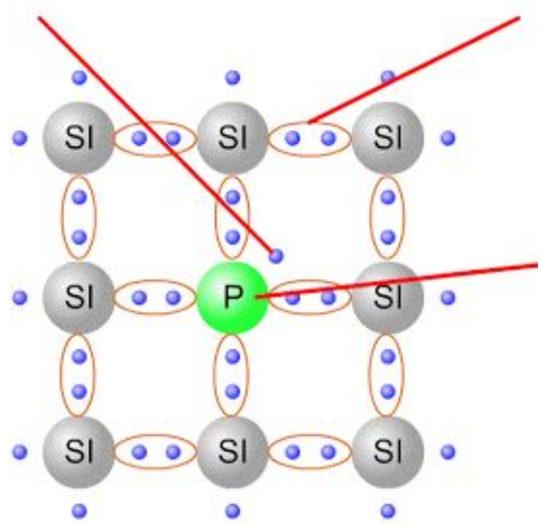
EXTRINSIC SEMICONDUCTOR

- Two types of impurities added either Pentavalent impurity and trivalent impurity

  - N- type semiconductors
  - P- type semiconductors

N- Type Semiconductors

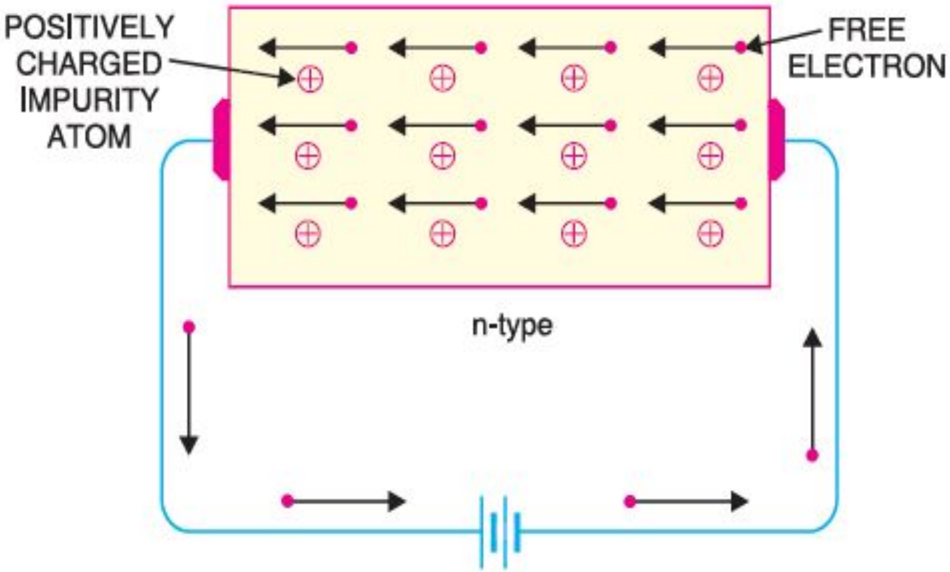
- Small amount of pentavalent impurity (5 Valence electrons) is added
  - Antimony (Sb)
  - Phosphorous (P)
  - Arsenic (As)
  - Bismuth (Bi)



- Donates excess e- carriers
- Leads to large amount of free e-
- Impurities which provide n-type is called donor impurities

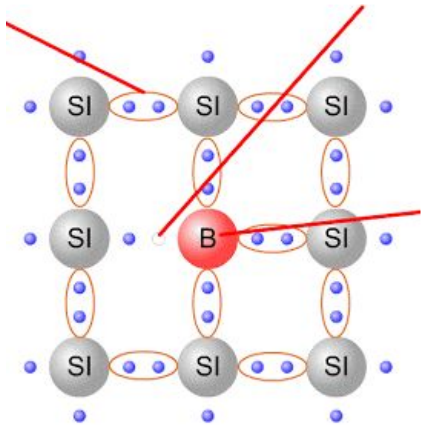
N-TYPE Conductivity

- Free e- is more than the holes, so e- are majority carrier and hole are minority carrier
- Current conduction is predominantly by free e- is called n-type and electron type conductivity



P- Type Semiconductors

- Small amount of trivalent impurities (3 valence electrons) is added
  - Indium (In)
  - Gallium (Ga)
  - Boron (B)
  - Aluminium (Al)

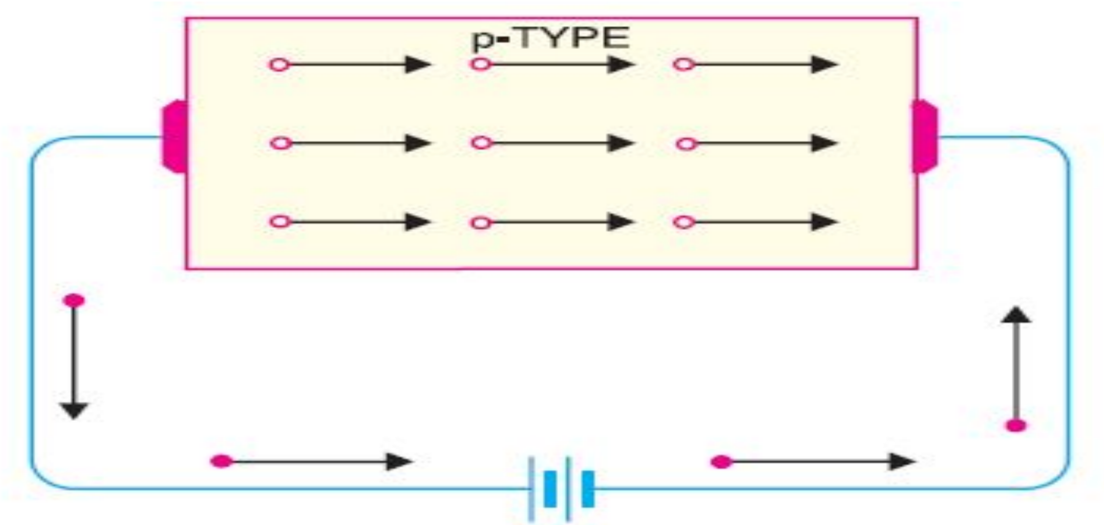


- Create holes to make positive charge carriers
- Leads to large amount of holes
- Impurities which provide p-type is called acceptor impurities

P-Type Conductivity

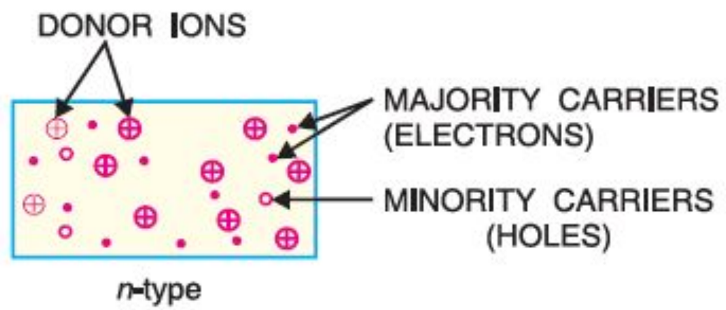
- Holes is more than free e-, so holes are majority carrier and e- are minority carrier

- Current conduction is predominantly by hole(+ve charge) is called p-type and hole type conductivity

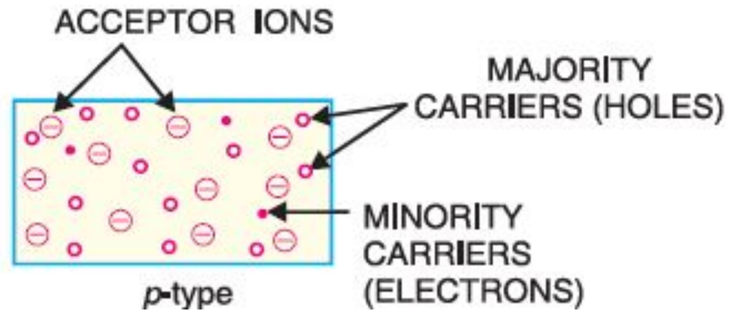


Majority and Minority carriers

- In N-type semiconductor
  - Majority carrier is free electrons
  - Minority carrier is holes



- In P-type semiconductor
  - Majority carrier is holes
  - Minority carrier is free electrons



Difference

Intrinsic Semiconductor	Extrinsic Semiconductor
Pure semiconductor	Impure semiconductor
Density of electrons is equal to the density of holes	Density of electrons is not equal to the density of holes
Electrical conductivity is low	Electrical conductivity is high
Dependence on temperature only	Dependence on temperature as well as on the amount of impurity
No impurities	Trivalent impurity, pentavalent impurity

PN JUNCTION

PN JUNCTION

- A p-type semiconductor is suitably joined to n-type semiconductor, the contact surface is called PN JUNCTION

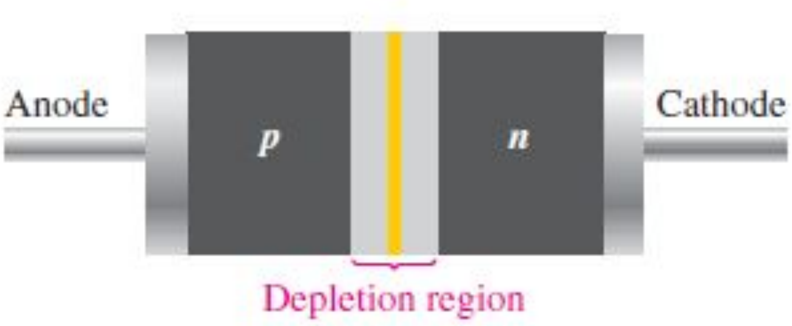
- Cannot formed by simple joining (or) welding the two pieces together

- PN junction is fabricated by special techniques
  - Commonly used method is alloying

DIODE

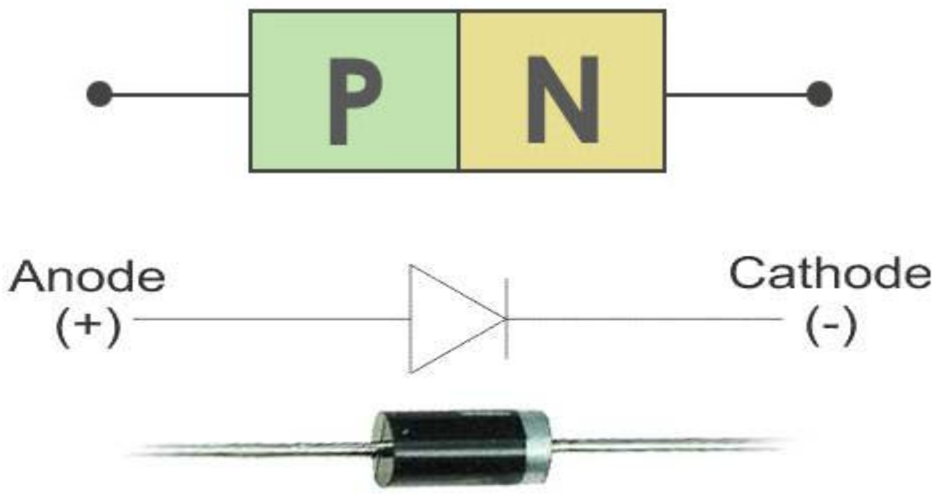
- A diode is a device which only allows unidirectional flow of current if operated within a rated specified voltage level
- The name diode is derived from "di - ode" which means a device having two electrodes

- **Made from a small piece of semiconductor material,** in which half is doped as a *p region and half is doped as an n region with a pn* junction and depletion region in between.



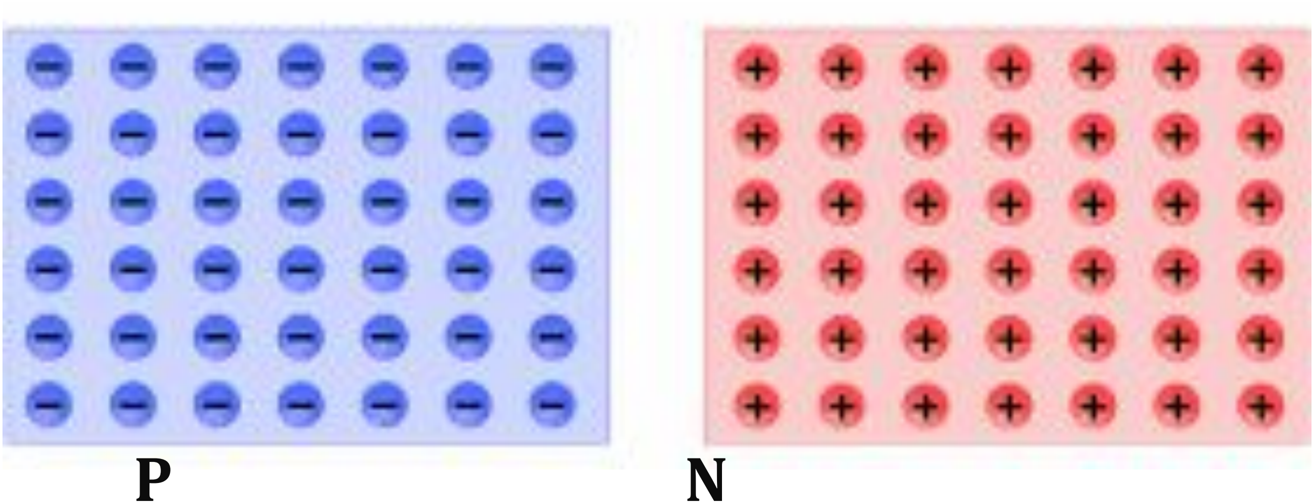
PN JUNCTION DIODE

- A PN junction diode consists of a PN Junction
- Formed either in Germanium or Silicon crystal
- Two terminals namely Anode and Cathode
- 1N 4007 (1N – single junction of different material 4007 – diode identification number)



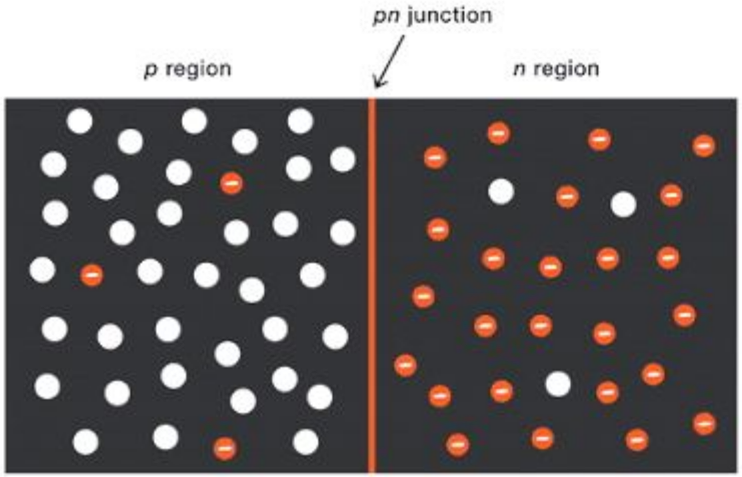
Formation of Depletion Layer

- The free e- and holes near the junction in N region and P region begin to diffuse across the junction and combine near the junction to create Positive and Negative Charges
- These two layers of Positive and Negative charges form the Depletion Region (or) Depletion Layer



Depletion region

- The term depletion means Empty of charge carries
- This region is thin compared to N and P region
- This region behaves like insulator

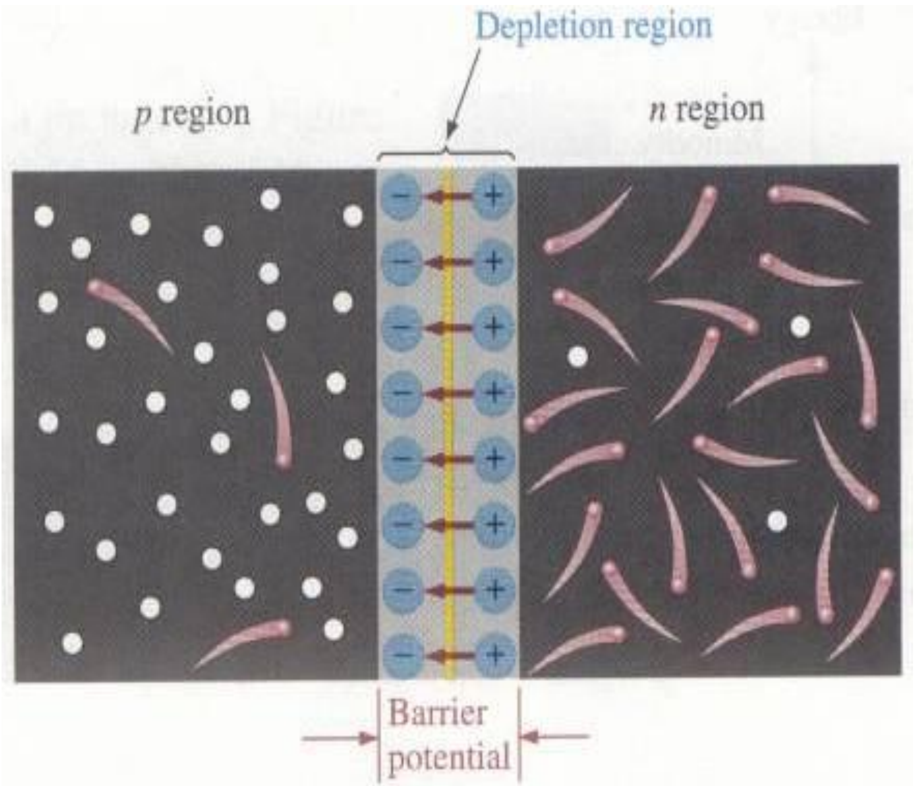


Junction or Barrier Voltage

- Contains fixed rows of oppositely charged ions on its two sides
- Because of this charge separation, an ELECTRIC POTENTAIL (V_B) is established across the junction even before external voltage

- This Electrical Potential is called Junction or Potential Barrier

The barrier potential $V_B \cong 0.6 - 0.7\text{V}$ for Si and 0.3V for Ge at 300K : as $T\uparrow, V_B\downarrow$.



Unbiased PN Junction

- A PN junction, across which No external voltage source is connected is known as Unbiased PN Junction
- Minority carrier current flows in a direction opposite to Minority carrier current
- No Net flow of current

Biasing the PN-Junction

- There is no movement of charge through a PN-JUNCTION at equilibrium.

- The term Bias in Electronics refers to the use of DC VOLTAGE to establish certain operating condition for an Electronic Device.

- A PN Junction connected to an external voltage source is called Biased PN Junction

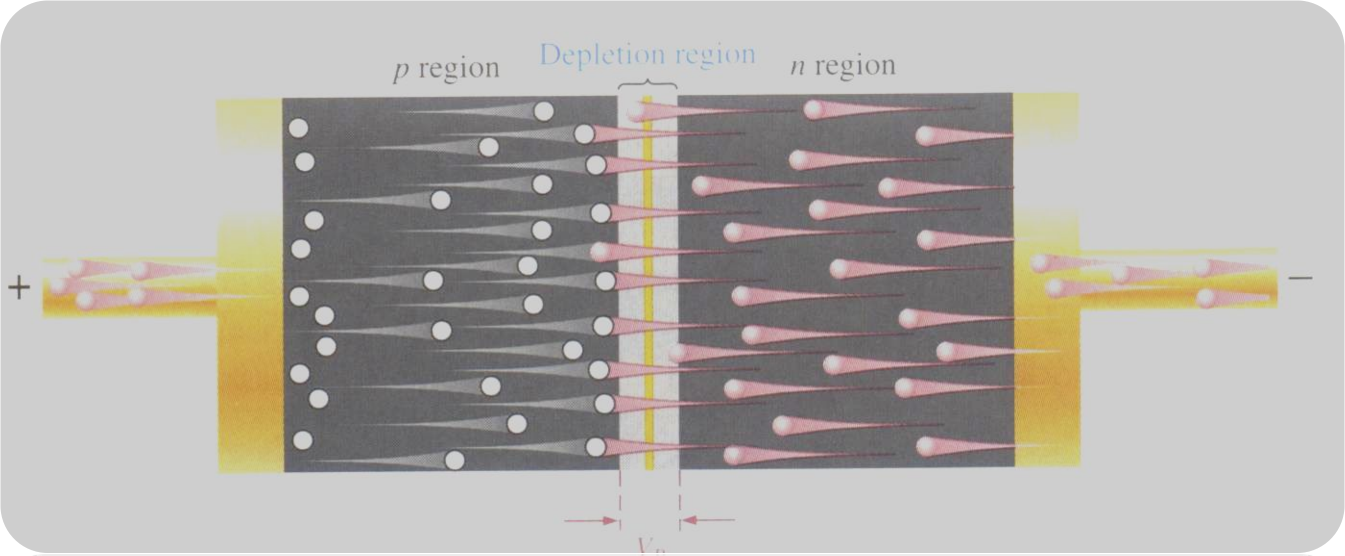
Biasing of PN Junction

- The width of the depletion region is controlled by an external voltage across the PN junction
- Resistance is controlled to control the flow of current

- Two types of biasing
  - Forward biasing
  - Reverse biasing

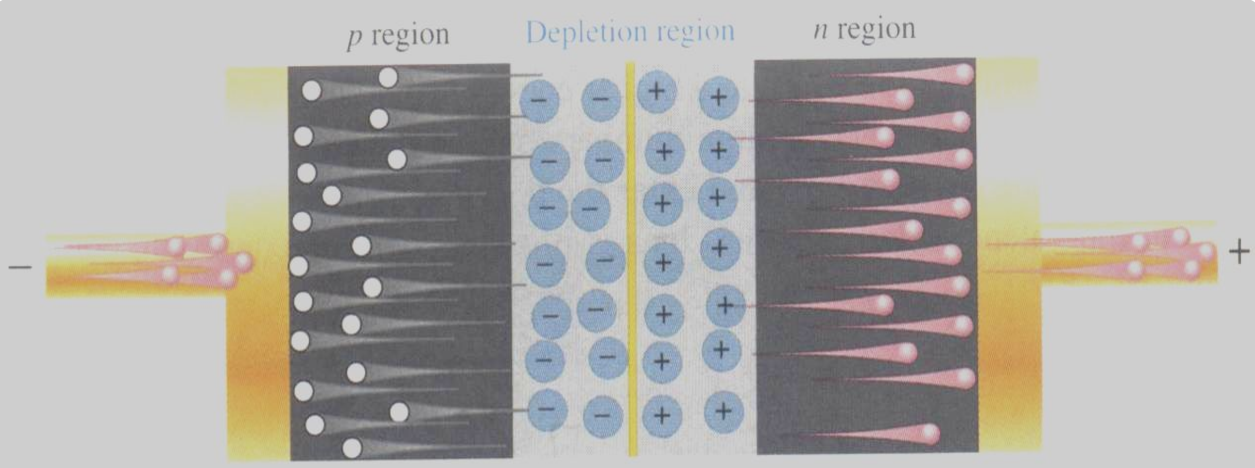
Forward Bias

- *Dc voltage positive terminal connected to the p region and negative to the n region*.
- Width of depletion region is reduced
- A large amount of current flows through the junction under this condition.



Reverse Bias

- *DC voltage negative terminal connected to the p region and positive to the n region*.
- *Depletion region widens* until its potential difference equals the bias voltage, *majority-carrier current ceases*.



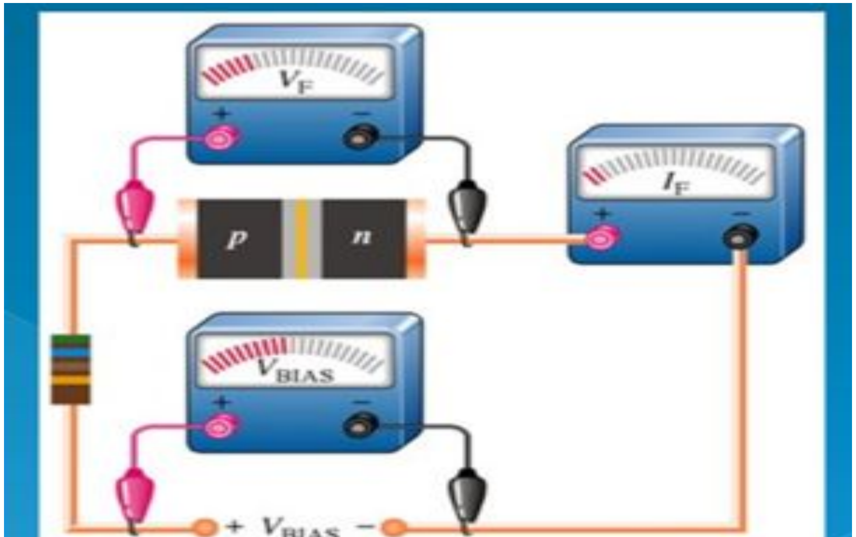
(a) There is transient current as depletion region widens.

CHARACTERISTICS OF PN JUNCTION DIODE

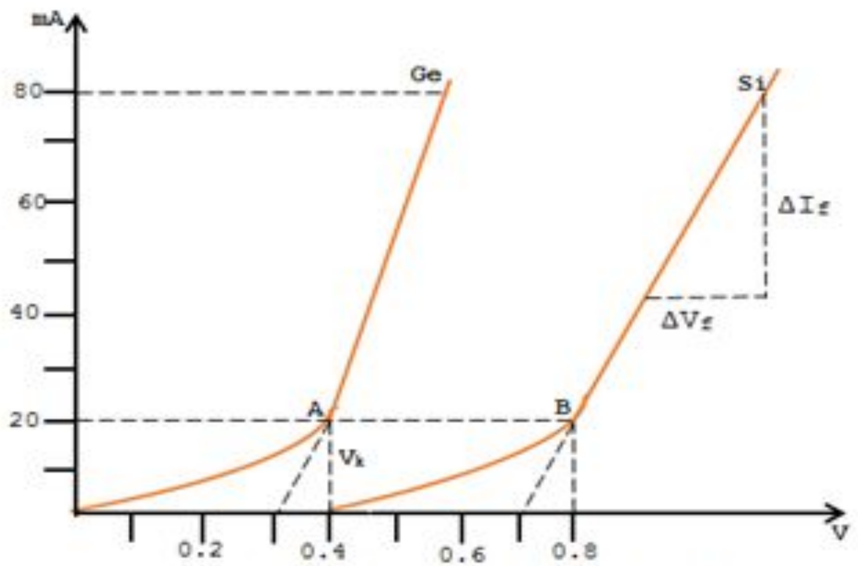
- To know the behavior (response) of the device when it is connected to electrical circuits
- Obtained by graph known as volt-ampere (or) VI characteristics (or) simply characteristics
- Graph drawn between voltage applied across the device and the current flows through it

FORWARD CHARACTERISTICS

- It is seen that the forward current rises exponentially with the applied forward voltage.
- The point A and B is known as threshold voltage V_{th} (OR) CUT IN VOLTAGE (OR) KNEE VOLTAGE V_k
- Its value for silicon junction is about 0.7 volt
- Its value for germanium junction is about 0.3 volt

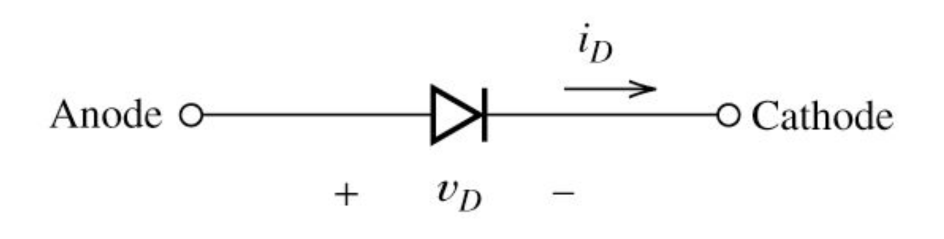


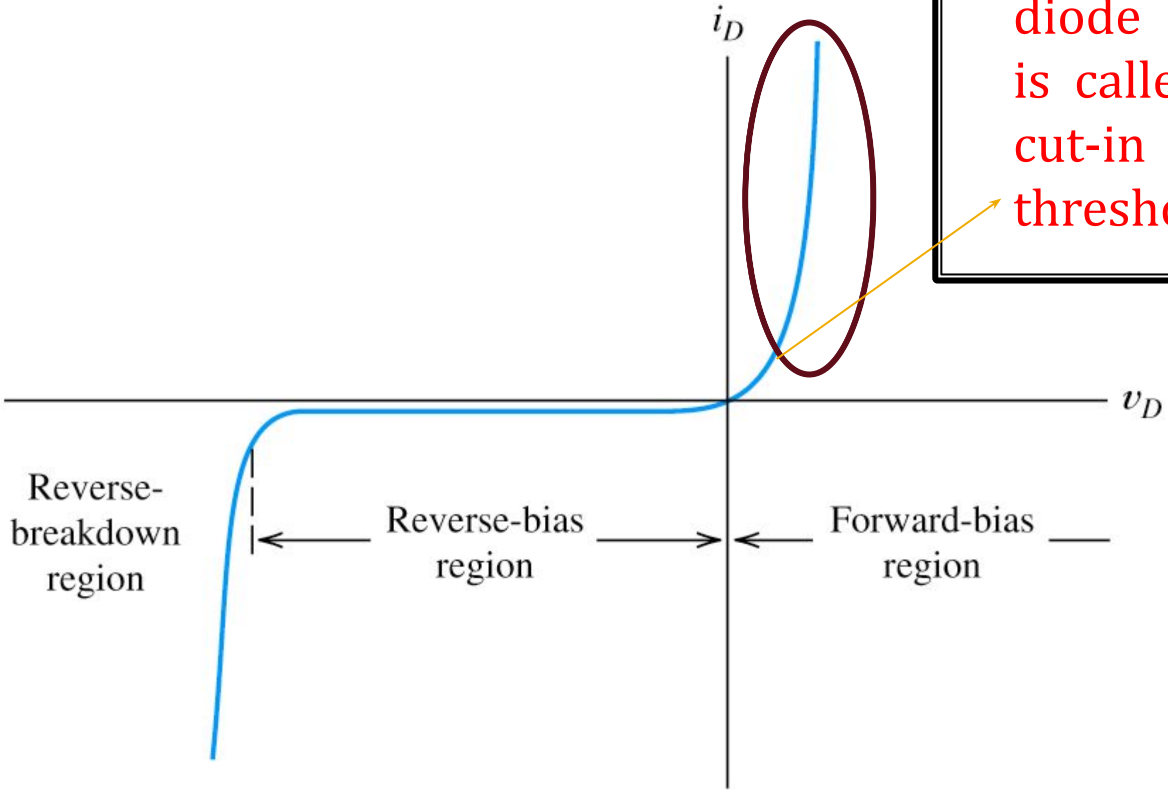
(a) Small forward-bias voltage ($V_F < 0.7$ V), very small forward current.



Forward Biased VI Characteristic

Biasing the PN-Junction
Forward Bias

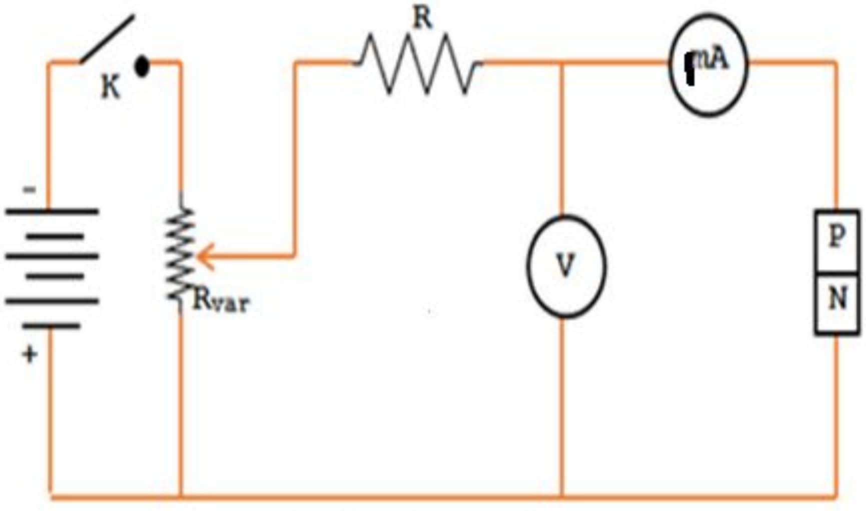


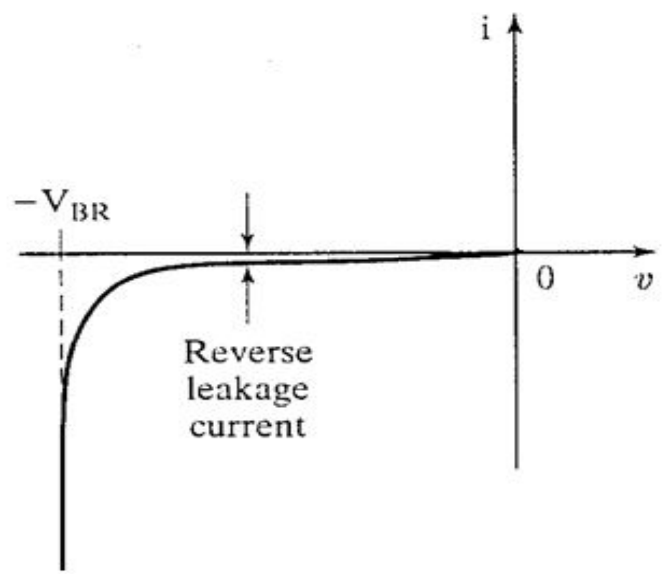


- The voltage at which the diode starts conducting, is called a knee voltage, cut-in voltage or threshold voltage

REVERSE CHARACTERISTICS

- It is seen that as reverse voltage is increases from zero; the reverse current quickly rises to its maximum or saturation value.
- This leakage current is due to minority carrier in terms of µA
- Leakage current of Ge junction is much more than that of Si junction
- V_{BR} – Reverse Breakdown voltage

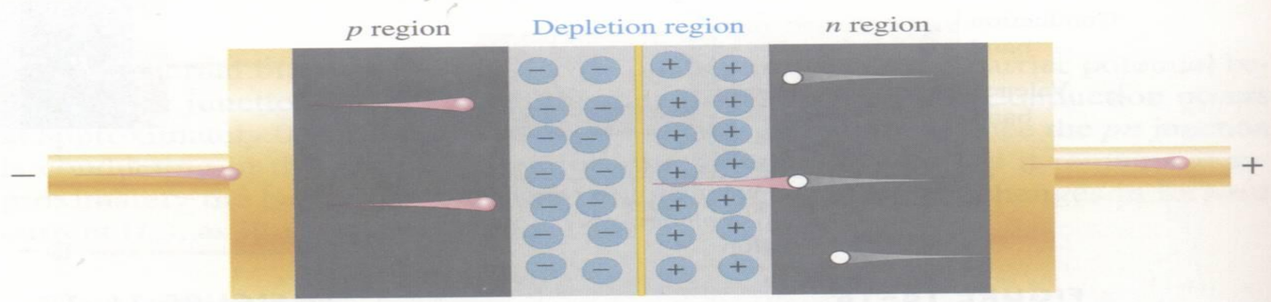




Reverse Bias:

majority-carrier current ceases.

* However, there is still a very small current produced by minority carriers.

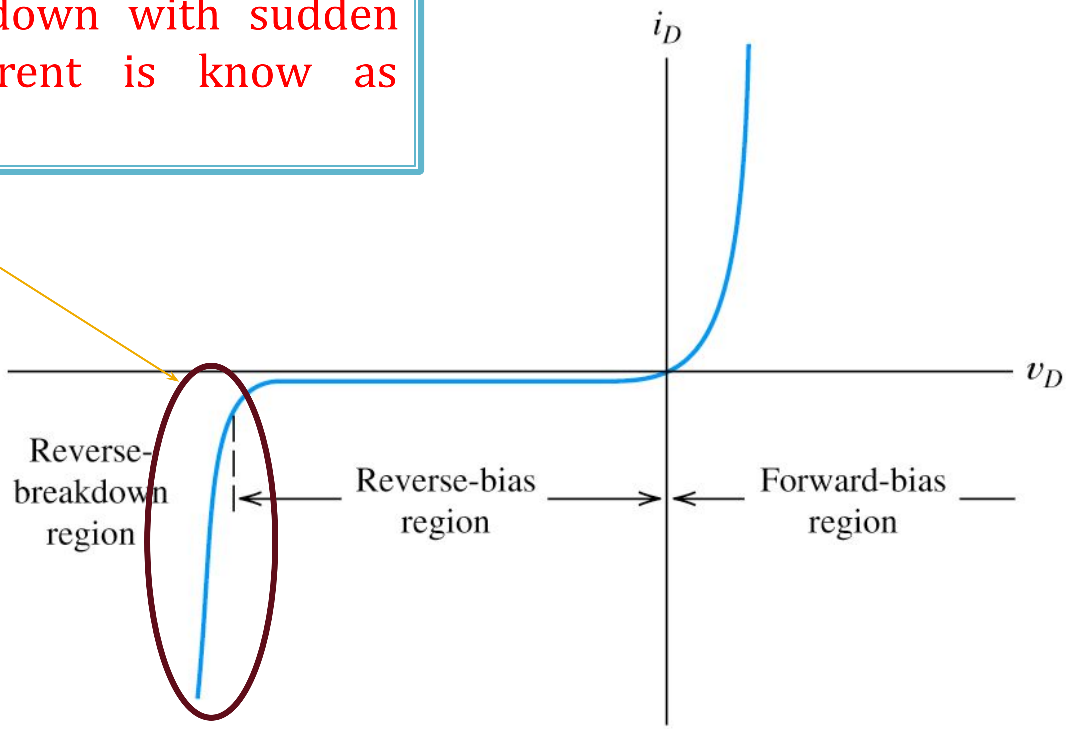


(b) Majority current ceases when barrier potential equals bias voltage. There is an extremely small reverse current due to minority carriers.

Biasing the PN-Junction

* ***Reverse Breakdown:*** As reverse voltage reach certain value, avalanche occurs and generates large current.

- The minimum reverse voltage at which PN junction breaks down with sudden rise in reverse current is know as breakdown voltage



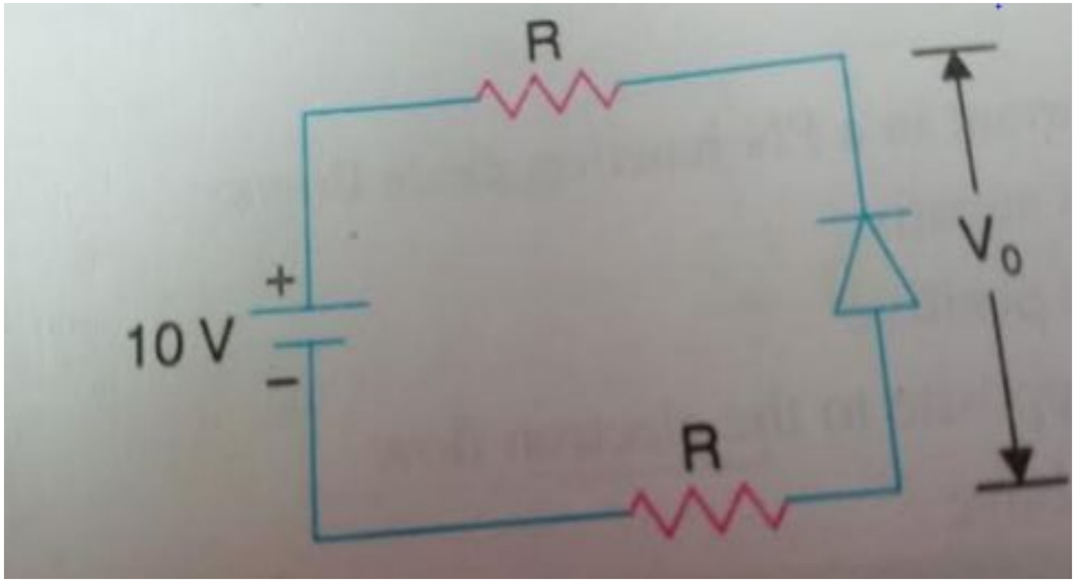
(b) Volt–ampere characteristic

TYPES OF DIODE

- The **types of diode** are as follow-
  - Zener diode
  - PN Junction diode
  - Tunnel diode
  - Varactor diode
  - Schottky diode
  - Photo diode
  - PIN diode
  - Laser diode
  - Avalanche diode
  - Light emitting diode

EXAMPLE

The approximate value of output voltage across the diode is



(A) ZERO

(B) 10Volt

(C) Dependent on the value of R

STATIC AND DYNAMIC RESISTANCE

- **Diode resistance** can be defined as the effective opposition offered by the diode to the flow of current through it.
- Ideally speaking, a diode is expected to offer zero resistance when forward biased and infinite resistance when reverse biased.
  - The forward resistance is nothing but the resistance offered by the diode when the diode is working in its forward biased condition
  - Forward resistance is classified into two types viz., static or dynamic depending on whether the current flowing through the device is DC (Direct Current) or AC (Alternating Current), respectively.

Static or DC Resistance

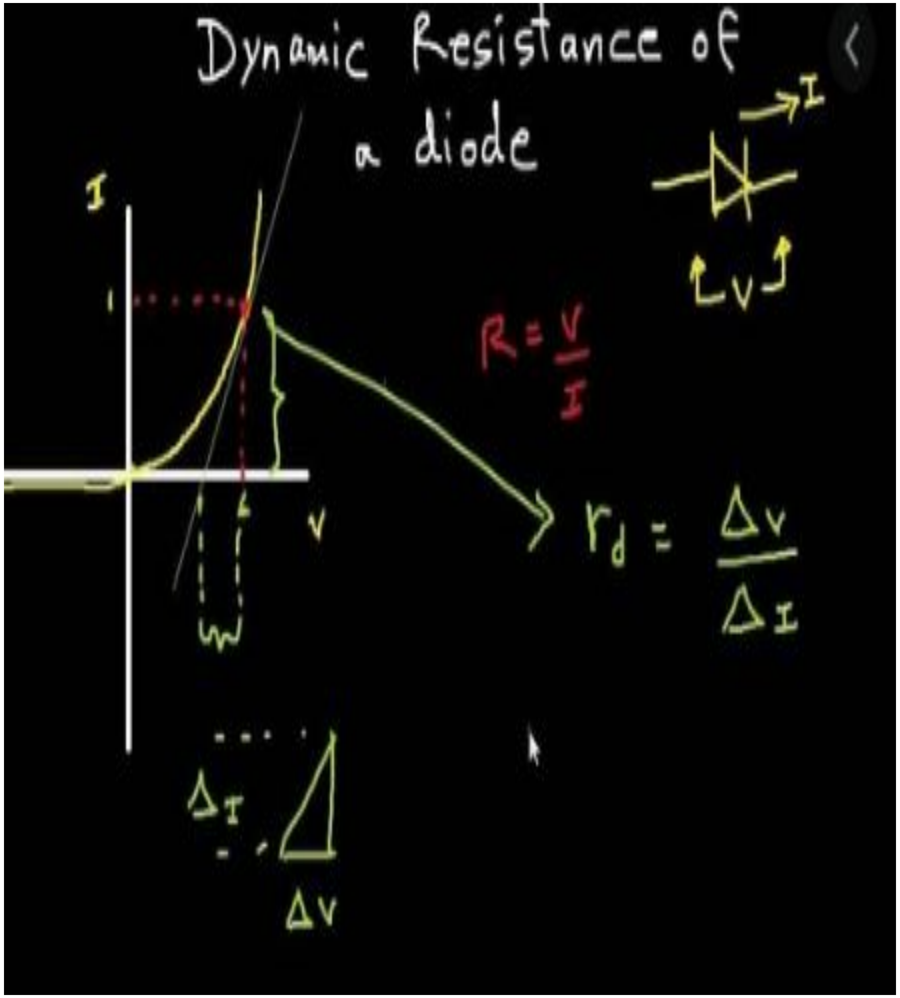
- It is the resistance offered by the diode to the flow of DC through it when we apply a DC voltage to it. Mathematically the static resistance is expressed as the ratio of DC voltage applied across the diode terminals to the DC flowing through it

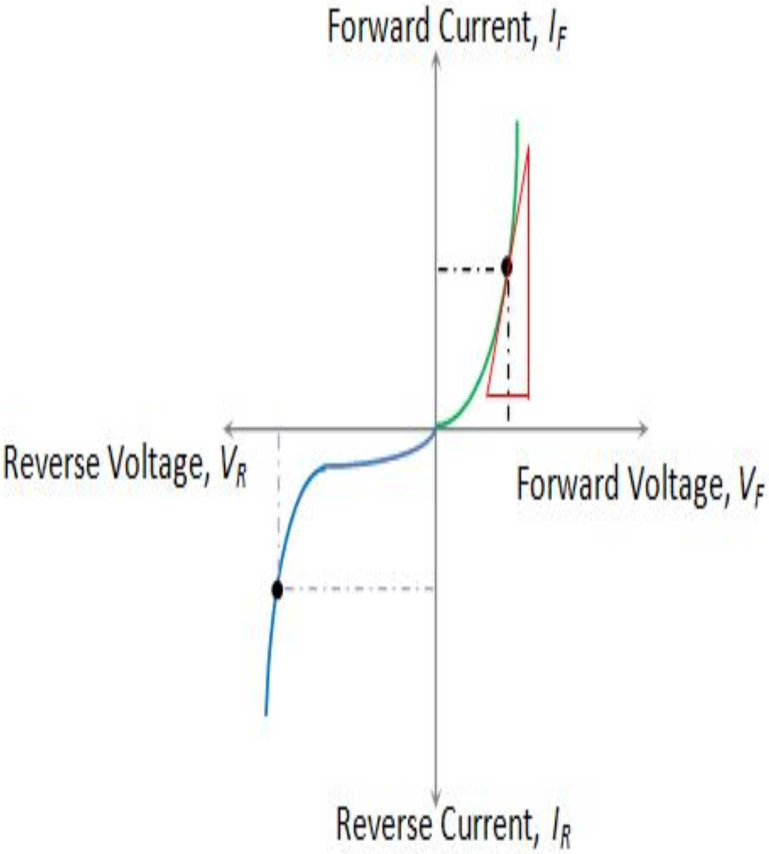
$$R_{dc} = \frac{V_{dc}}{I_{dc}}$$

Dynamic or AC Resistance

- It is the resistance offered by the diode to the flow of AC through it when we connect it in a circuit which has an AC voltage source as an active circuit element. Mathematically the dynamic resistance is given as the ratio of change in voltage applied across the diode to the resulting change in the current flowing through it.

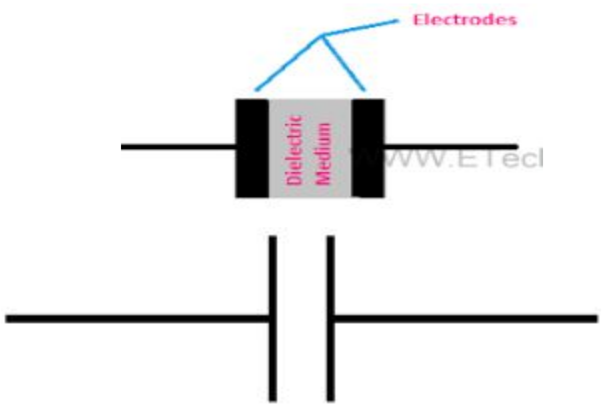
$$r_{ac} = \frac{v_{ac}}{i_{ac}}$$

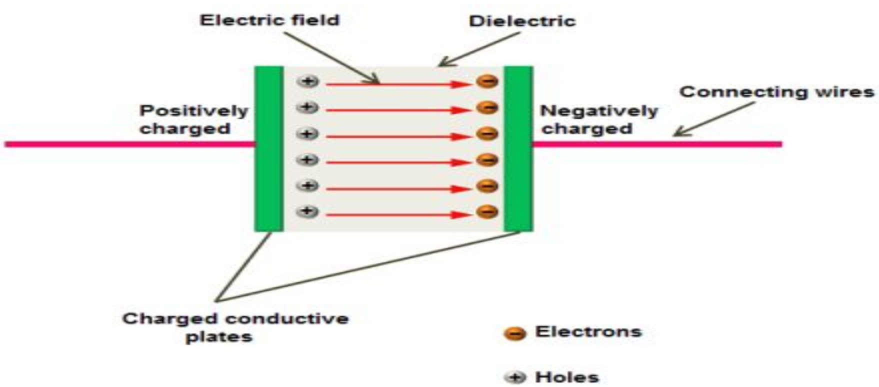

Dynamic Resistance of a diode
I
V
$R = \frac{V}{I}$
$r_d = \frac{\Delta V}{\Delta I}$
ΔI
ΔV


Forward Current, I_F
Reverse Voltage, V_R
Forward Voltage, V_F
Reverse Current, I_R

DEPLETION LAYER CAPACITANCE

- When PN junction is formed, a layer of positive and Negative impurity ions called depletion layer is formed
- This layer will act as dielectric medium between P and N region and has low resistance
- Two region resembles like two plates of capacitor and separated by a dielectric medium





DEPLETION LAYER CAPACITANCE

- The capacitance formed in junction area is called Depletion Layer capacitance.
- Denoted by C_T
- Also called as
  - Depletion region capacitance,
  - Space charge capacitance,
  - Transition Region capacitance
  - Junction Capacitance

DIFFUSE CAPACITANCE

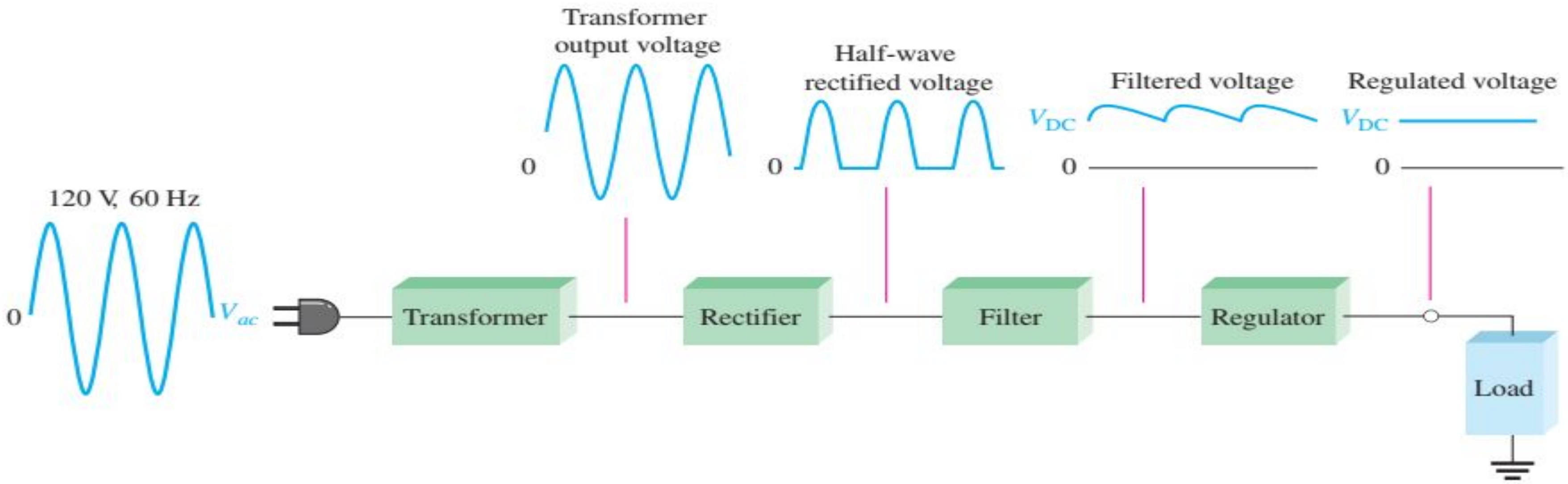
- Capacitance that exists in a forward biased junction is called Diffusion Capacitance or Storage Capacitance
- Denoted by C_D
- Different from depletion region Capacitance
- Larger than Depletion region capacitance
- It arises due to arrangement of minority carrier density

Application of Diodes

RECTIFIERS

RECTIFIERS

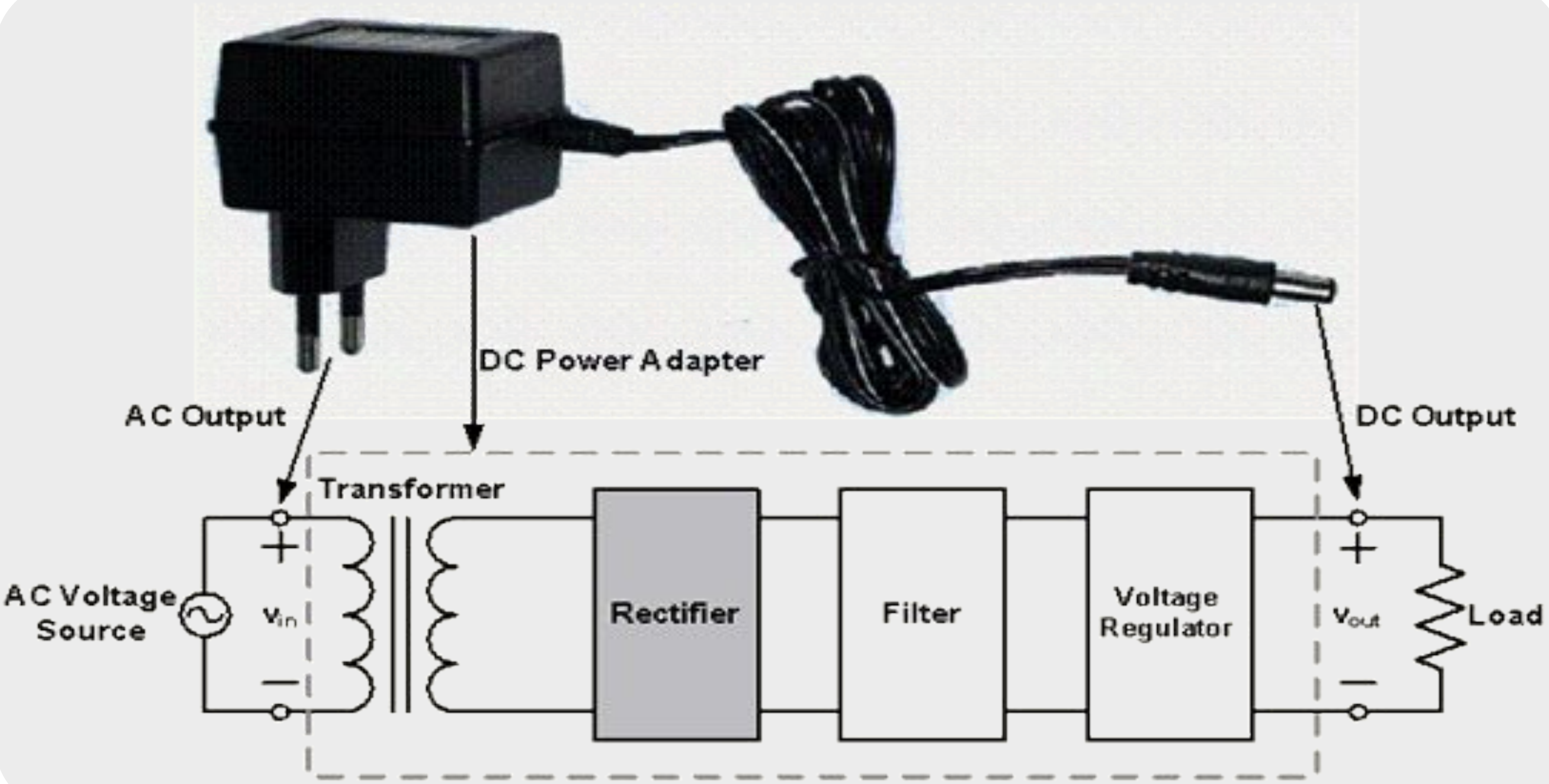
- A circuit which uses one or more diodes to convert the **Alternating Voltage** into **Direct Voltage**



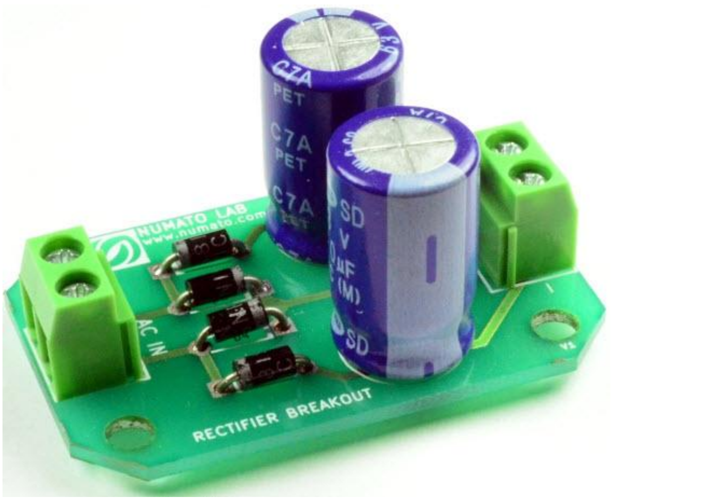
Need for Rectifiers

- This circuits which are used in initial stages of DC Power Supply.
- Every electronic circuit such as amplifiers, needs a DC power source for its operation.
- This DC voltage has to be obtained from AC supply.

Practical Examples

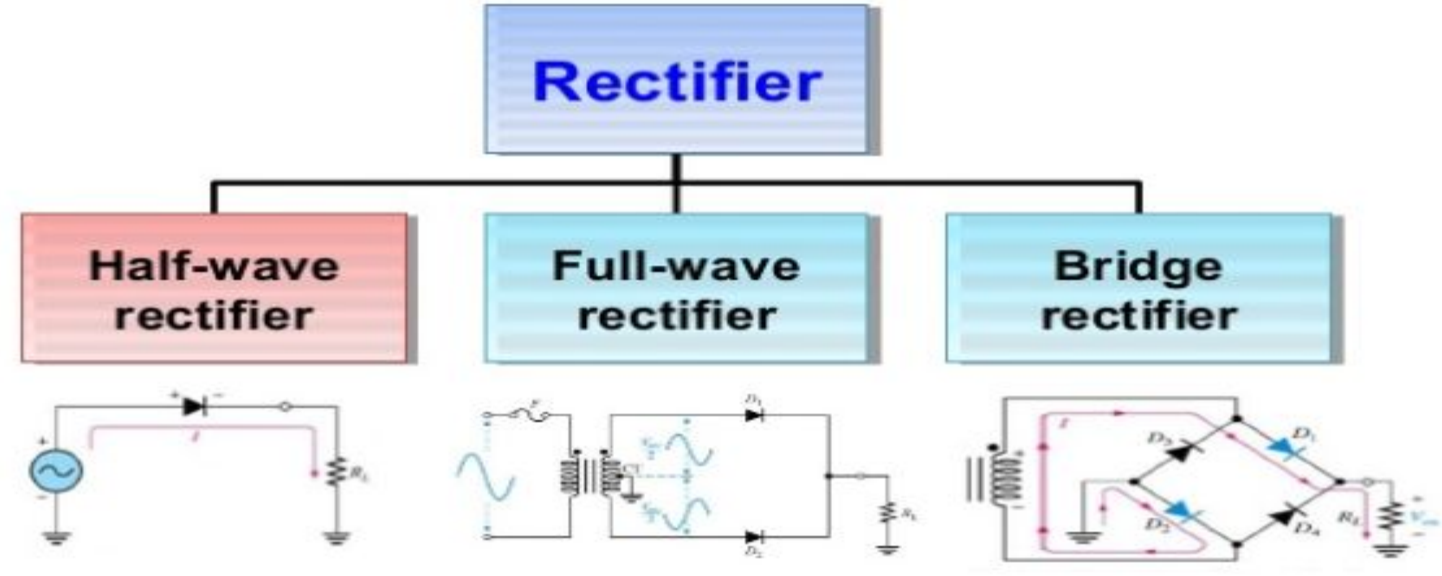


Practical Application of Rectifier



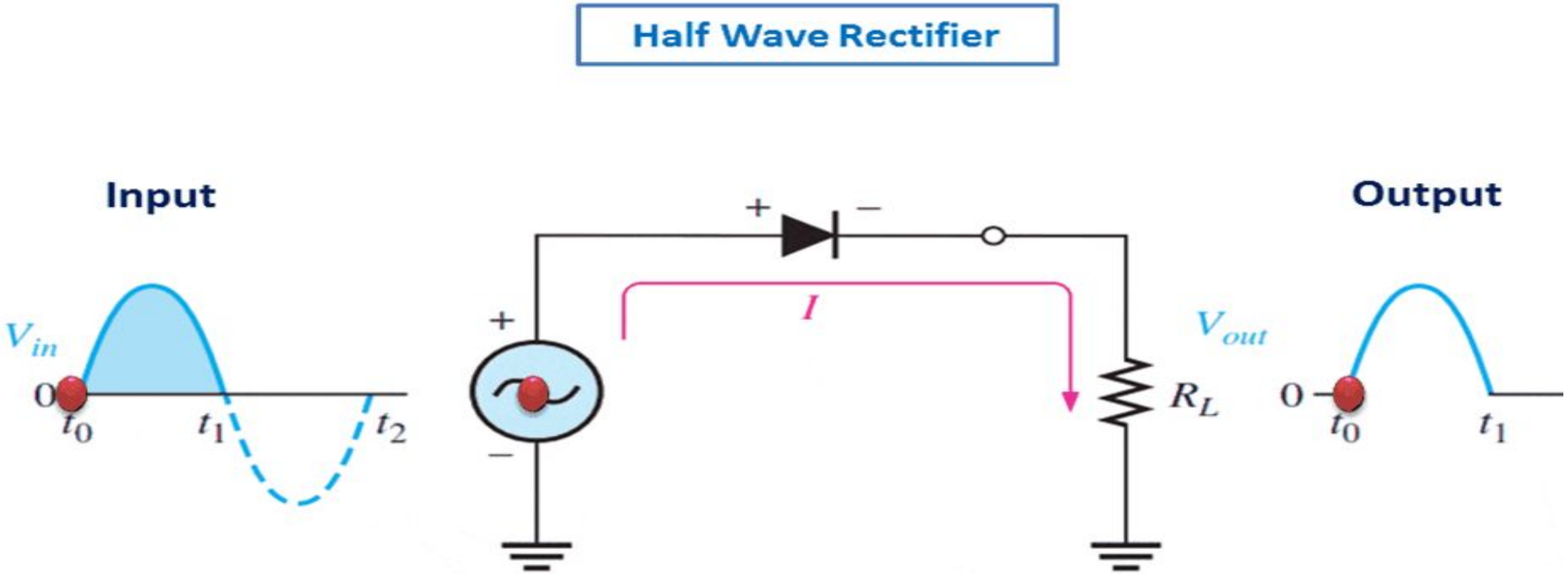
Types of Rectifier

- Generally two types of rectifiers:
  - Controlled Rectifier (SCR, MOSFET, IGBT)
  - Uncontrolled Rectifier (Diodes)



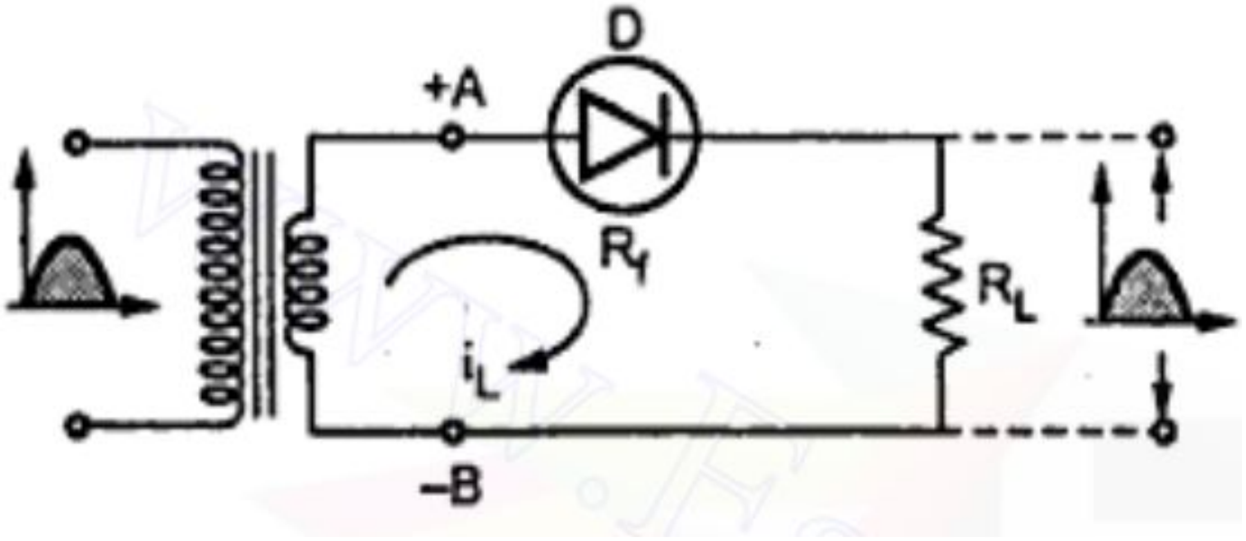
HALF WAVE RECTIFIER

- Circuit consists of a single diode in series with load resistor
- Input is 50 Hz single phase supply



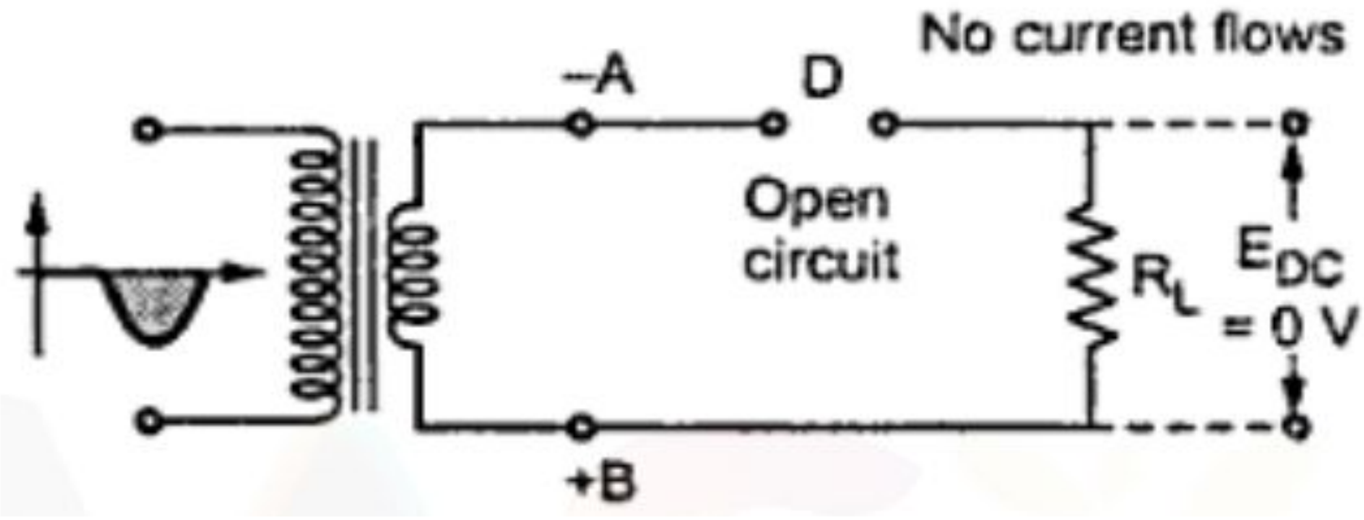
Half wave rectifier - Operation

- During positive half cycle terminal A is positive with respect to terminal B
- D is forward biased, I_L flows in the clockwise direction
- The current is flowing through the load R_L, that current is called as load current

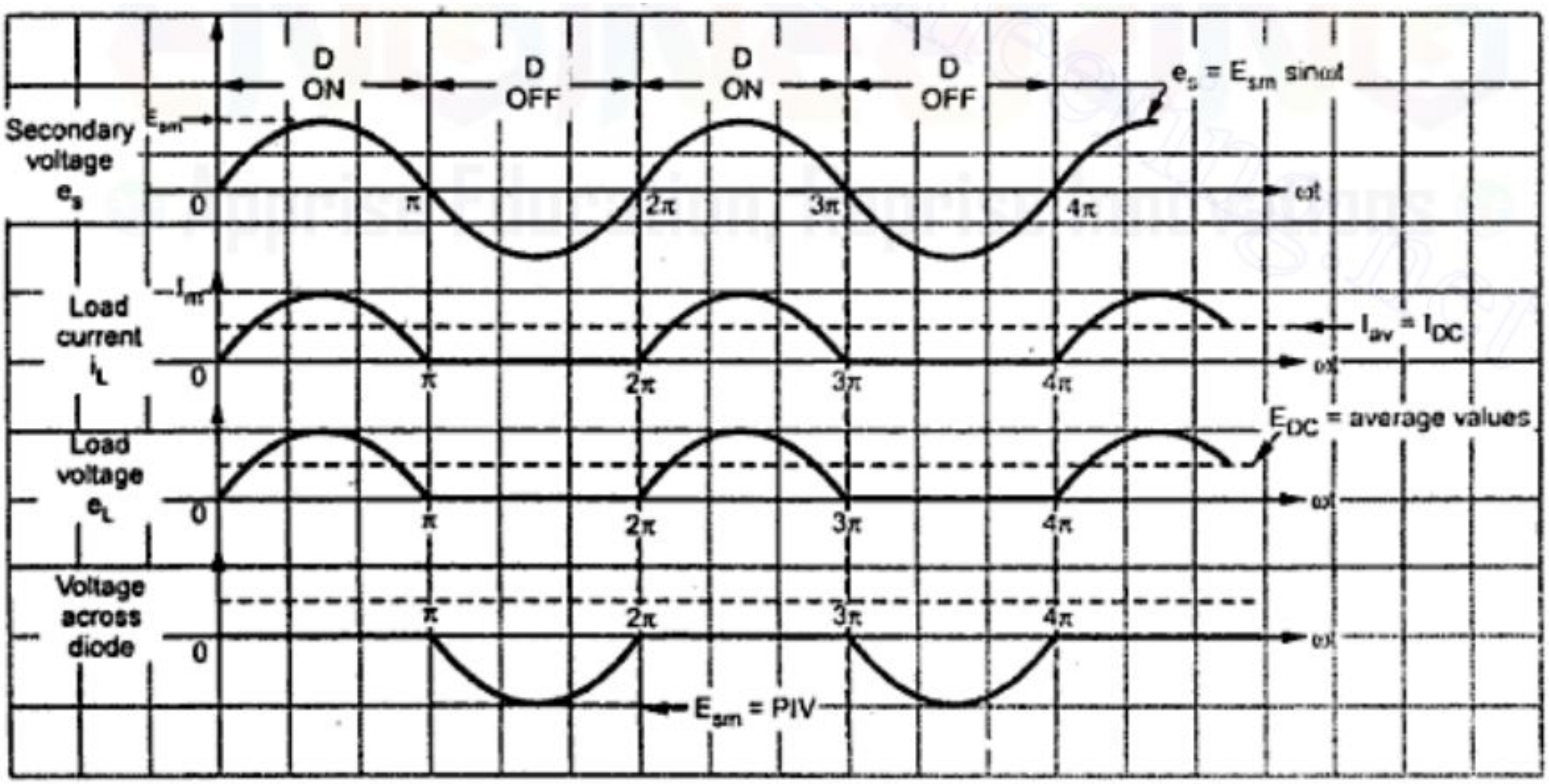


Half wave rectifier - Operation

- During negative half cycle, terminal A is more negative than B- So, the diode becomes reverse biased
- Hence no current flow in the circuit (Load current =0)



Load current and Load voltage waveform



Advantages of Half Wave Rectifier

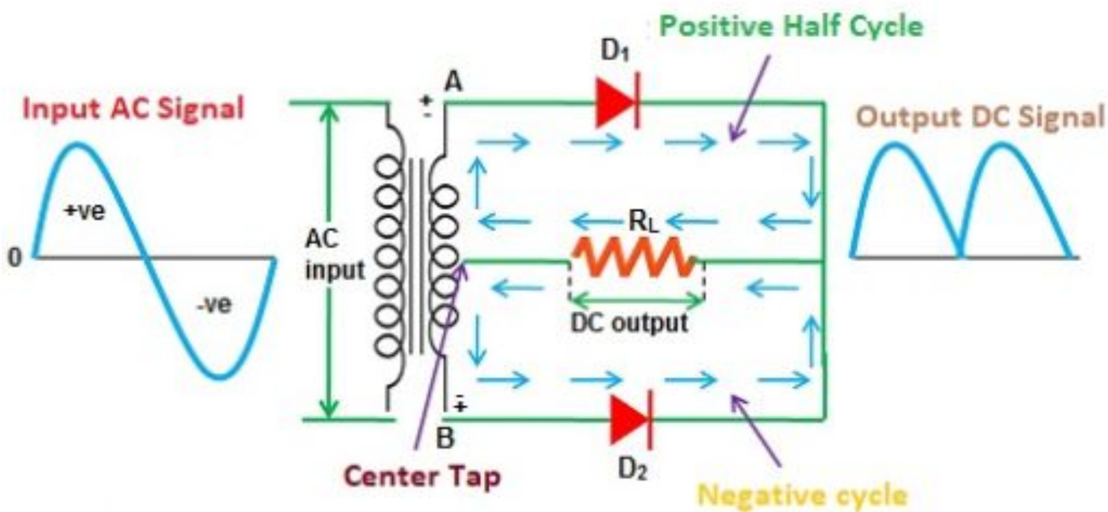
- Simple (lower number of components)
- Cheaper up front cost (as their is less equipment.)
- Easy to construct

Disadvantages of Half Wave Rectifier

- Only allow a half-cycle through per sinewave, and the other half-cycle is wasted. This leads to power loss.
- Produces a low output voltage.
- The output current we obtain is not purely DC, and it still contains a lot of ripple (i.e. it has a high ripple factor)
- Efficiency is quite low

FULL WAVE RECTIFIER

- A Full wave rectifier is a circuit arrangement which makes use of both half cycles of input alternating current (AC) and converts them to direct current (DC)

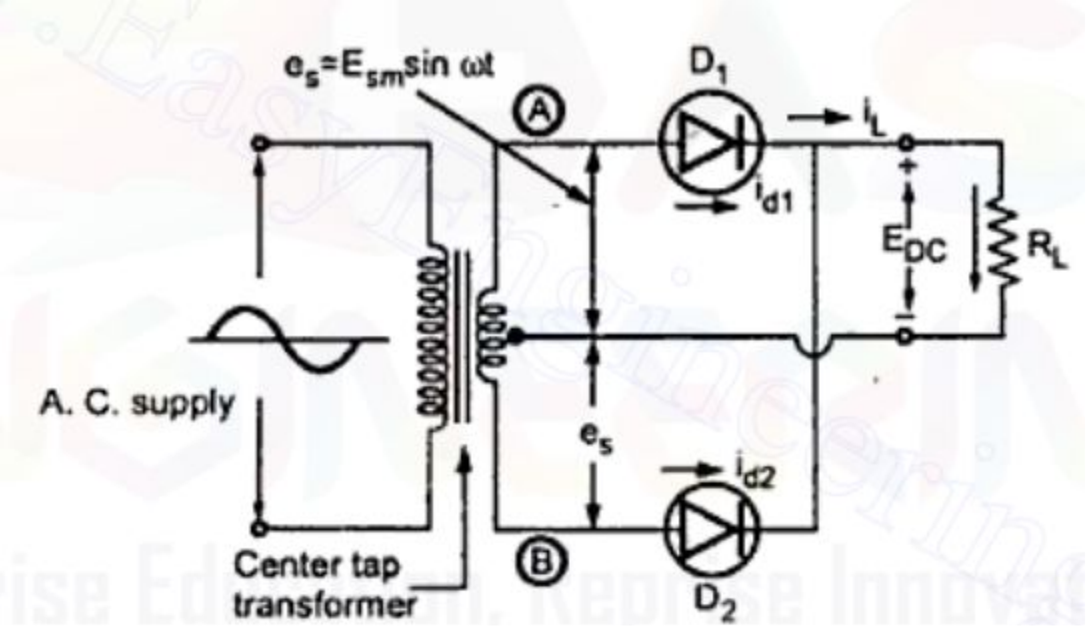


Types of Full wave Rectifier

- Centre tapped transformer full wave rectifier

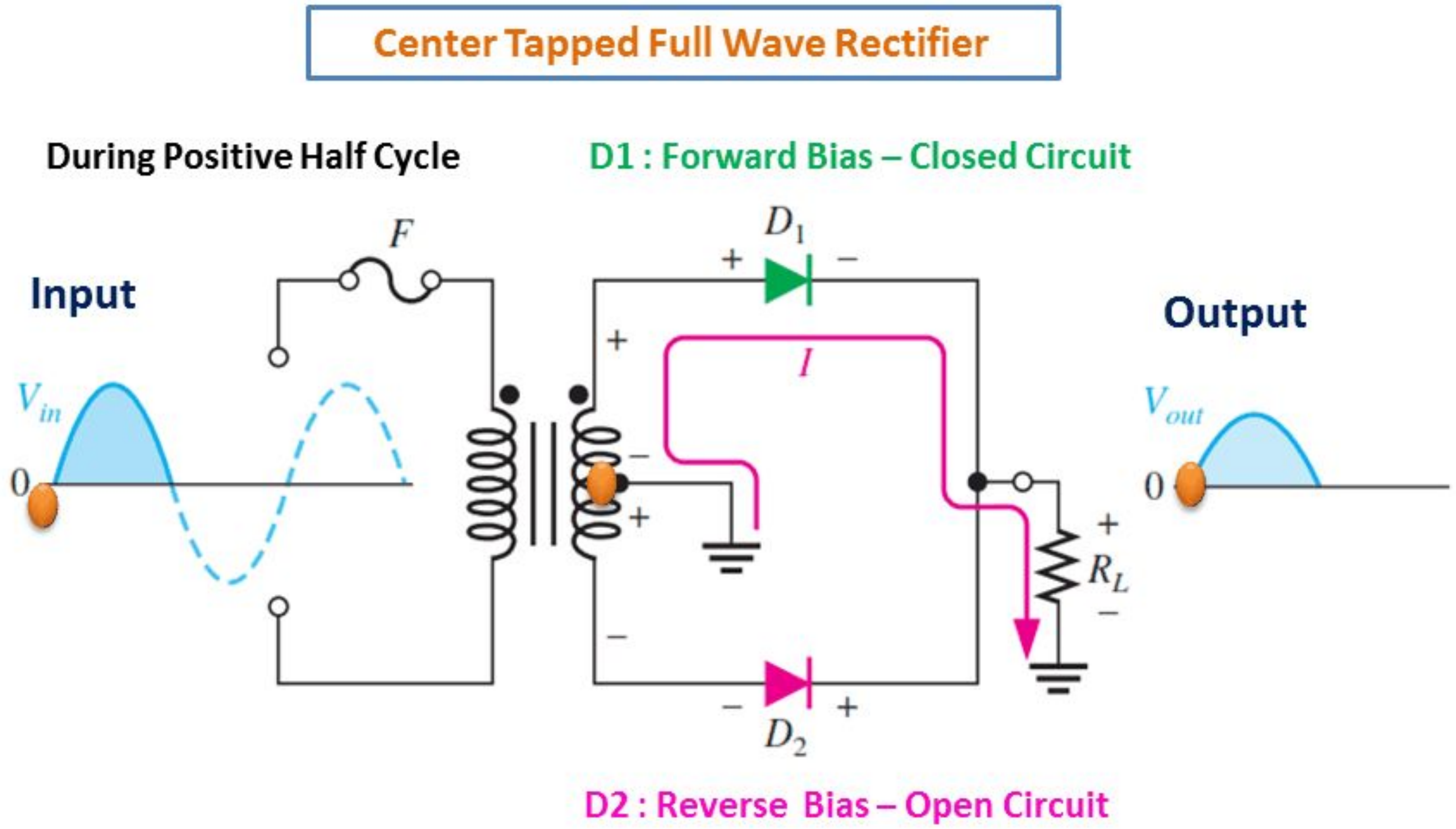
- Bridge type rectifier

Full wave rectifier with center-tapped transformer



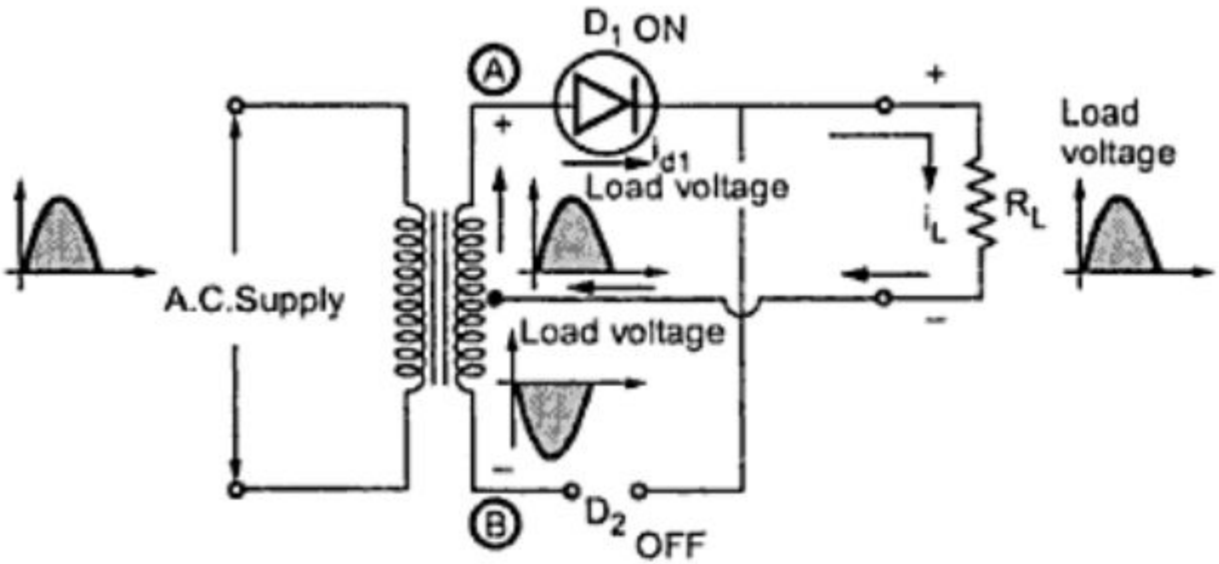
- Full wave rectifier conducts during positive and negative half cycles of input
- Two diodes are used – feed a common load R_L with the help of center tapped transformer

During positive cycle

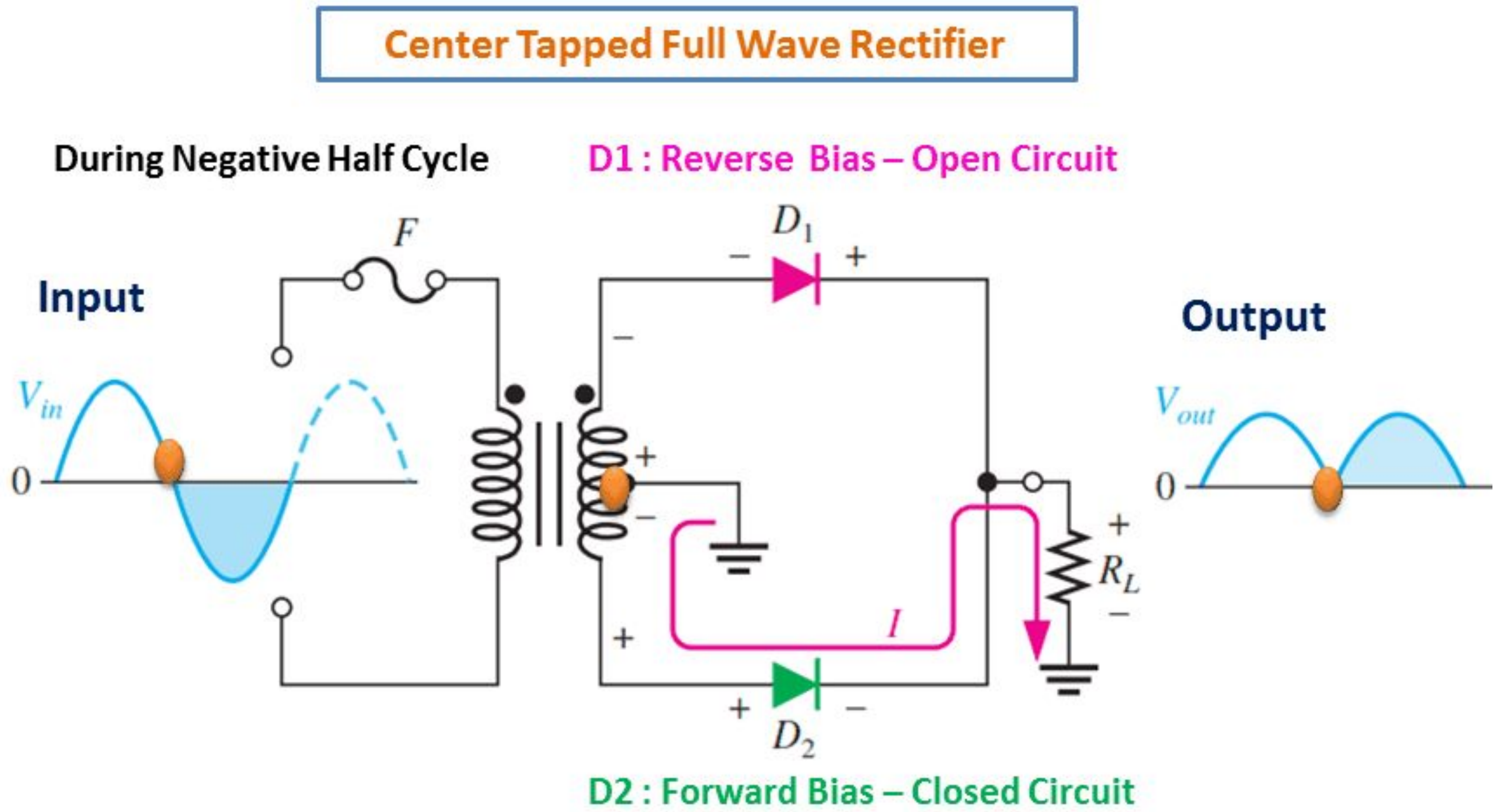


Operation

- During +ve half cycle-terminal A is positive and terminal B is –ve.
- Diode D1 is forward biased and hence will conduct while D2 will be reverse biased and will act as open circuit / will not conduct. Load current is supplied through D1 alone.

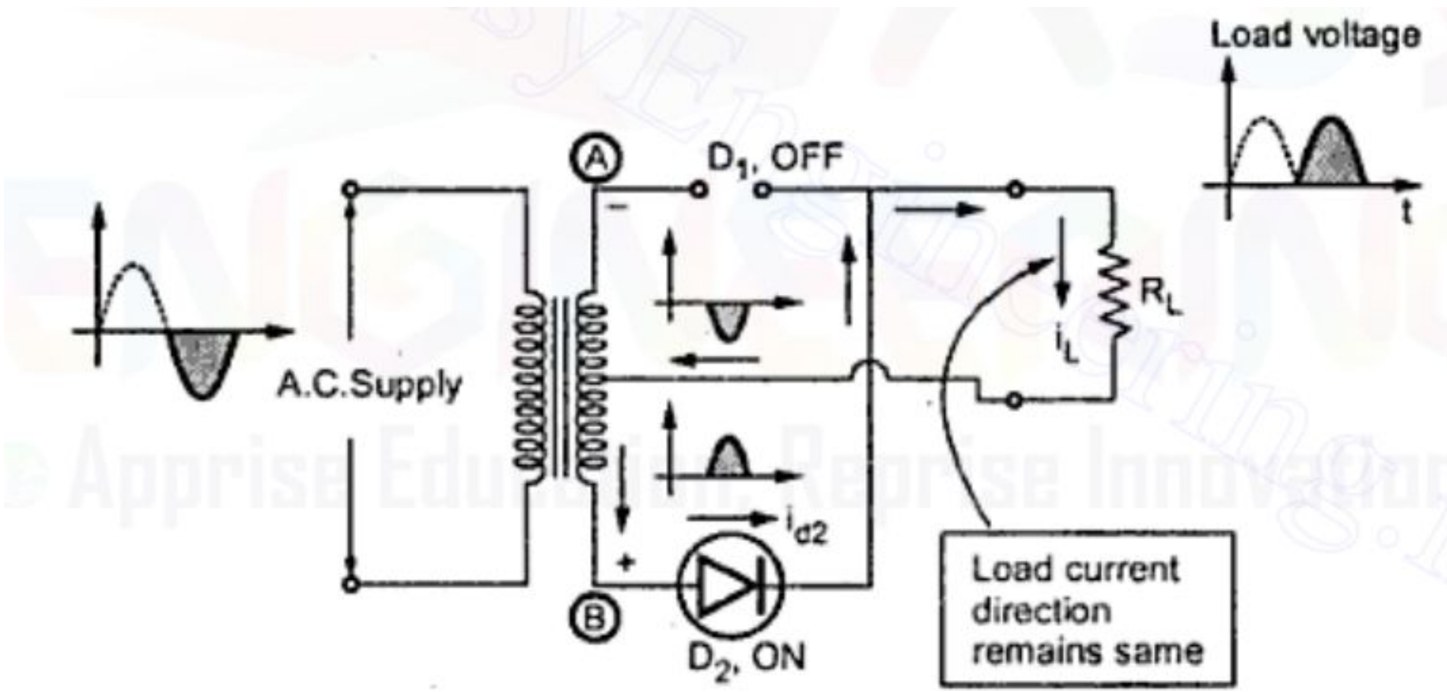


During negative cycle



Operation

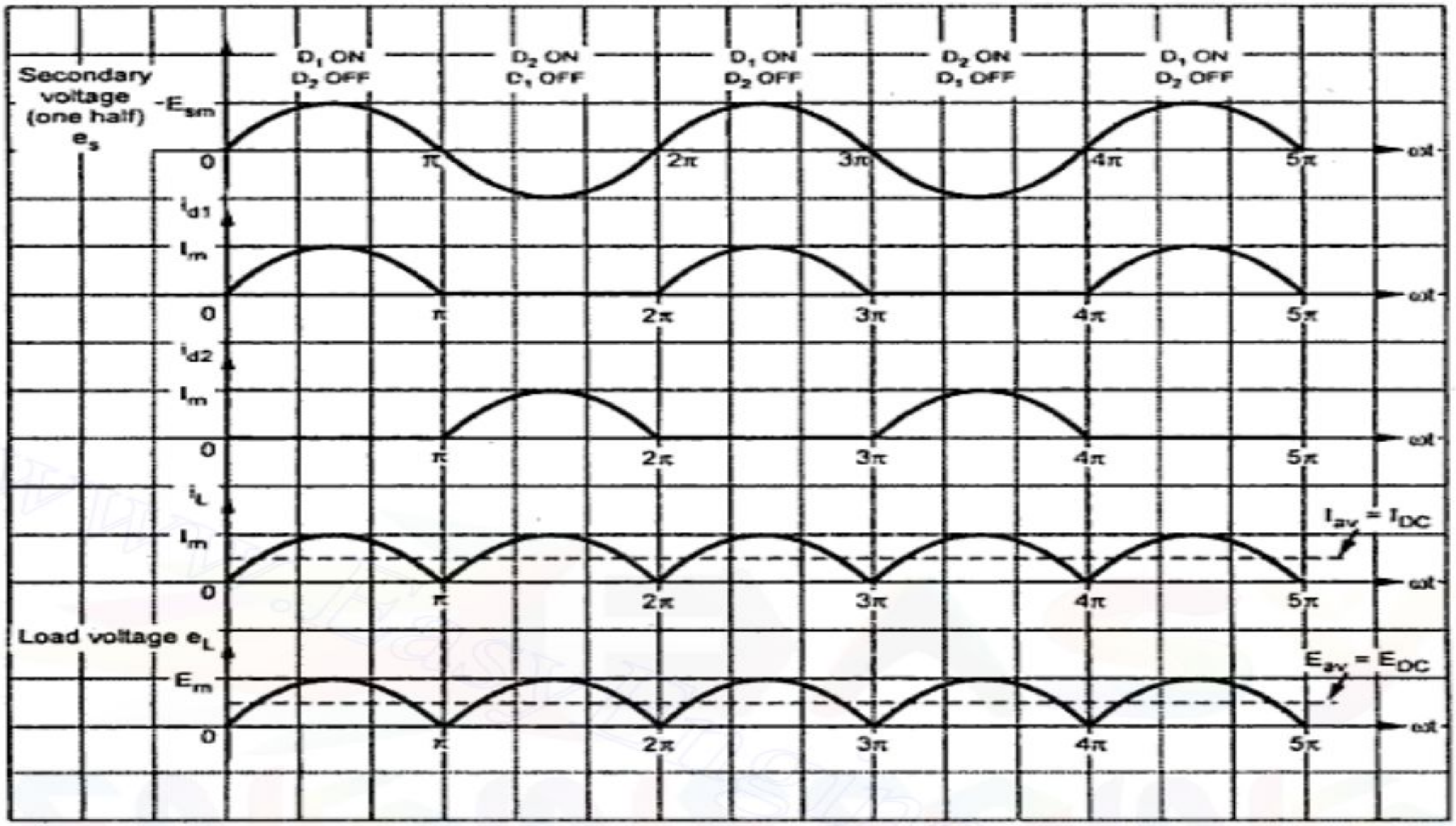
- During –ve half cycle, polarity is reversed and terminal A becomes –ve and B becomes +ve.
- Therefore D2 is forward biased and conducts while D1 does not conduct being reverse biased.
- In this case, diode D2 supplies the load current



Full wave rectifier with center-tapped transformer

- It is noted that the load current flows in both the half cycles and in same direction.
- The two diodes does not conduct simultaneously
- Ripple content in the output

Output voltage and current waveforms



Advantages

- DC output voltage and current are twice than those of half wave rectifier

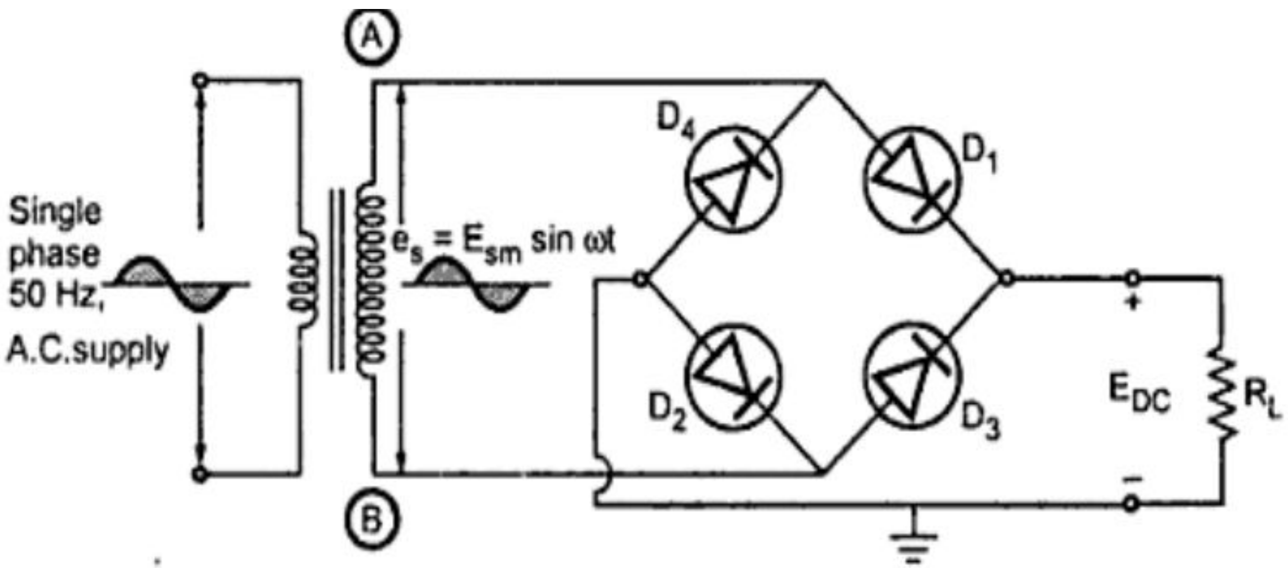
- Efficiency is twice (81.2%) that of half wave rectifier (40.6 %)

Disadvantages

- The output voltage is half of the secondary voltage
- PIV of diode is twice that of diode used in half wave rectifier
- Cost of center tapped transformer is higher

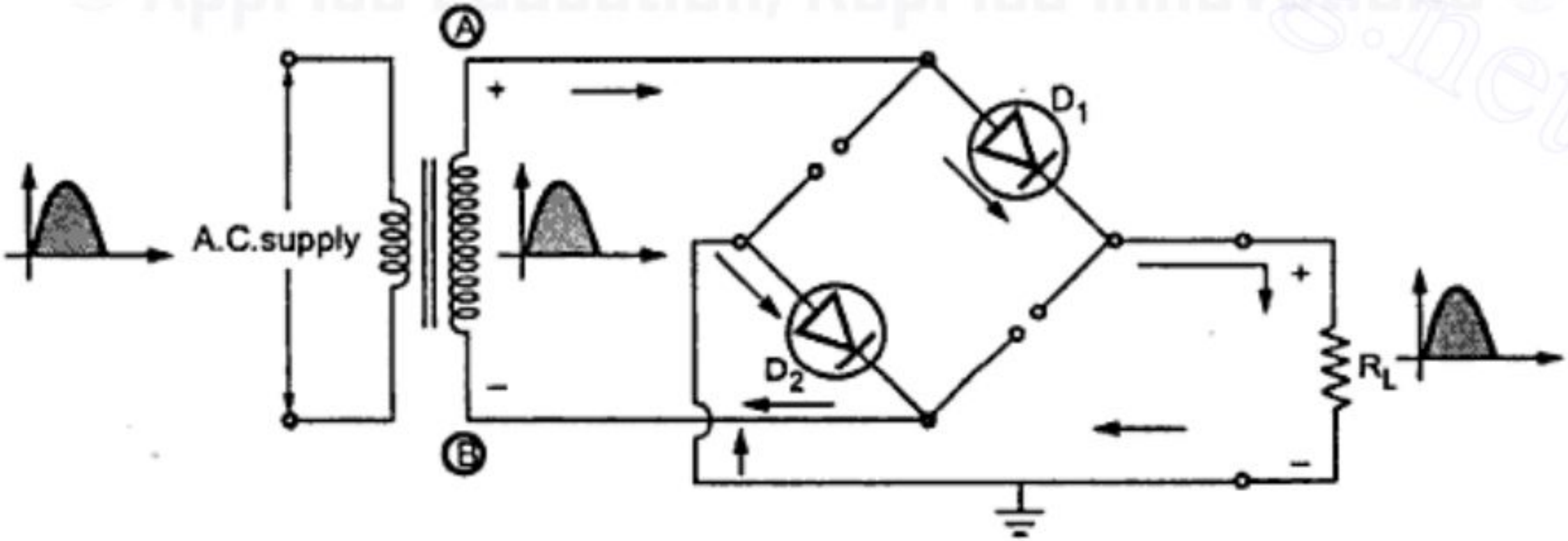
Full Wave Bridge Rectifier

- Bridge Rectifier is a Full wave rectifier circuit using four diodes
- The main advantage of this circuit is that it does not require center tapped transformer

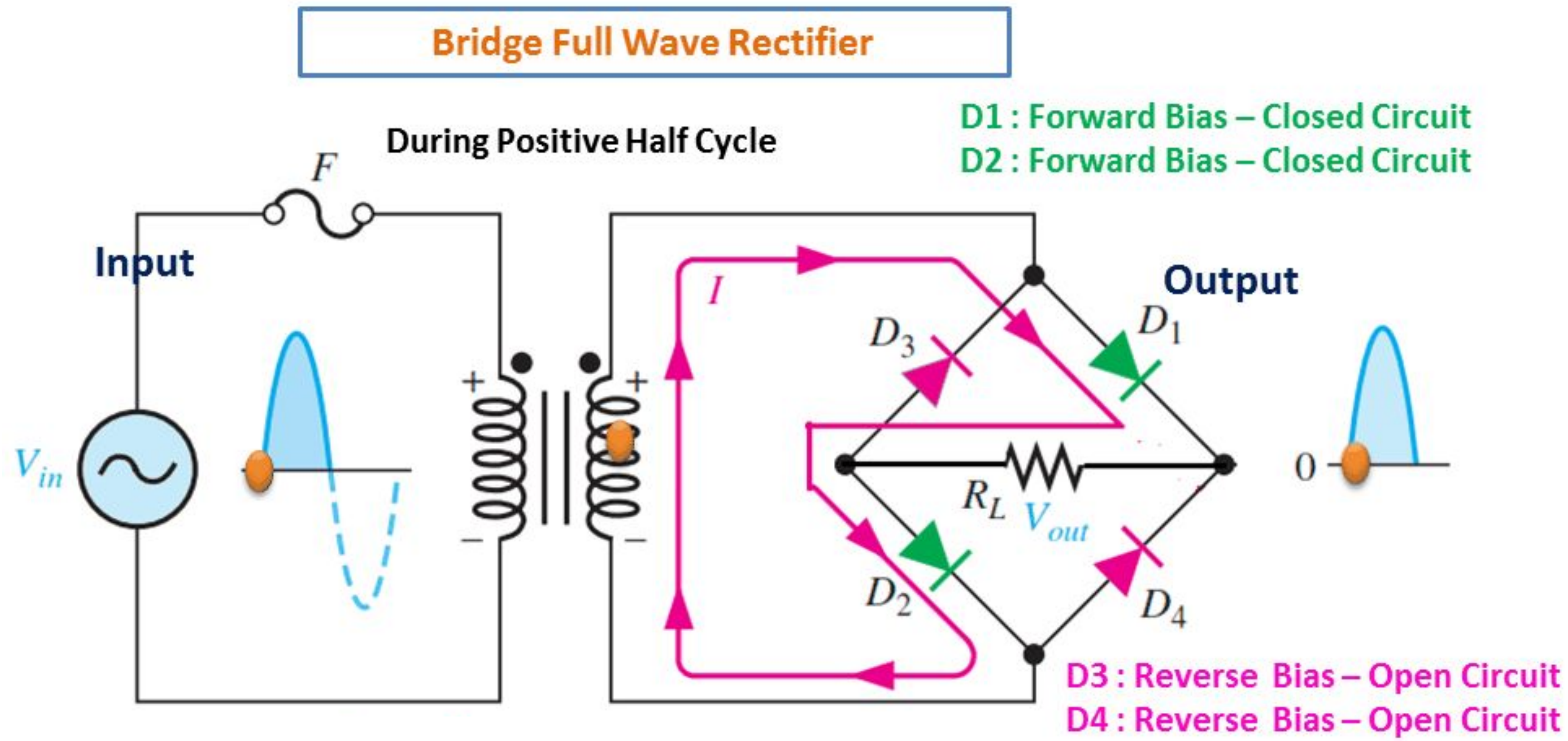


Positive cycle

- Point A of the secondary becomes positive
- D1 and D2 will be forward biased while D3 and D4 are reverse biased
- The two diodes D1 and D2 conduct in series with the load and load current flows

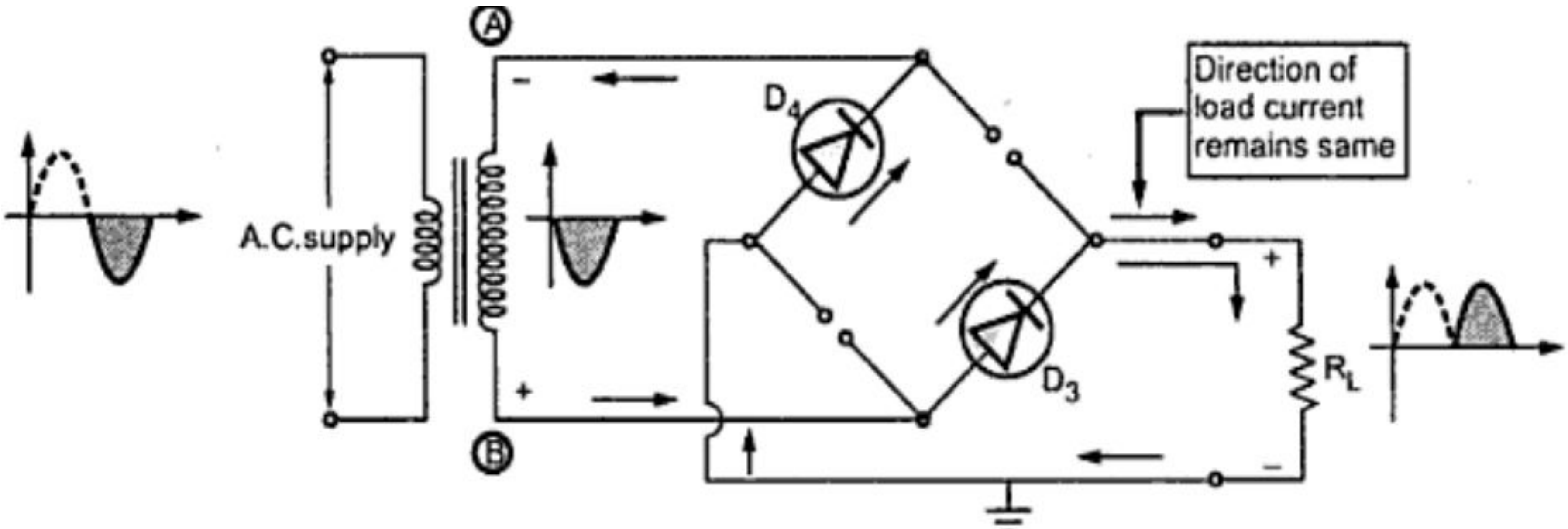


Positive cycle

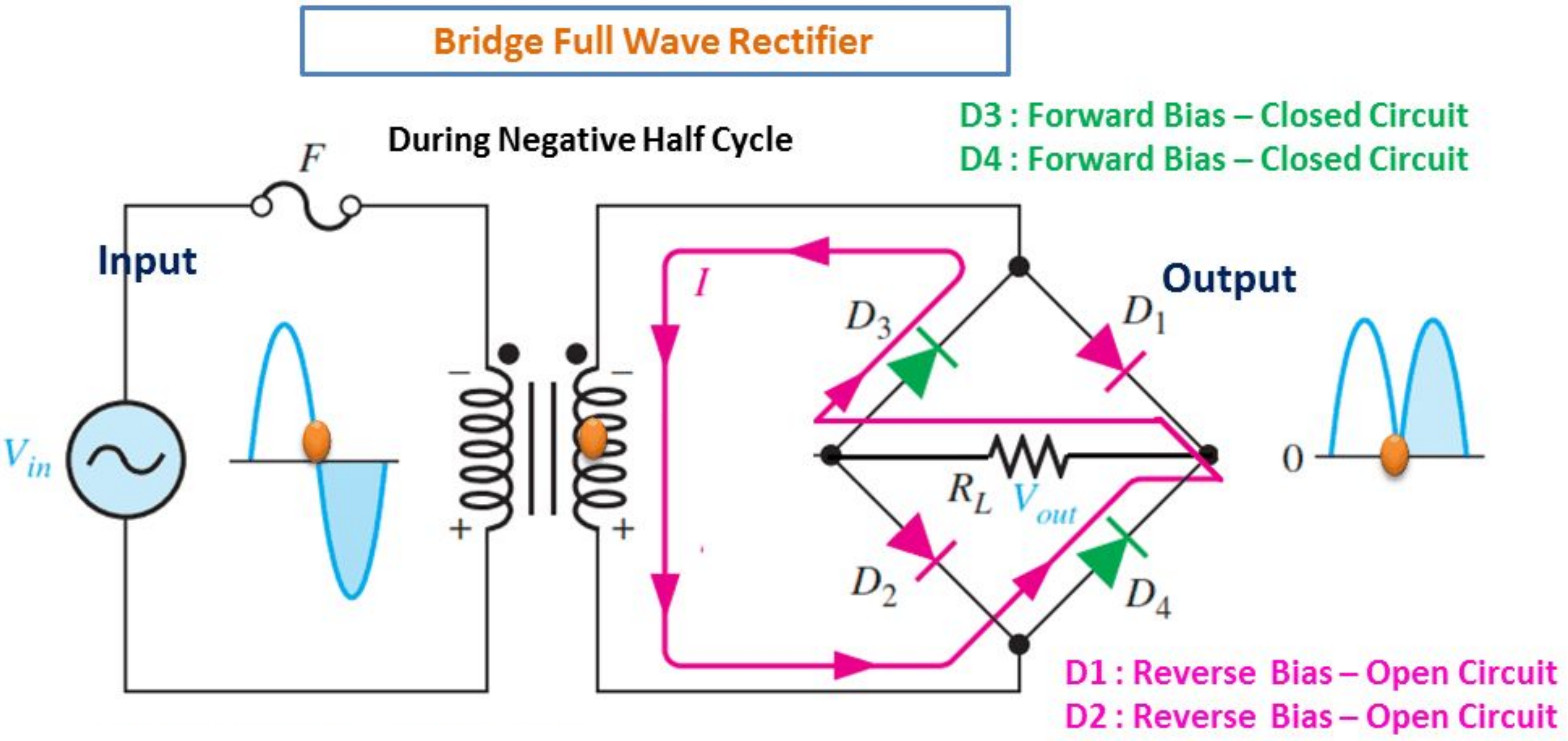


Negative cycle

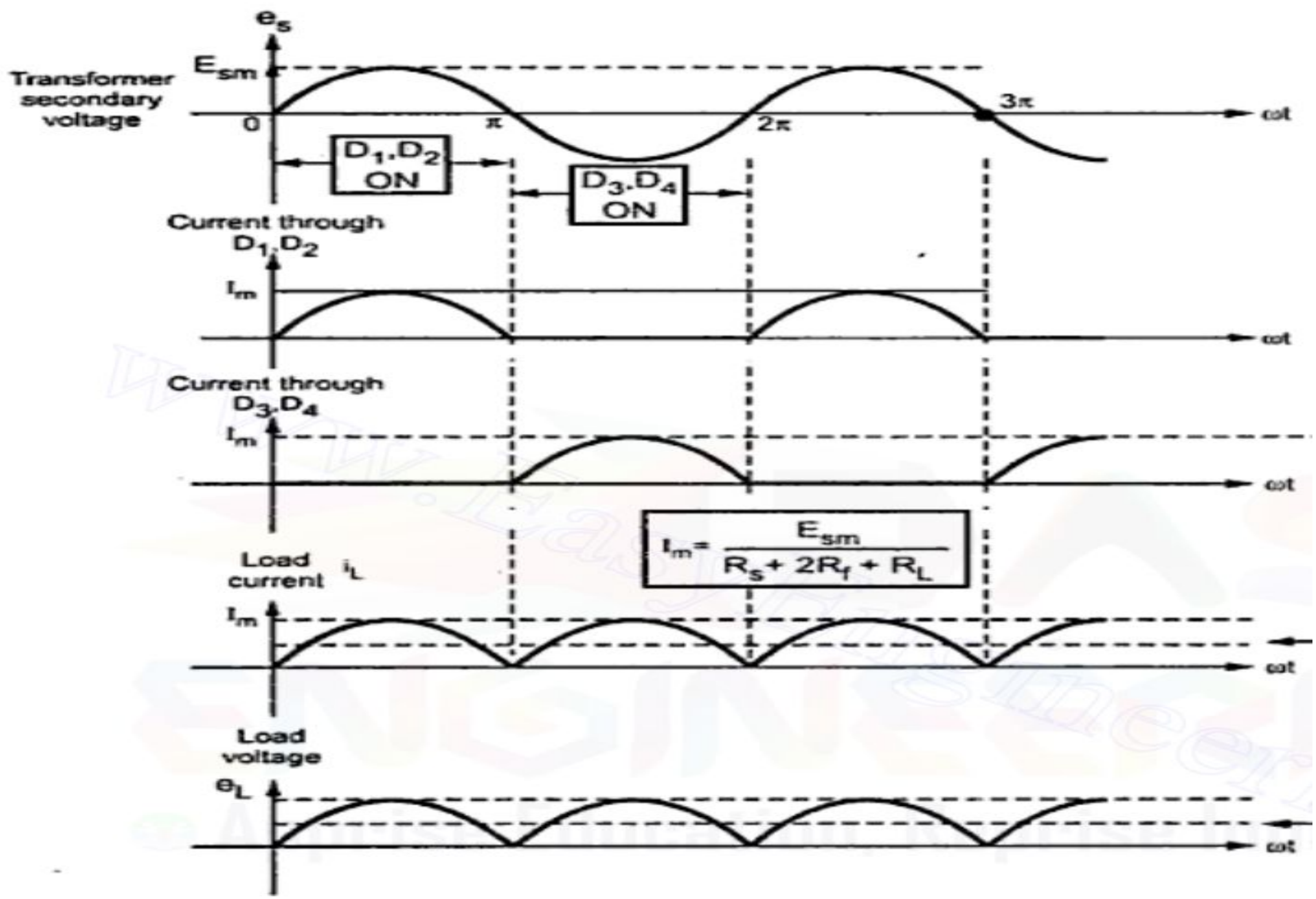
- Point B of the secondary becomes positive
- D3 and D4 will be forward biased while D1 and D2 are reverse biased
- The two diodes D3 and D4 conduct in series with the load and load current flows



Negative cycle



Output Voltage and Current



Advantages

- Need for centre tapped transformer is eliminated
- The output is twice that of the centre –tap circuit for the same secondary voltage
- PIV is one half that of the centre tap circuit

Disadvantage

- It requires four diodes, power loss will be higher

ZENER DIODE

- Also called as
  - Voltage reference diode
  - Voltage regulator diode
  - Breakdown diode

- Invented by American Physicist Clarence Melvin Zener in 1934 at Bell Labs

- Zener diode, junction formed by combining highly doped PN semiconductors.

ZENER DIODE

- Heavily doped semiconductor devices
- It works on the principle of Zener breakdown and is operated in reverse breakdown region.
- In reverse breakdown region high current flow through the diode leading to high power dissipation.

- Manufactured with a great variety of Zener voltages (Vz)
- Fixed (or) Variable.

BREAK DOWN MECHANISM

- The breakdown voltage depends upon the width of depletion layer.
- The width of depletion layer depends upon the doping level.
- The following two processes cause junction breakdown due to the increase in reverse bias voltage,

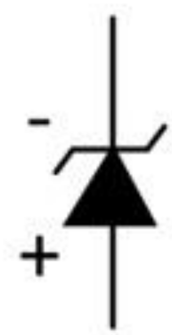
1. Zener Breakdown
2. Avalanche Breakdown

ZENER EFFECT

- When the voltage across its terminals is reversed and the potential reaches the Zener Voltage (knee voltage), the junction will break down and the current flows in the reverse direction.
- This effect is known as the Zener Effect.

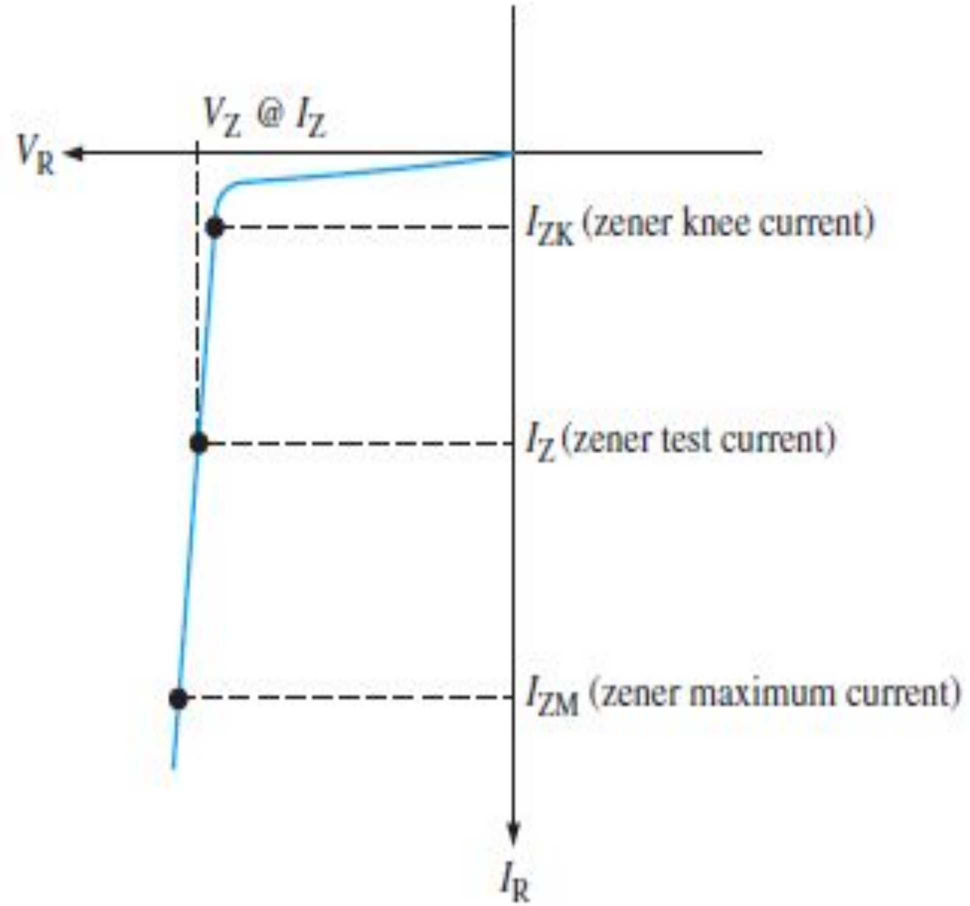
Zener Diode Symbol

- Different packages are available
- Common type is contained with a small glass encapsulation
- It has a band around one end marking the cathode side



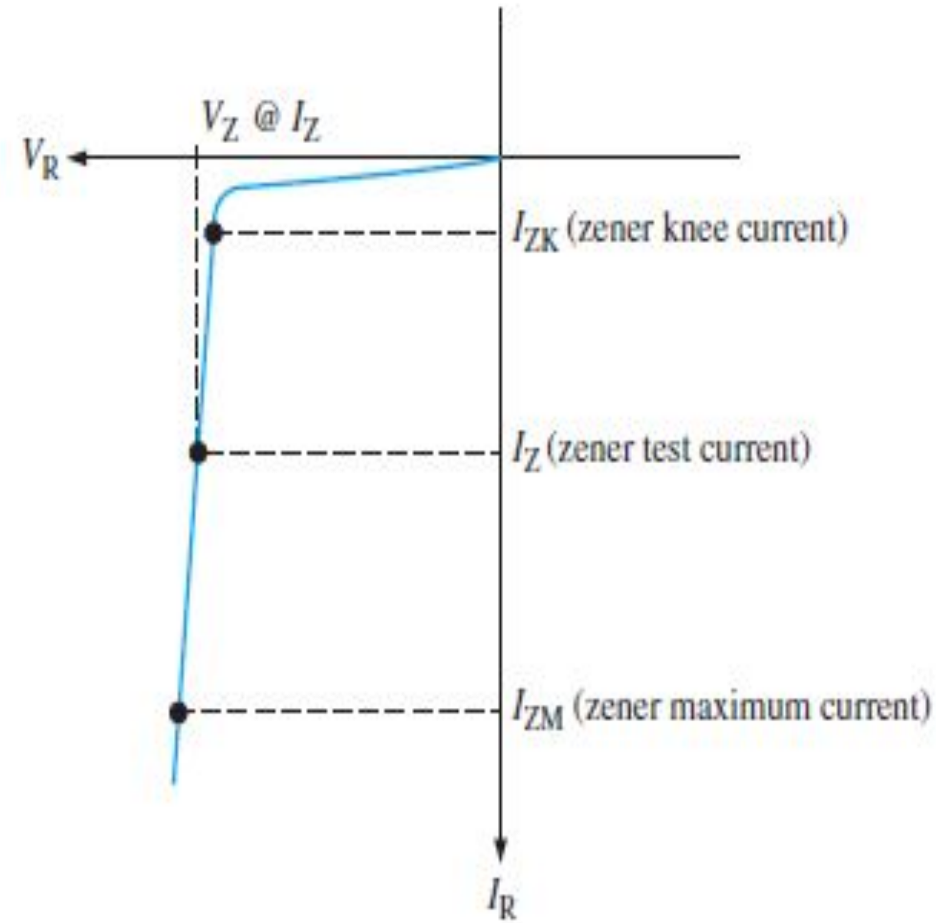
ZENER DIODE OPERATION

- Operates like normal diode in forward bias
- But in reverse bias
- As the reverse voltage (V_R) is increased, the reverse current (I_R) remains extremely small up to the "knee" of the curve.
- The reverse current is also called the zener current (I_Z)



Operation of Zener diode

- At this point, the breakdown effect begins; the internal zener resistance (or) zener impedance (Z_Z), begins to decrease as the reverse current increases rapidly.
- From the bottom of the knee, the zener breakdown voltage (V_Z) remains essentially constant although it increases slightly as I_Z, increases.



Difference between zener and avalanche breakdown

Zener breakdown	Avalanche breakdown
1. The Zener breakdown occurs in HIGH doping diodes.	1. The avalanche breakdown occurs in LOW doping diodes.
2. The breakdown occurs within the depletion region.	2. The breakdown occurs outside the depletion region.
3. The breakdown voltage is lesser than zener that of avalanche breakdown.	3. The breakdown voltage is more than breakdown voltage.

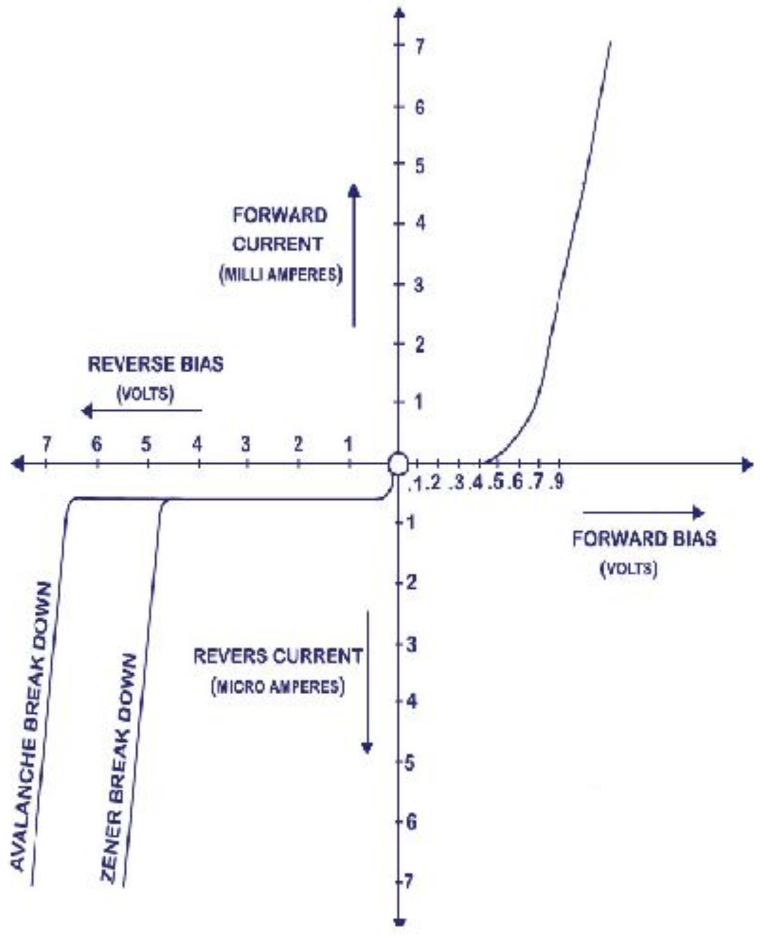
Zener Breakdown

- It is observed in Zener diodes having Vz 5 to 8 volts.
- The valence electrons are pulled into conduction due to very intense electric field appearing across the narrow depletion region.

Avalanche Breakdown

- The avalanche breakdown is observed in the Zener Diodes having Vz greater than 8 V.
- The valence electrons are pushed into conduction band due to the energy imparted by colliding accelerated minority carriers.

VI Characteristics



ZENER DIODE SPECIFICATIONS

- **Zener/Breakdown Voltage** – The Zener or the reverse breakdown voltage ranges from 2.4 V to 5 V,.
- **Current Iz (max)** – It is the maximum current at the rated Zener Voltage (Vz – 200µA to 500 µA)
- **Current Iz (min)** – It is the minimum value of current required for the diode to breakdown.
- **Temperature Stability** – Diodes around 5 V have the best stability
- **Voltage Tolerance** – It is typically ±5%

Advantages

- Small in size, so used in smaller circuits
- Less expensive
- Can be used as controlling, regulating and stabilizing the voltage in circuit
- Compatibility with other device, so used for regulating voltage

ZENER DIODE APPLICATIONS

- Used in Voltage Stabilizers (or) Voltage Regulators
- Used in Over voltage protection circuits
- Used in switching applications

VOLTAGE REGULATOR

- A device that regulates the voltage level.
- It essentially steps down the input voltage to the desired level and keeps it in that same level during the supply. This ensures that even when a load is applied the voltage doesn’t drop.

VOLTAGE REGULATOR

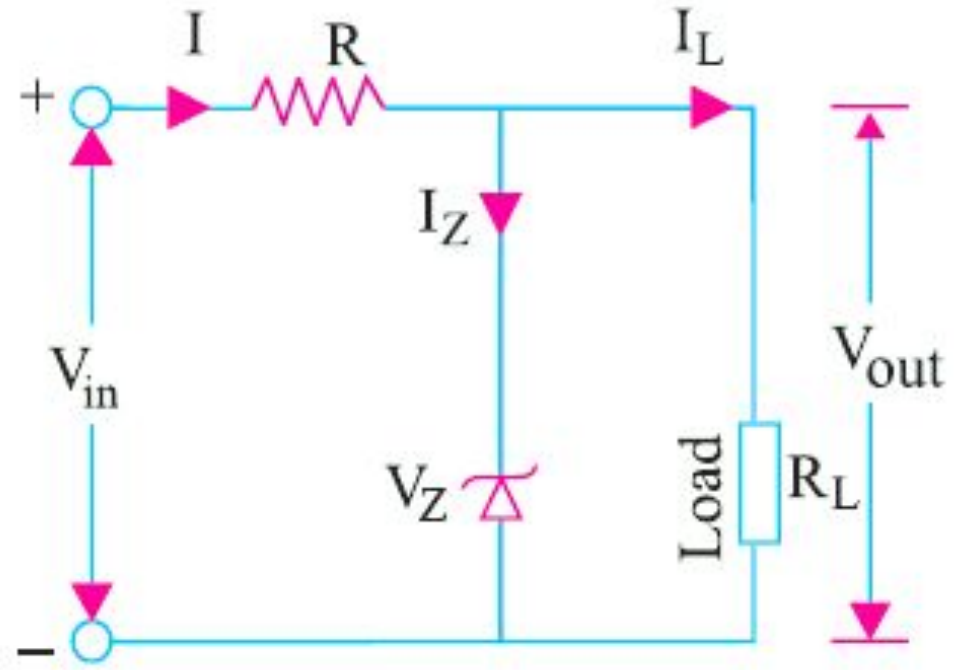
- The voltage regulator is used for two main reasons and they are:
  - To vary or regulate the output voltage
  - To keep the output voltage constant at the desired value in spite of variations in the supply voltage.

- Voltage regulators are used in computers, power generators, alternators to control the output of the plant

Zener Diode as Voltage Regulator

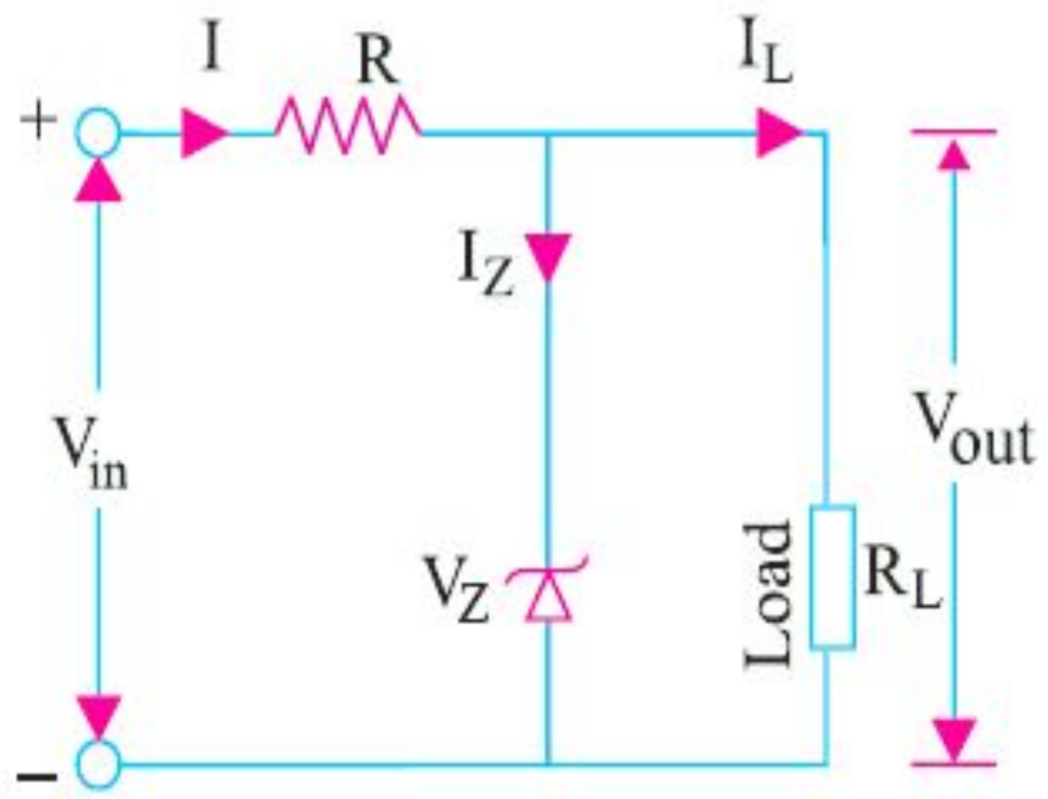
- Zener is connected in parallel or shunt with load, therefore also called as shunt regulator

  - Regulation with varying input voltage
  - Regulation with varying load resistance

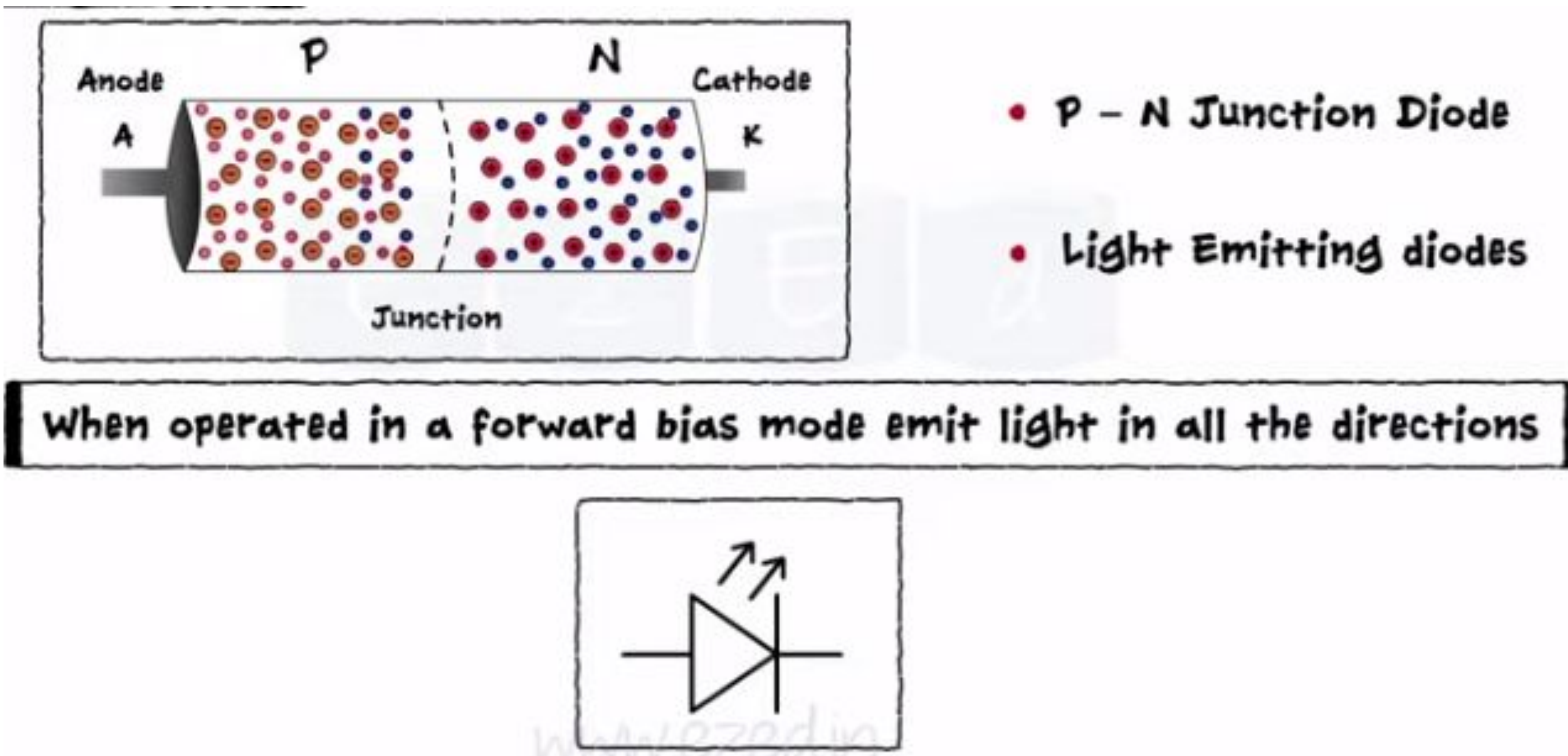


REGULATION WITH VARYING INPUT VOLTAGE

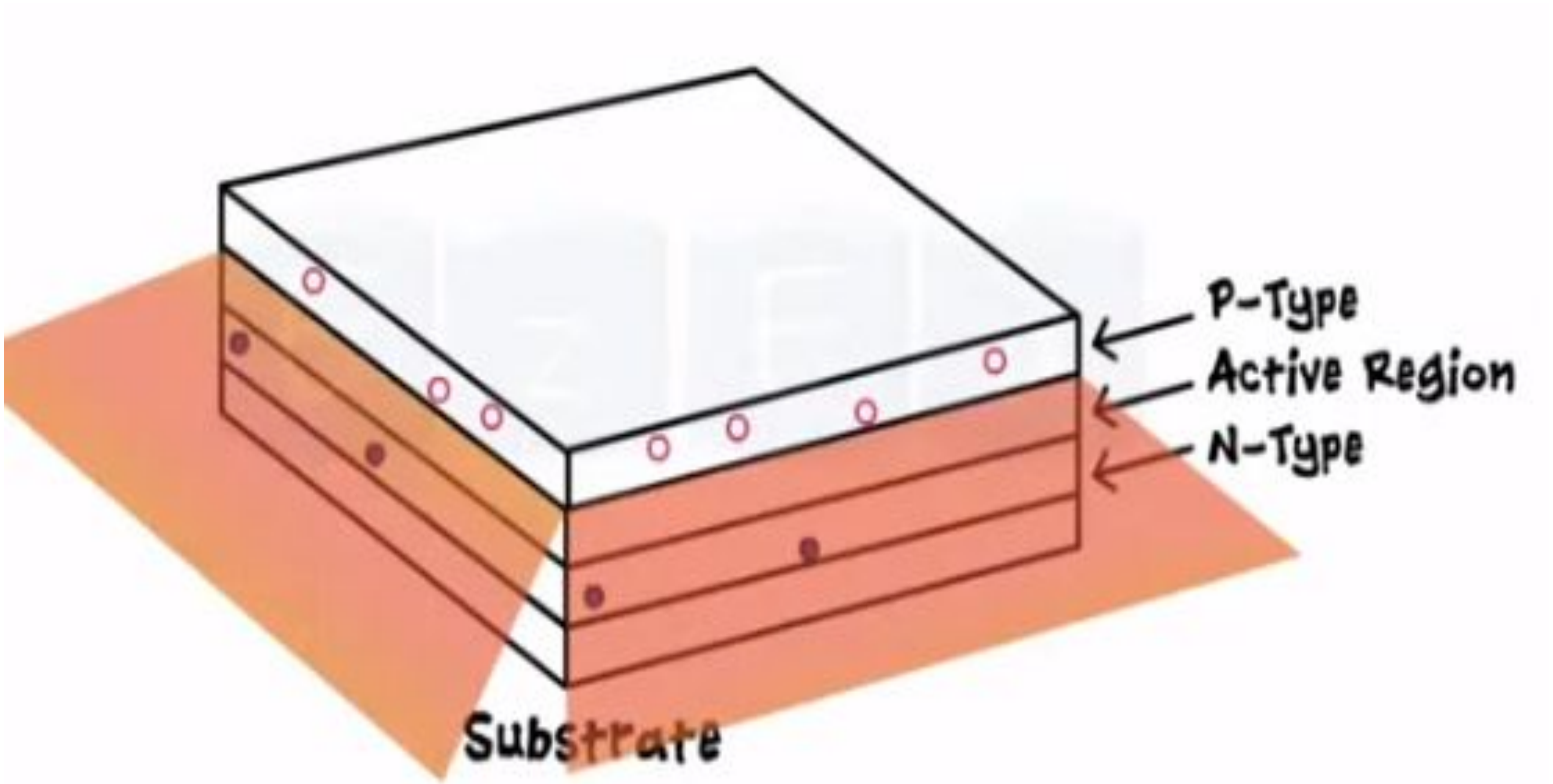
- V_{in} is Variable
- R_L is Fixed

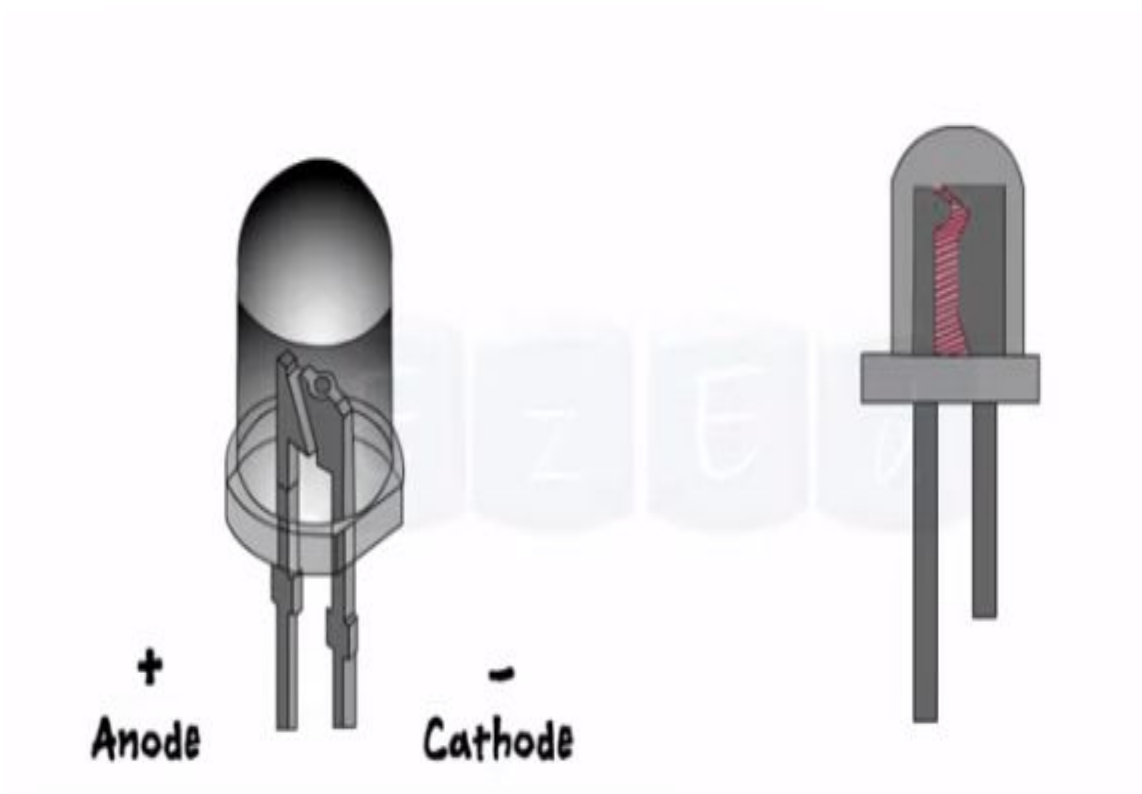


LED

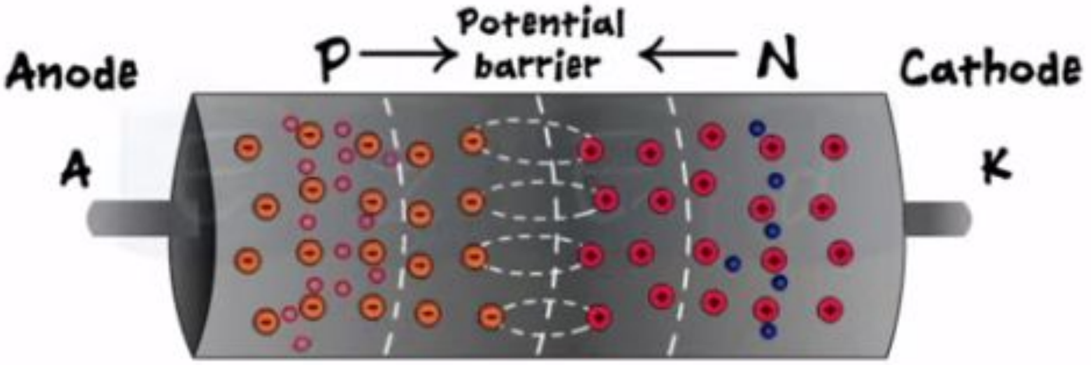

Anode
A
P
N
Cathode
K
Junction
P – N Junction Diode
Light Emitting diodes
When operated in a forward bias mode emit light in all the directions
www.ezed.in

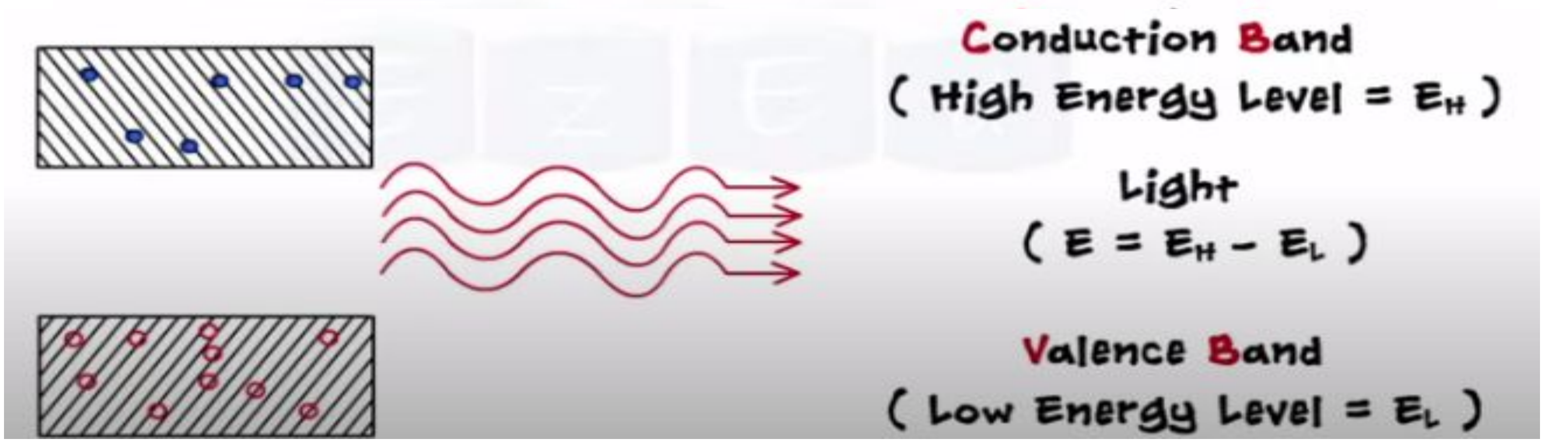
Construction of LED




+
Anode
-
Cathode

Working of LED

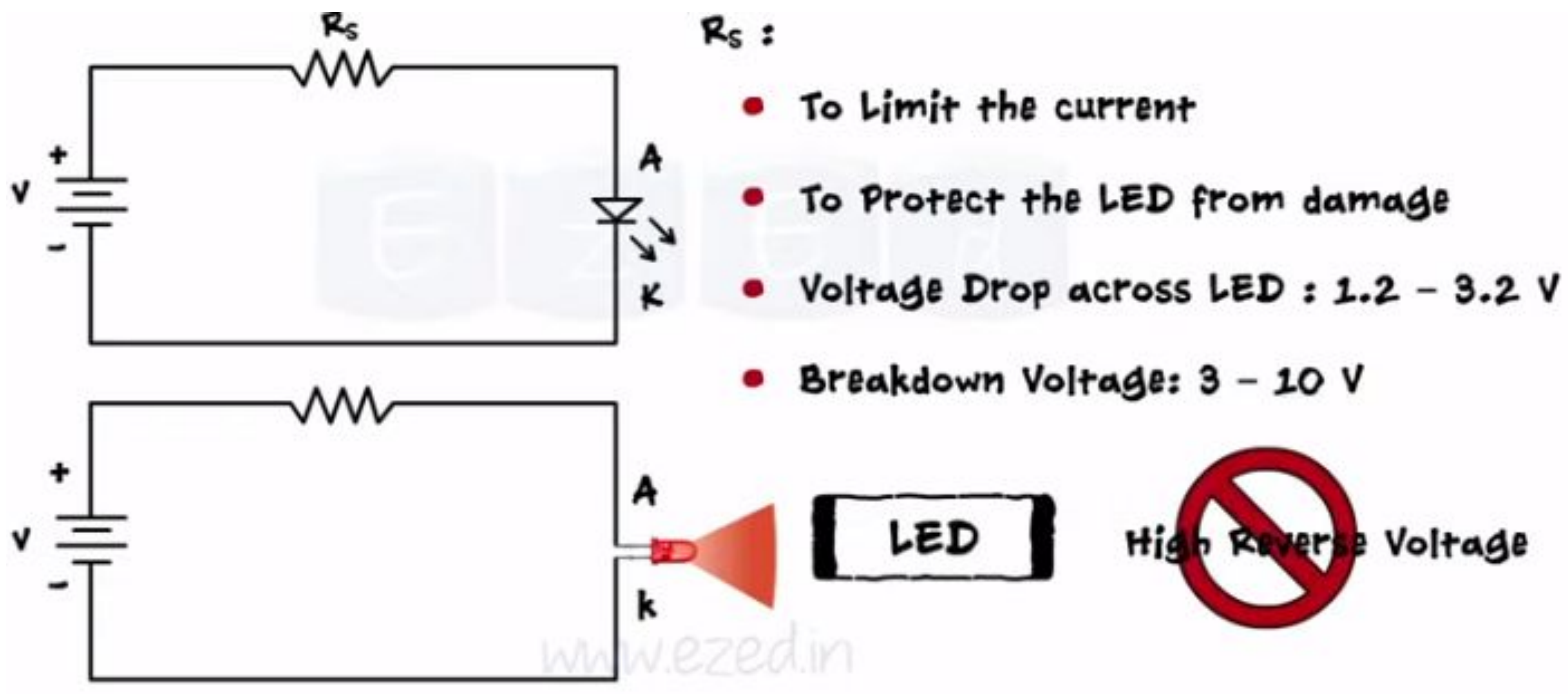




Note :

For LEDs, Silicon and Germanium are not used as their forbidden gaps do not allow light emission in the visible spectrum (wavelength is too low). Thus LEDs are made up of Gallium Arsenide (GaAs), Gallium Phosphide (GaP), etc

Biasing of LED



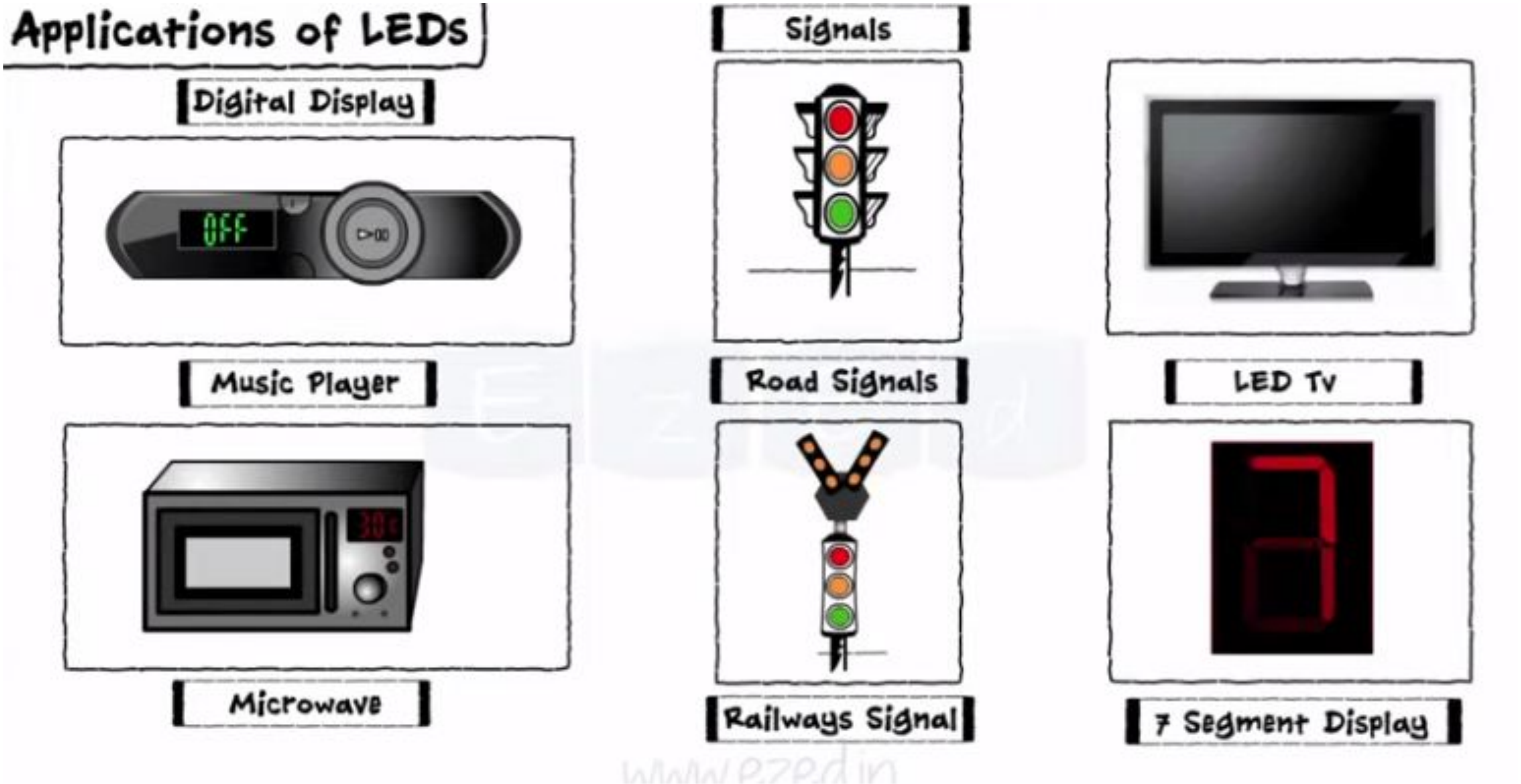
Advantages of LED

- Small Size and Light Weight
- Available in different spectral colours
- Have longer life as compared to lamps
- Can be easily interfaced with other electronic circuits
- Operating Speed is high (take only 1 micro second to turn ON or OFF)

Disadvantage of LEDs

- Output power is affected by changes in temperature
- Luminous Efficiency of LED is low
- LEDs get easily damaged due to Over Current

Application of LED



PV Cell

Photovoltaic (PV) Effect:

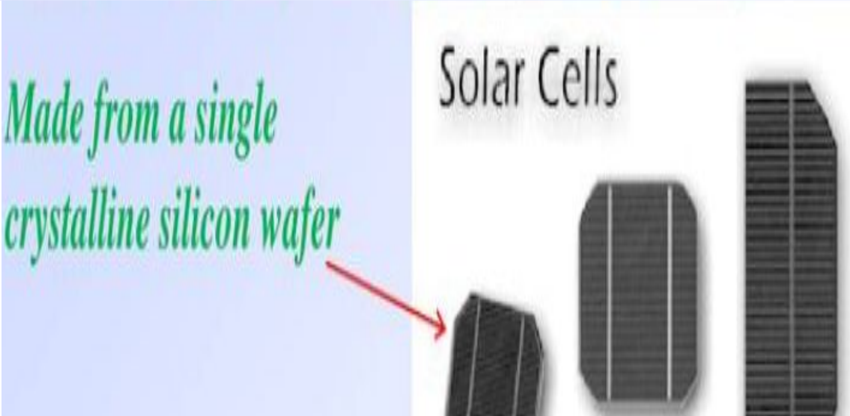
Electricity can be produced from sunlight through a process called the PV effect, where "photo" refers to light and "voltaic" to voltage.

Solar Cell

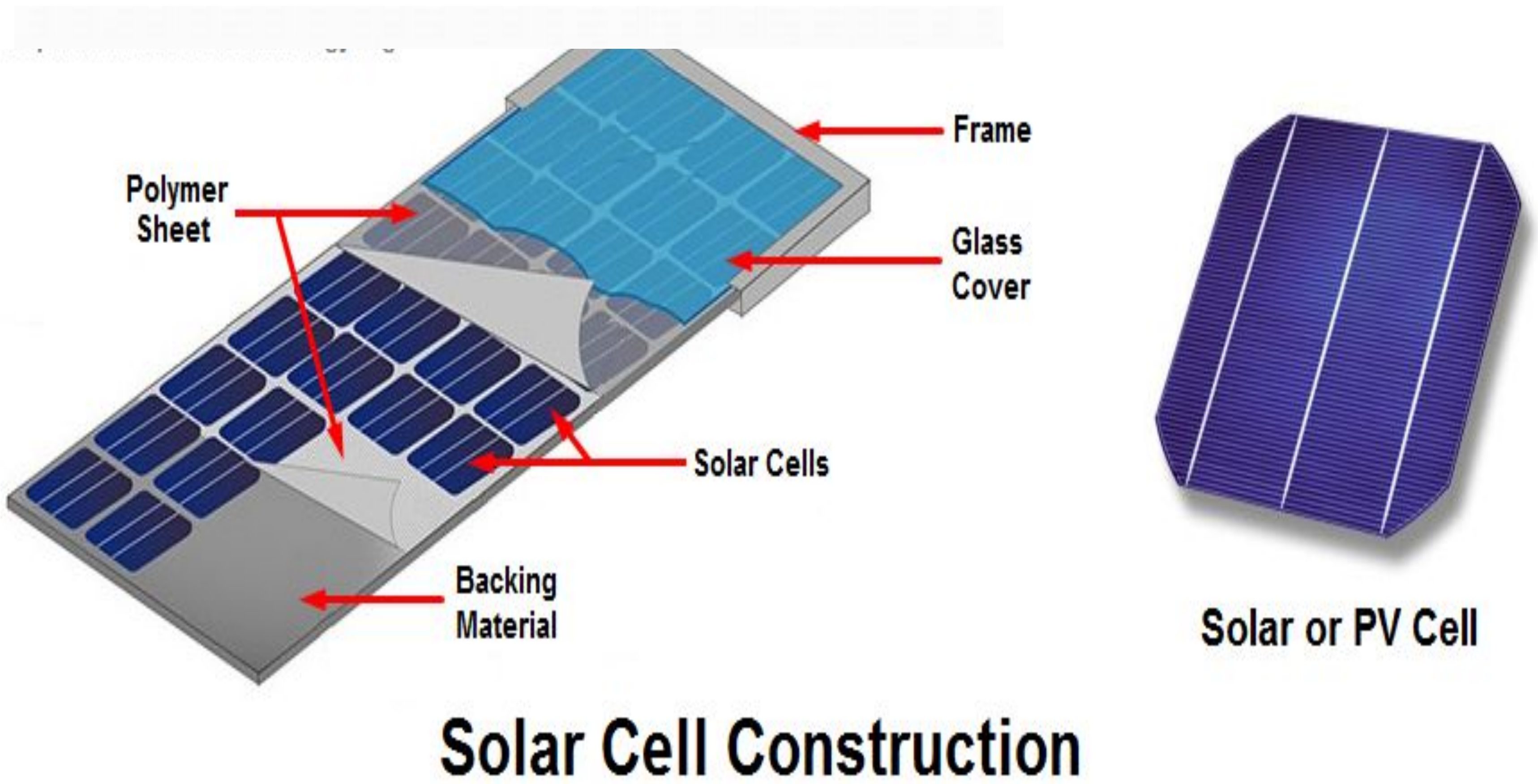
Solar cell is a device that converts the light energy into electrical energy based on the principles of photovoltaic effect.

PV CELL(Solar cell)

- It is also known as Photovoltaic cell (PV cell)
- A device that converts light energy (solar energy) directly to electricity.
- The term solar cell is designated to capture energy from sunlight, whereas PV cell is referred to an unspecified light source.
- It is like a battery because it supplies DC power.



Choice of Material

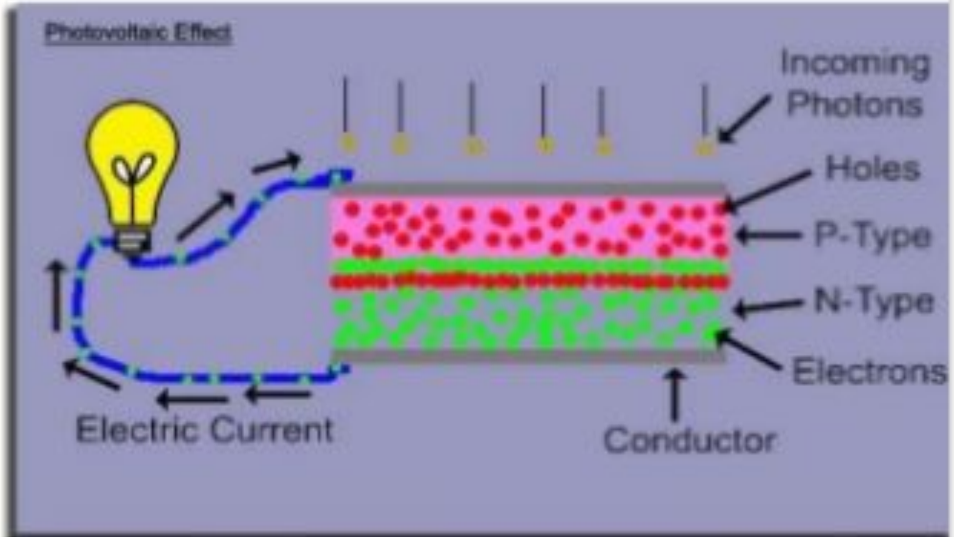


PV CELL

- A SOLAR CELL is a solid state electrical device that converts energy of light directly into electricity by Photovoltaic Effect.

PHOTOVOLTAIC EFFECT:

- When sunlight hits the solar panel generation of charge carriers(electrons and holes) in a light absorbing material and separation of the charge carriers to conductive contact, that will transmit the electricity.



Why PV cell

- Low maintenance, long lasting sources of energy
- Provides cost-effective power supplies for people remote from the main electricity grid
- Non-polluting and silent sources of electricity
- Convenient and flexible source of small amounts of power
- Renewable and sustainable power, as a means to reduce global warming

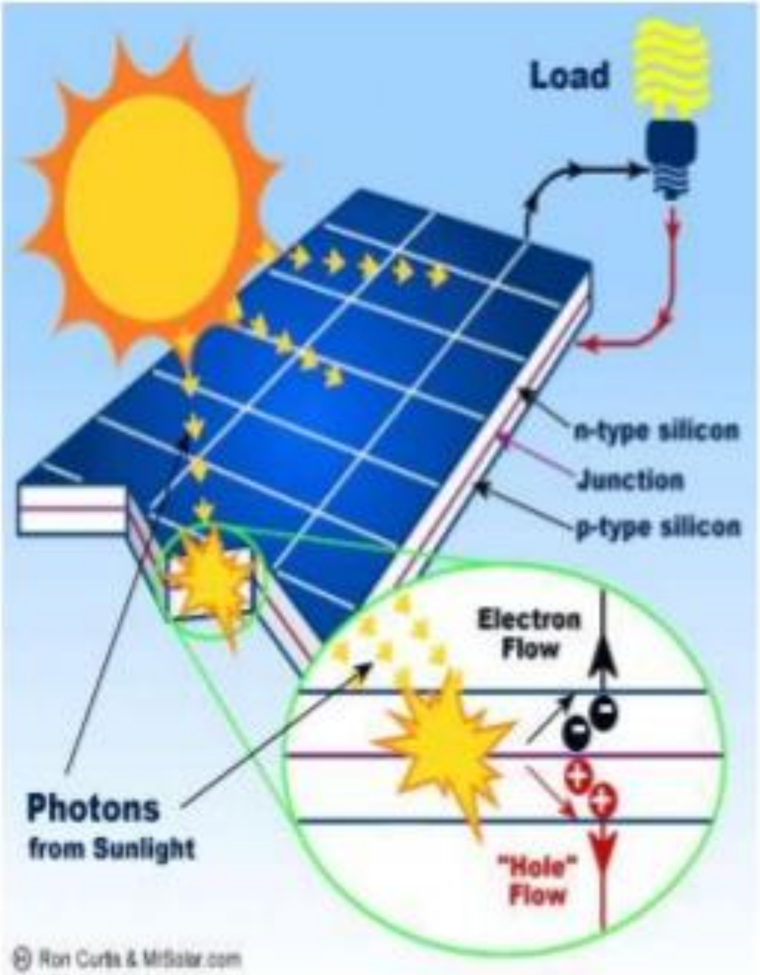
- In 2002, the global market for photovoltaic panels and equipment was valued at 3.5 billion dollars

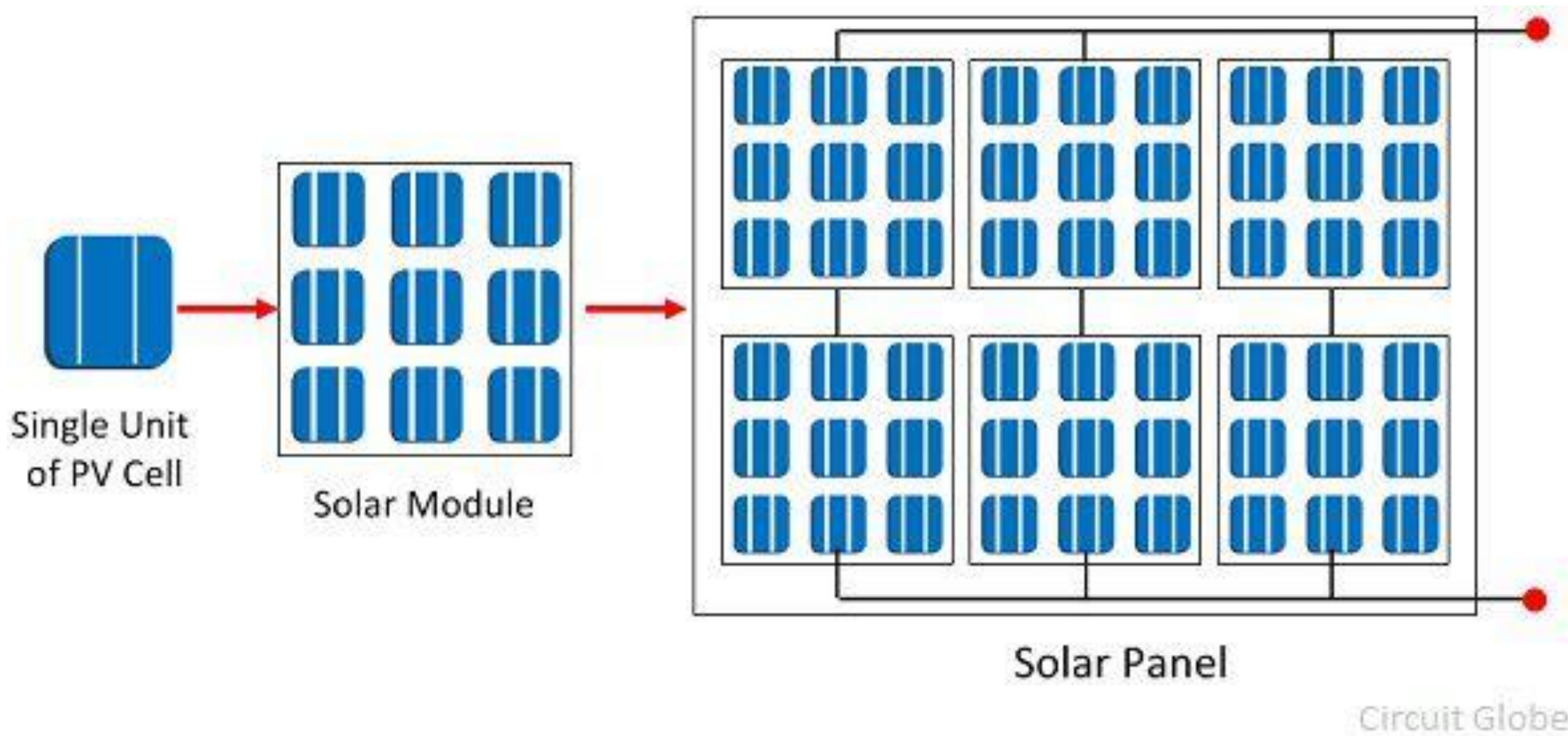
Working of PV cell

➢Photovoltaic cell converts sunlight into electric energy and this effect is known as photovoltaic effect.

➢Solar cells essentially generate electricity by converting photons of light into electrons.

➢Solar cell producing direct current, or DC, this DC current is converted to alternating current, or AC by using inverter.




Single Unit
of PV Cell
Solar Module
Solar Panel
Circuit Globe

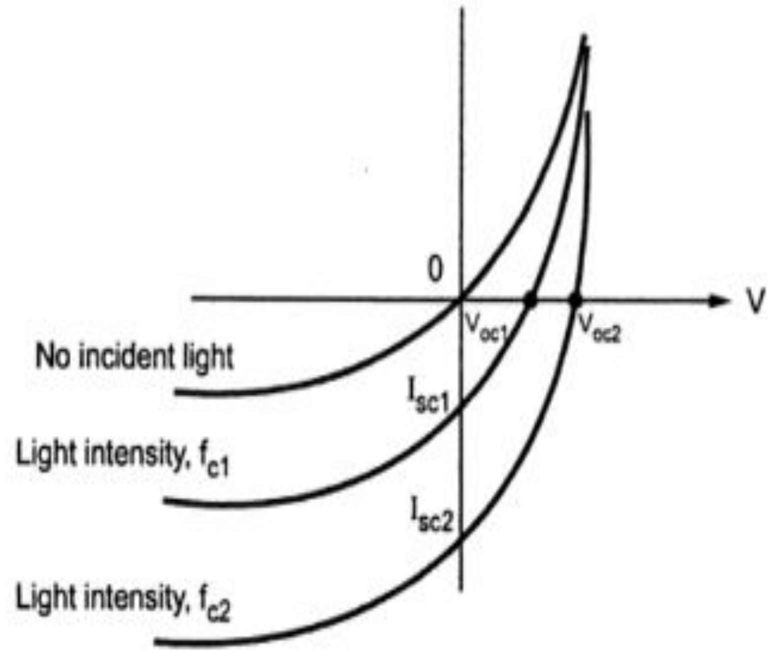


Fig. 3.73 I_{SC} and V_{OC} versus light intensity for a solar cell

Advantage of PV cell

- It is clean and non-polluting.
- It is a renewable energy.
- Solar cells do not produce noise and they are totally silent.
- They require very little maintenance.
- They have long life time.
- There are no fuel costs or fuel supply problems.

Disadvantage of solar cell

- Soar cells (or) solar panels are very expensive.
- Energy has not be stored in batteries.
- Air pollution and whether can affect the production of electricity.
- They need large are of land to produce more efficient power supply.
- Sun does not shine consistently.
- Less efficient and costly equipment.
- Reliability Depends On Location

Applications of Solar Cells

- Renewable energy
- Can be powered for remote locations
- It's free, limitless, and environmentally friendly…